Pitch Resources for New Music: an Integrated Approach to Instrument Development and Composition

Volume I: Thesis

José Antonio Martín Salinas

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To My Parents

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Abstract

This thesis explores microtonality, specifically the use of microdiscrete intervals and sliding pitch, in new music. It presents a newly designed microtonal percussion instrument (the *conic bellophone*), a portfolio of inextricably associated compositions, in score and recordings, and a video recording illustrating the technique of the instrument. The question whether an instrument must exist in order for music to be composed for it is addressed by means of experimental composition for the bellophone.

Analysis and comparison of the work of Julián Carrillo and Harry Partch, twentieth-century composers deeply involved in microtonality, sliding pitch, and the development of new and modified instruments, shapes the research method used. A detailed review of the achievements of these composers in creating novel instruments, which informs this comparison, is presented in appendices. Whereas Carrillo and Partch mostly built instruments before composing, this research proposes and applies an instrument-development-led composition strategy, which systematically promotes interaction between design, construction, composition and theory. A tuning system with very small, equal steps (allowing for smooth, microdiscrete-sliding pitch – see Glossary – progressions) is chosen for the bellophone: 96-equal temperament is a practical compromise between infinitely small quantisation of the pitch continuum and the realisation of a playable instrument. The exploration of microdiscrete-sliding pitch, whose innovative use is sought throughout the composition portfolio, is supported by means of an original development of established microtonal notation.

This research evaluates successive prototypes of the bellophone in relation to compositional practice: the playability of short compositions (solo studies) is assessed in relation to built and virtual prototypes of the instrument, and to defined conceptual variants of it. These variants, which exemplify alternative solutions to the aims embodied in each prototype built, inform the progressive development of the bellophone. Several variants of posterior prototypes are considered for compositional use too. A wide range of further newly conceived instruments, including aerophones, chordophones, and idiophones of materials other than metal, generated by further extending application of the instrument design methodology developed, are illustrated and discussed in an appendix. Informed by the composition of several solo studies, a three-movement ensemble work, *Seasons*, using a finalised form of the bellophone is presented. The research method arrived at, which instigates a system of instrument-development-led compositional theory and practice, is shown to be transferable to musical parameters other than pitch.

Acknowledgements

Support and encouragement for this research have been provided by many people, and in many different ways, for which I am most grateful.

My supervisors' guidance went far beyond my expectations, and their intensive dedication deserves special mention. Lewis Jones, the Director of Studies, provided broad advice in the areas of instrument development, tunings, music theory and performance, and also conducted a major performance of one the works, *Autumn*. Javier Garavaglia guided the development of my composition skills and advised me on how best to use those skills to complete the portfolio of compositions. Both supervisors devoted an incredible amount of time and effort outside of their schedules, for which I will be in debt for the rest of my life.

I would like to thank composition and other tutors who played an important role in my education prior to this research: they include David Renouff, Kevin Jones, Jeremy Peyton-Jones, and Peter Bowcott. Special thanks go to Jamie Linwood, instrument-making tutor at the former London Guildhall University (now London Metropolitan), who taught me the skills of marimba making before the research started. Allan Seago (London Metropolitan University) provided advice about the acoustics of bells. I am thankful especially to Christina Paine for her advice concerning the thesis text.

I would also like to thank London Metropolitan University for sponsoring a major performance of my composition work, and two lecture demonstrations. I am also grateful to the University for giving me the opportunity to teach the modules *Scales, Tunings and Temperaments* and *Musics of the World*, which made a substantial contribution to my development.

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Acknowledgements

I would like to thank three of Julián Carrillo's relatives: Angel Carrillo Soberón (grandson of Julián Carrillo, and recipient of the Carrillo Archive) for extremely kindly granting me access to the Carrillo Archive and particularly the scores; Daniel Langarica (Angel Carrillo Soberón's nephew) for taking pictures, used in the thesis, of Carrillo's instruments; and Carmen Viramontes (granddaughter of Julián Carrillo), who provided important biographical information. Gabriela Barrón of the Carrillo Archive scanned the required scores and provided support with great devotion. Other people who provided additional support through correspondence were Alejandro Madrid, Christina Taylor-Gibson, and Ernesto Solís Wrinkler. Other help with Carrillo documentation came from Arturo Soriano, Fabrice Lengronne, Milton García, and Jimena Giménez Cacho (cellist), who trained with two of Carrillo's students (David Espejo and Oscar Vargas) and who corresponded with me, providing ideas and advice.

Thanks to Brian McLaren for providing extensive research materials. Other people who provided such materials were: Johnny Reinhard (Director of the American Festival of Microtonal Music), Donald Bousted (Curator of the UK MicroFest), Aaron Hunt, Bruno de Florence, Graham Breed, Paul Erlich, Bradford A. Blackburn, Jon Szanto and Phillip Blackburn. Special thanks are due to Dave Keenan and George Secor, the creators of Sagittal notation, with whom I worked for two years on an addition to the Sagittal accidentals, notating the 9600 equal division of the octave (dividing the sixteenthtone into one hundred steps). This work was done in parallel with the thesis and inspired my research on microtonal notation.

All the performers involved in this research provided important feedback, and I would like specially to mention Lee Ferguson (percussionist), who played the full version of the *conic bellophone* on several occasions and gave valuable demonstrations. Other players involved were: Guido Arbonelli (bass clarinet), Alan Tomlinson (trombone), Steve Altoft (Quartertone trumpet), Wim Hoogewerf (Sixteenthtone Guitar), Bozidar Vukotic (cello), Mathew West (timpani) and Petar Curic (*conic bellophone*).

I am also in great debt to my Carnatic music *guru* and violin teacher, B. K. Chandrashekar, whose passion for teaching has been of greatly inspiration to my music and life. Also thanks to Manickam Yogeswaram, Carnatic vocal tutor, and the teachers at the Bhavan Centre from whom I briefly received Carnatic music tuition: Sivashakthy Sivanesan (Carnatic vocal), M. Balachander (mridangam) and Richard Marr (Carnatic music theory).

Gerry Tilling provided advice on metalworking, including spinning techniques. Mathew Dart, John-Paul Williams and Mick Battley, technicians of the Music Technology division of London Metropolitan University, provided much support, and the Whitechapel Bell Foundry provided handbells and square handchimes to be sampled.

Jesús Martín Salinas, of the Engineering Department of Seville University, provided advice concerning the virtual *extended conic bellophone* which, though not included in the thesis, help my modelling and creative process and Dan Garland, who helped with its programming. Miguel Angel Martín Salinas (architect) provided advice about the structure of the *Snowdome*.

Thanks to David Seubert, Head of Special Collections at UC Santa Barbara Library (University of California) for granting me permission to use an excerpt of an original score by Mildred Couper, and to Greta Couper (grand-daughter of this inspiring Argentinian-American composer) for securing the permission.

I would like to give special thanks to my parents and my wife for their invaluable support, together with the rest of my family, friends and other people whose support, though not related to the research, encouraged me greatly.

Abbreviations and Conventions

Abbreviations

MIHP Kakinuma, T. 1989. *The musical instruments of Harry Partch as an apparatus of production in musical theater.* PhD dissertation. University of California, San Diego.

GM Partch, H. 1949. *Genesis of a music.* Second edition (1974). New York: Da Capo Press.

STTWJC Bellamy, Sr. L. 1973. *The Sonido Trece theoretical works of Julián Carrillo: a translation with commentary.* PhD dissertation. Indiana University.

CIAJC Hernández-Hidalgo, O. 2000. *Catálogo integral del archivo Julián Carrillo.* Culture Institute at San Luis Potosí, Mexico: Editorial Ponciano Arriaga.

PADTS Five musical parameters of composition, these being correspondently: pitch, amplitude, durations (or tempo) and spatial projection (of the sound).

Conventions

This research considers a total of twenty-six compositions by Harry Partch, and all of them microtonal. In this thesis they are represented by a 'P' followed by the number of the work in chronological order (P01-P26).

According to *CIAJC*, Carrillo composed sixty-five microtonal works and many others that are not microtonal. This research is confined to his microtonal works which, in this thesis are represented by 'C' followed by the number of the microtonal work in chronological order (C01-C65). The Spanish titles of these works are translated by the author (see full list on p. 296). The titles of Carrillo's books and other writings are referred to in Spanish.

Introduction

This thesis gives an account of a process of practice-led research into dynamic and microdiscrete aspects of musical pitch, which was undertaken within a framework of instrument-development-led compositional practice. It explores how treatments of sustained pitch, employing a wide range of tunings, and treatments of dynamic pitch,[1] culminated in the development of a stable-pitch musical instrument, the *conic bellophone*, with microtonal and microdiscrete-sliding pitch capabilities. This instrument is presented alongside an inextricably associated body of compositional practice, which developed simultaneously with it, which systematically explores the use of microtonality, with an emphasis on microdiscrete-sliding pitch. As a starting point for the instrument, a tuning system with very small steps (ideally of equal size, to allow smooth, microdiscrete-sliding pitch progressions) was envisaged, to enable fair approximations of a wide range of micro-intervallic structures to be played. The tuning chosen for the bellophone; 96-equal temperament,[2] is a practical compromise between an infinitely fine quantisation of the pitch continuum and the realisation of a playable instrument. Reflection upon and comparison of the pitch-related and instrument-centred research of Julián Carrillo and Harry Partch – two twentieth-century composers deeply involved in static and dynamic microtonality and the development of new and modified instruments – has been foundational to the development of the research method proposed and applied here (see Fig. 5, p. 13).

Influences upon my composition

The origins of the research reported here warrant a brief explanation of the background and the influences that led me to weave together the related disciplines of composition and musical instrument development. After two years studying electronic engineering, I changed direction and began to study music. My interest in tunings and instrument development were partly the result of an unconventional musical education. Following a brief period of intensive training in Western classical music (piano, guitar and music theory), I took a combined music and performance Bachelor of Arts degree at Nottingham

[1] Dynamic pitch here refers to pitch continuum or to the perception in the listener of a pitch continuum.
[2] 96-equal temperament is abbreviated here as 96-et, and the same applies to other equal temperaments.

Trent University, where my main study was composition. Instrument development and the use of microtonality were intuitively incorporated into my compositional practice at that early stage. I composed exercises for a 15-et guitar, a portative organ tuned in 14-et, a string trio playing in quartertones, and for six hands on a 31-tone-per-octave marimba. During a transitional period in which I completed the degree and planned this research, two microtonal pieces were composed: *Corrientes*, a string quartet in just intonation, using only harmonics of the open strings, and a duet for 19-et recorder,[3] which was commissioned by Alternative Tuning Projects.[4] My subsequent involvement with microtonality, especially in relation to this research, was inspired equally by avant-garde twentieth-century microtonality and by specific non-Western musical traditions, primarily South Indian Classical (Carnatic) music, but also Japanese Shigin, Flamenco and Classical Arabic music, all of which make extensive use of gliding tones.

This research project was influenced strongly by my introductory study of Arabic, Chinese and Japanese music traditions at the School of Oriental and African Studies, London; of Carnatic music and dance at the London Institute of Indian Art and Culture (Bharatiya Vidya Bhavan);[5] and a year of intermission from my PhD registration during which I undertook intensive study of violin performance and compositional practice in the Carnatic tradition, both with B. K. Chandrashekar in the traditional guru-student system. During this period I formulated a theoretical system of scales of from 5 to 7 notes per octave, inspired by the early-seventeenth-century Carnatic system of heptatonic scales, the 72 *melakarta* scheme proposed by Venkatamakhi in the treatise Caturdandhi Prakashika;[6] and composed an extensive portfolio of melodic sketches for each of the transposing patterns of 5, 6 and 7 pitches in a 12-note-per-octave scale system. This study of modal music influenced my succeeding compositional work. My involvement in Carnatic music, an oral tradition that is not fully documented in existing publications, has had a particularly strong influence on my conceptualization of pitch. My experience of dealing with modes and ragas, and my increasing need to notate sliding pitch with precision in my compositions, led me to conceive the pitch continuum through binary subdivisions of the 12-et into quartertones, eighthtones, and so forth. Consequently, a sliding pitch notation

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[3] These recorders, tuned in 19-et, were designed by Lewis Jones, who made them with David Armitage as part of an Arts Council UK commission.
[4] Funded by Arts Council UK.
[5] I studied Carnatic theory with John Marr, Carnatic violin with B. K. Chandrashekar, mridangam with M. Balachander, Carnatic vocal practice with S. Sivanesan and M. Yogeswaram, and Bharatanatyam dance with P. Yadagudde.
[6] Bhagyalekshmy, S. 1990. *Ragas in Carnatic Music*. p. 34.

needed to be developed. While building upon this oral tradition and by systematic use of microdiscrete pitch increments, I hope to provide a secure ground for a future developing such a notation.

The fundamental document of Carnatic music, the *Abyasa Ghanam*, is based on scalar steps represented by the syllables *Sa, Ri, Ga, Ma, Pa, Da, Ni.* In South Indian Classical music, for example, a raga provides guidelines for the performance of sliding pitch contours, and for determining such points within a specific time frame, but it also allows for the personal expression of the performer. Ragas are taught through an oral tradition. If, however, several parts with contrasting sliding pitch contours of such complexity as a raga were written to be played in synchrony, no matter how accurate the written guidelines were, the performer would still require special training or preparation to execute them with the necessary precision. The performance guidelines in this case would need to be more specific and less improvisatory if performance results were to be obtained with a reliable degree of prediction.

Precise, sustained micro-intervals are also difficult to achieve in limited rehearsal time. Since in performing such compositions it is necessary for the performers to have accurate control of pitch at all times, they would need practice in performing both precise sustained micro-intervals and synchronous dynamic treatments of pitch, as these are not usually part of conventional Western musical training. This can be achieved in several ways: by using the human voice or instruments with dynamic pitch capabilities (both of which require extensive ear training); by providing computer generated simulations via headphones; or with support from parts written for stable-pitch percussion instruments. Time limitations and other constraints can make additional training impractical if not impossible, whilst relying on headphones risks isolating the performer and inhibits interaction with the other players, which can negatively affect the integrity of the overall performance.

Stable-pitch percussion instruments of the Western orchestra require neither significant ear training nor extensive rehearsal time, compared to instruments with dynamic pitch capabilities or the voice, and they allow the performer to integrate fully and immediately into the group performance. Dynamic treatments of pitch can be achieved by establishing discrete ultrachromatic units, which can be perceived as a continuum when played in sequences of variable speed. For such a purpose, tuned percussion instruments offer a pitch precision and stability that other instruments do not. A wide range of microtonality can be achieved through ultrachromatic instruments offering a vast range of melodic intervals and a rich array of harmonic possibilities. These possibilities are systematically explored in this thesis.

My compositional work before and during this research had an emphasis on microtonality and sliding pitch. However, I have also found inspiration in composers who have explored the microdiscretism and dynamicism (pp. 216-218) of other musical parameters like amplitude, durations (and tempo), timbre, and spatial projection.

Pitch in context

That other musical parameters, amplitude, duration, timbre and spatial projection,[7] can likewise be treated in a microdiscrete manner (in small steps) and a dynamic manner (with values gradually changing in time), is borne in mind in defining the research approach adopted to the study of pitch as a musical parameter (see Fig. 1), and the specific instrument-development-led compositional strategies used to explore pitch. This is done for two reasons: firstly, treating a musical parameter in isolation can lead to conclusions out of context; and secondly, to allow the research method to be utilised with other musical parameters, thereby extending the potential of the research.

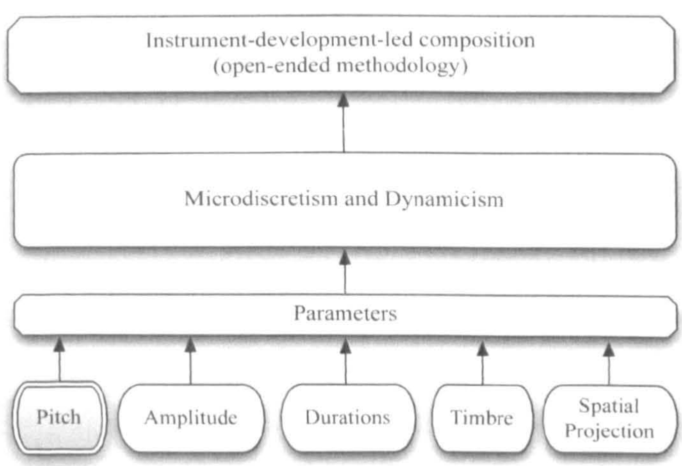

Fig. 1. Research approach followed in the study of pitch as a musical parameter.

[7] These four musical parameters and pitch are referred to as *PADTS* parameters from here onwards (see Abbreviations).

The first step in the method applied is stating the musical parameter of research, already defined as pitch (see Stage I in Fig. 5, p. 13), and then defining the aims and objectives, which is done in the following section.

Research aims and objectives

The main research aim is to explore microtonality from the dynamic and static perspectives, with an emphasis of the first of these, employing an instrument-development-led compositional platform in interaction with: research on two historical models; their strategies; their compositional theory; their instrument development practices, and; the ideas derived from it. The main research objectives are to produce a musical instrument and a portfolio of compositions for the instrument by means of integrating the compositional and instrument development practices.

Since the research aims and objectives are considered to be an essential guide to follow the text of the thesis, they have been detailed for reference purposes in diagram form (Fig. 2). This diagram illustrates the hierarchy of the main and consequent aims and objectives.

The four consequent aims, as described in Fig. 2, emerge resulting from the apprehension and interpretation of the music-making process and strategies of Carrillo and Partch, analysed and compared in §1.1.1-1.1.4 (pp. 15-35). These consequent aims are directly connected to the research strategy explained in §1.1.5 (pp. 35-46).

The six consequent research objectives, as described in Fig. 2, are achieved by each of the six corresponding sections of the method (see stage groups A to F in Fig. 3), and therefore the relation between research objectives and method is settled and beyond question.

RESEARCH AIMS AND OBJECTIVES

AIMS

The main aim is to systematically investigate microtonality, and in particular the use of sliding pitch, in a historical and theoretical context and, by composition and the development of instruments, in practice.
Consequent aims, which have shaped the research strategy are:

(1) To devise an interactive research method who's flexibility accommodates four musical parameters other than pitch which, like pitch, can be approached from dynamic and microdiscrete perspectives.

(2) To make innovative use of microdiscrete-sliding pitch, an area of convergence between static and sliding microtonality.

(3) To develop accessible notation systems appropriate to the music and instruments created.

(4) To develop a conceptual approach to instrument development which informed by and integrated with compositional practice and theory.

OBJECTIVES

The main objectives in meeting the research aim above are to create a portfolio of compositions, and to develop a new musical instrument closely integrated with compositional practice. Consequent objectives, directly informing the research method, are:

(1) By making a systematic comparative study of the strategies, compositional theory and instrument developments of two composers, to define a new research strategy responsible for the research and refining it towards devising the research method. Then, defining its application considering the objectives that follow (objective 1 is also the objective of method stage group A):

(2) To define the geometries, proportions and materials of the instrument created (also the objective of method stage group B).

(3) To consider the musical and ergonomic implications of alternative dispositions of sounding bodies (also the objective of method stage group C).

(4) To design and compare several prototype instruments and related compositions (also the objective of method stage group D).

(5) To propose MIDI-activated and extended versions of the instrument created, as well as other ranges (also the objective of method stage group E).

(6) To propose further concepts and projects for further development (also the objective of method stage group F).

Fig. 2. Research aims and objectives.

The relations between the four consequent research aims (as described in Fig. 2) and the method, are described in detail in §1.4.1 (pp. 72-76) and here briefly introduce individually as follows:

(1) Devising an interactive research method. The method demands parallel development processes in time between disciplines, which inform each other. The chart in Fig. 3 lays out the 27 stages of the research method in relation to the chapters and sections of this thesis. This illustrates how the theory interacts with the practice, the compositional practice with the instrument development, and

simultaneous compositional projects (with three layers most of the time) with each other. Then the chart in Fig. 4 lays out the instrument-development-led compositional practice roadmap of the method, showing the interaction of these two disciplines.

(2) Innovative use of microdiscrete-sliding pitch. In order to achieve this, dynamic (sliding) microtonality is the leading instrument capability from the very beginning starting with prototype 1 (see 'Pr.1' in Fig. 3).[8] This capability is not compromised after prototype 1, while the static pitch capabilities are being gradually improved. By prototype 8, both capabilities already reach the best that could be improved, which is when the instrument is built and used for performance purposes. Consequently, the compositional practice that these prototypes inform (and vice versa) – as part of the method strategy – offer a wide range of experimentation with this microdiscrete-sliding pitch.

(3) Development of accessible notation systems. At an early stage of the method (Stage III), a notation system for the chosen tuning has to be developed. In general all compositions informed by the instrument development practice from prototype 1 to 8 have to be notated thinking of a possible short-time rehearsal scenario. Ideally, all the works are expected to be performed, so as to get technical feedback from the performer prior and after performance. This process is also expected to inform the notation systems proposed.

(4) Integration of conceptual instrument development with compositional theory. Instruments are treated as concepts when working forwards and backwards between compositional theory, instrument development practice and compositional practice. This is done by means of treating instrument capabilities and properties. This general process is reinforced by a comparison process with previous prototypes, and with alternative conceptual instruments of similar layout (but with different sounding bodies and/or sound producing action) conceived to compare evaluations with the one of the corresponding prototype, and compositional practice with the corresponding prototype.

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[8] Prototype 1 and 2 are reviewed in Stages XVII-XIX (see diagonal lines linking in Fig. 3), while the other prototypes are conceived in Stages XVII-XIX (stage group D of cyclic nature is repeated 14 times), and is also open to reconsiderations throughout the whole research project. When the open nature (flexibility) is relevant to the method, this is indicated with dotted areas.

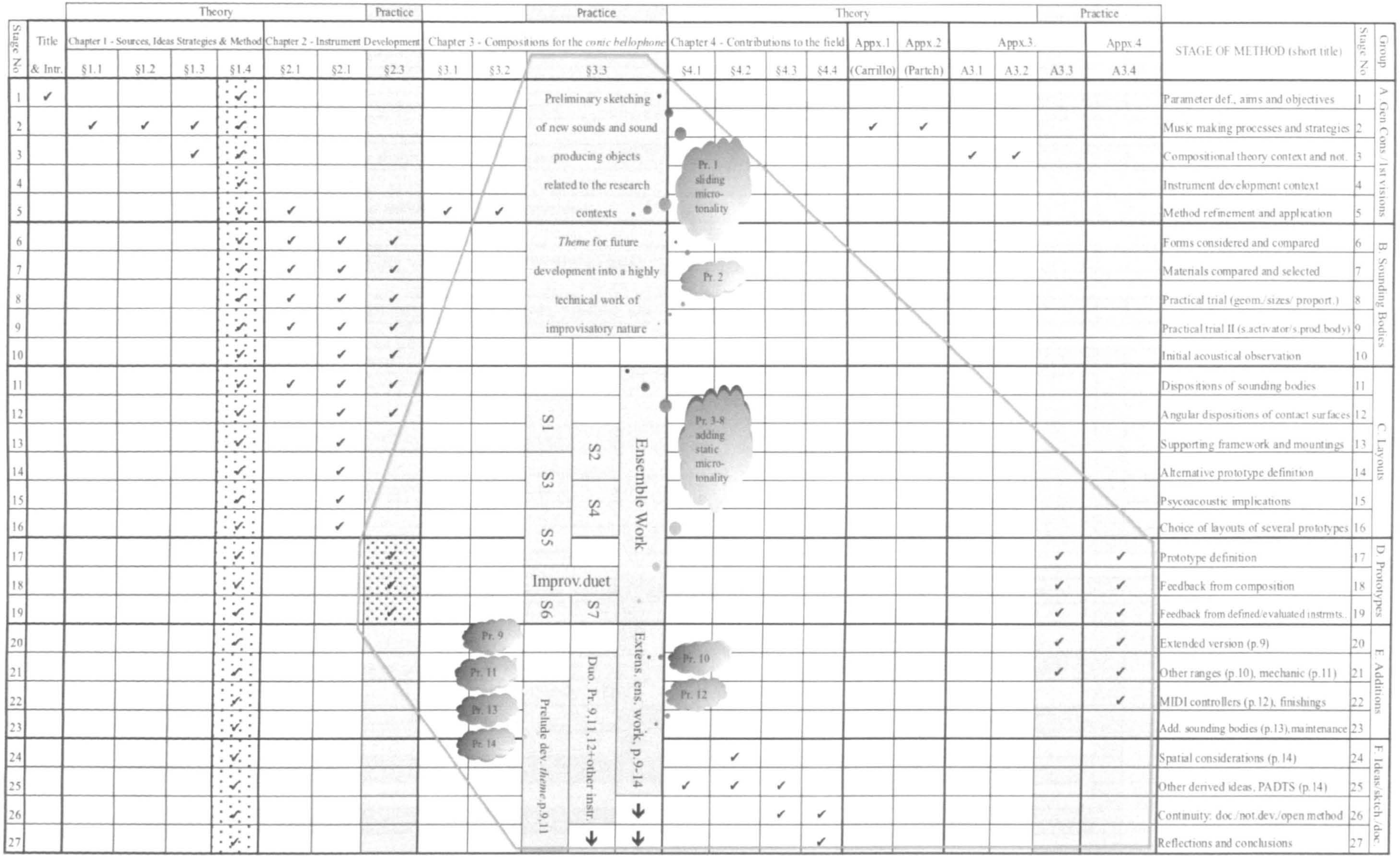

Fig. 3. Diagram showing the stages of the method in relation to the sections of the thesis.

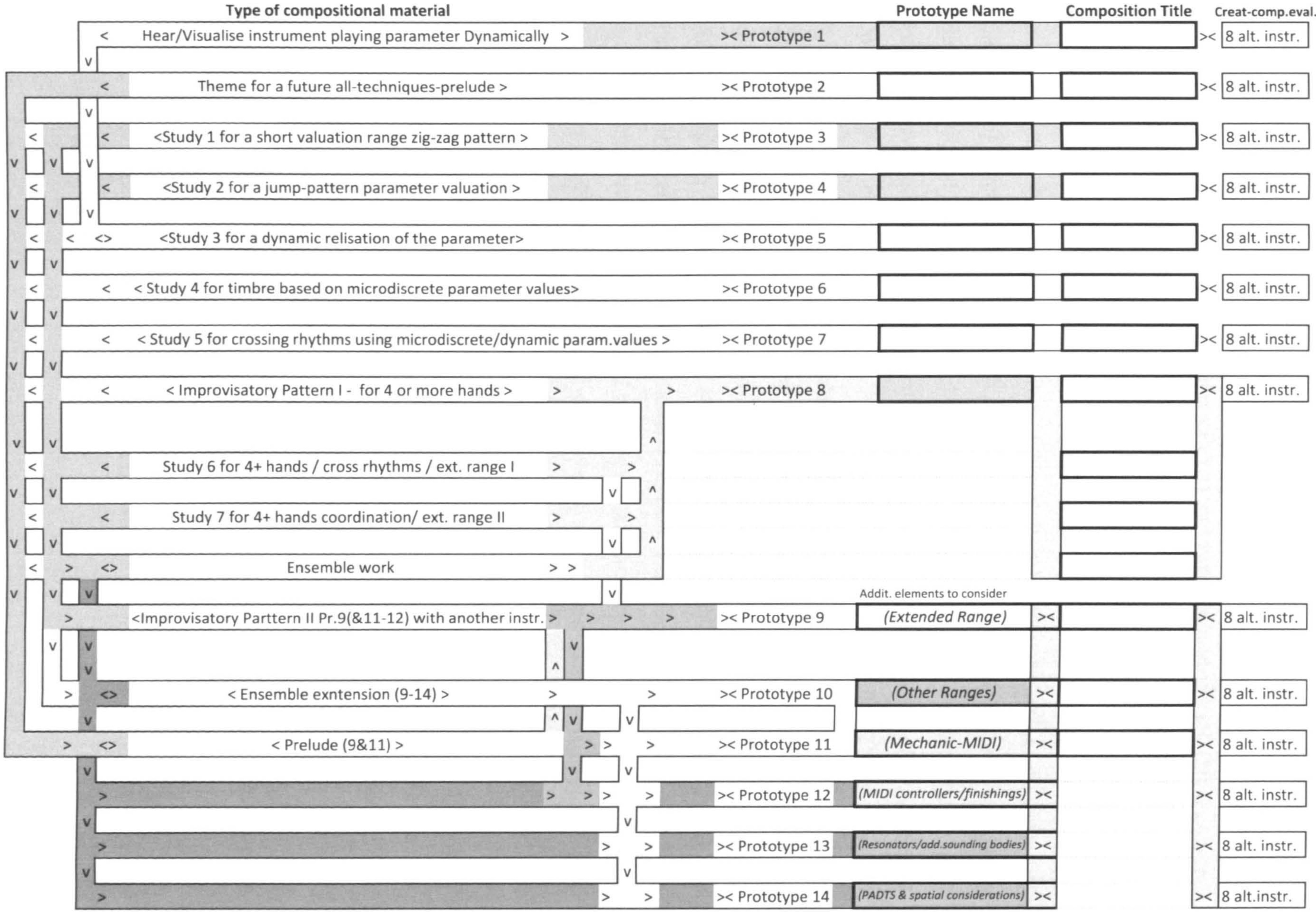

Fig. 4. Diagram showing how instrument development and composition processes interact in the method.

Overview of the thesis

The written thesis (Volume I) is accompanied by a portfolio of compositions in score, the *conic bellophone*, and three discs (an audio CD and two audio-visual DVDs) presenting performances and demonstrations, and other materials illustrating the text and scores.

Chapter 1 begins by examining the intellectual context of this research by reviewing the work of Julián Carrillo (1875-1965) and Harry Partch (1901-1974) as exemplars of pioneers of microtonality. Carrillo's innovations in composition and instrument development and his use of binary divisions of the tone (as far as sixteenthtones) and Partch's development of tuned percussion instruments in the context of experimental composition are considered essential, and are examined here in detail. This is followed by a comparison of their compositional strategies in relation to their instrument development practices, and the one followed in this research. Their practices and compositional strategies are compared, and the compositional theory context is considered. After examining the microtonal theories and compositional practices of Carrillo and Partch, their original ideas, compositional strategies, and notations are compared. The most relevant areas of interest treated are: the use and aesthetics of micro-discrete sliding pitch, polymicrotonality, the use of non-octaval scales, and the development of new notations. The instrument development context is considered: the instrumentaria of Carrillo and Partch are analysed, and an original taxonomy is proposed. As a consequence of this analysis, a conceptualisation of instruments in terms of their capabilities and properties is considered, with the aim of achieving fluid interaction between compositional theory, compositional practice, and instrument development. This strategy is reinforced by the systematic use of three feedback sources. Firstly, by comparing conceptual instruments which represent alternative solutions to the aims embodied in each prototype. Secondly, by considering how a composition conceived for the prototype would work on related conceptual instruments. Thirdly, by comparing the microtonal and sliding capabilities of the prototypes with those of conceptual counterparts. The chapter concludes with a thorough refinement of the method, informed by these preceding stages.

Chapter 2, which accounts for the instrument development practice, with reference to the conceptual developments addressed in Appendix 3, presents further decision of the application of the method in relation to the foundations of the instrument development by explaining sounding bodies, layouts, and other elements to consider. It finally describes the design process (with sketches included), and analyses capabilities (evaluated), detailing the fourteen *conic bellophone* prototypes, their integration to the compositional practice, and the feedback from the creative-comparative reinforcement process (described above).

Chapter 3 accounts for the development of the portfolio of compositions for the *conic bellophone*, and explains my compositional practice and its integration with the development of the instrument. It first defines the compositional aims, then the approaches, and finally it moves into describing the compositions. The composition portfolio consists of a set of eight short solo works for the *conic bellophone*, primarily responsible for the systematic approach to pitch resources; two duet works exploring the interaction between the two parts (4-hands on *conic bellophone* or with a 96-et Guitar), and; a major work for *conic bellophone* and ensemble with instruments representing each section of the orchestra. The ensemble work is titled *Autumn*, and is composed simultaneously with other works from which learns new techniques for the *conic bellophone* while exploring the interaction with instruments of very different nature (and harmonic spectrum), bass clarinet, trumpet, trombone, cello and percussion (using a wide range of instruments). Most of the compositional practice is strategically thought to have three simultaneous projects interacting with each other. The composition *Seasons*, still work in progress, is documented and explained at the end of this chapter (and also sketched in Volume II).

Chapter 4 explains and elucidates the contribution of this research to the field, explores its implications, and suggests future projects, which could result from this work. It concludes by explaining the overall conclusion of this research project.

The appendices include annotated reviews of the work of Carrillo (Appx 1) and Partch (Appx 2); an explanation of the classification and evaluation criteria used in the main text, and documentation of the instruments proposed for the creative-comparative feedback approach that takes place in parallel to the development of each of the bellophone prototypes (Appx 3); documentation of events related to this research, concerts and workshops (Appx 4); and a reply letter to the questions asked to the director of an organisation promoting the work of Julián Carrillo (Appx 5).

Volume II of the thesis contains the scores of compositions, backed up by audio files recordings of performances of the *conic bellophone* (ensemble, duo, and solo) in the attached audio CD and audio-visual DVD1.

Chapter One: Sources, ideas, strategies and method

The first three sections of this chapter examine and discuss the main research contexts: music-making practice and strategies (pp. 14-46), compositional theory (pp. 46-58), and instrument development (pp. 58-71). They also explain new ideas that underlie the instrument-development-led compositional method (see Fig. 5) employed in this thesis.

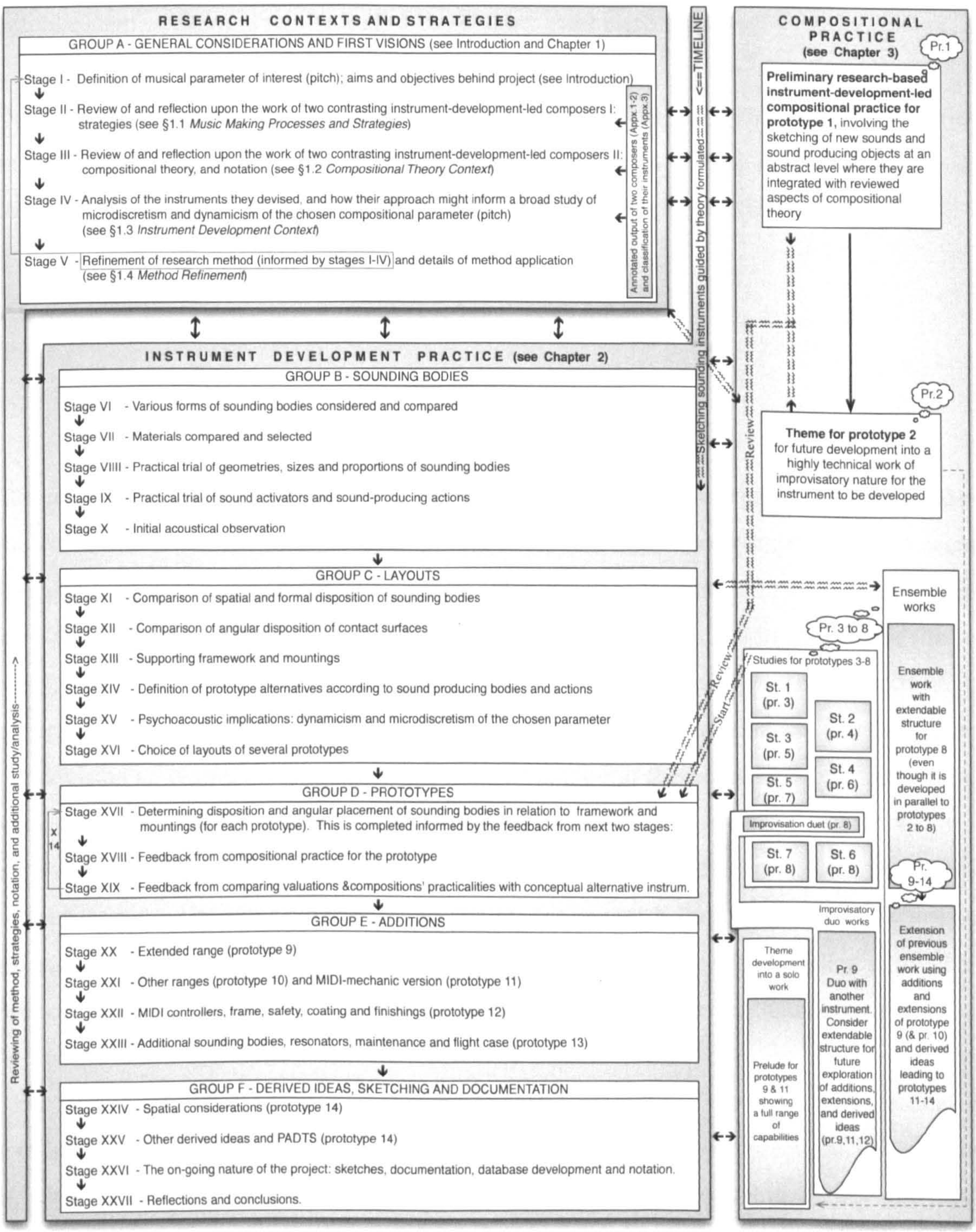

Fig. 5. Outline of the instrument-development-led composition method used for this research.

This chapter compares and reflects upon theoretical work in the field of pitch of Julián Antonio Carrillo Trujillo (1875-1965) and Harry Partch (1901-1975), and looks into the instrument-development-led compositional strategies they employed in their music. It argues that the incorporation into their compositional practice of their practical experience in instrument development allowed them prominently to pioneer microtonality and the use of sliding pitch, while other composers did not have the means to do so. It also argues that their assimilation of the discipline of instrument development into their compositional practice enabled them to realise and to corroborate their pitch theories.

Detailed hierarchies for the three stages of the method of this research (Fig. 5) are provided as follows: (Stage II) music-making practice and strategies in Fig. 6 (p. 15), (Stage III) compositional theory in Fig. 10 (p. 47), and (Stage IV) instrument development in Fig. 24 (p. 58).

1.1 Music-making processes and strategies

The microtonal works of Carrillo and Partch, who were based in neighbouring countries of the American continent (Mexico and the USA respectively), were composed in the second and third quarters of the twentieth century. It is noteworthy that both composers became involved in microtonal composition in the 1920s, when Carrillo was in mid-career (he was nearly fifty), whereas Partch, whose commitment to microtonality is evident from his earliest works, was young. Both composers were involved in performance, conducting, and the devising of tuning theory which was directly related to their compositional output; both were concerned with sliding pitch; and they shared contemporaneously a vision to revolutionise musical instruments and their tunings in order to realise new sonic possibilities in their music. Their achievement in exploring sliding pitch through the use of chromatic microtonal scales arose as a consequence of their instrument-development-led approach to microtonality, and it became an important compositional resource for both composers.

This section considers seven principal aspects of Carrillo's and Partch's composition and music-making processes in relation to their instrument development practices. This is done by first examining Carrillo and Partch individually, then comparing them, and finally deriving and proposing new ideas arising from this comparison, as set out in the hierarchical diagram in Fig. 6.

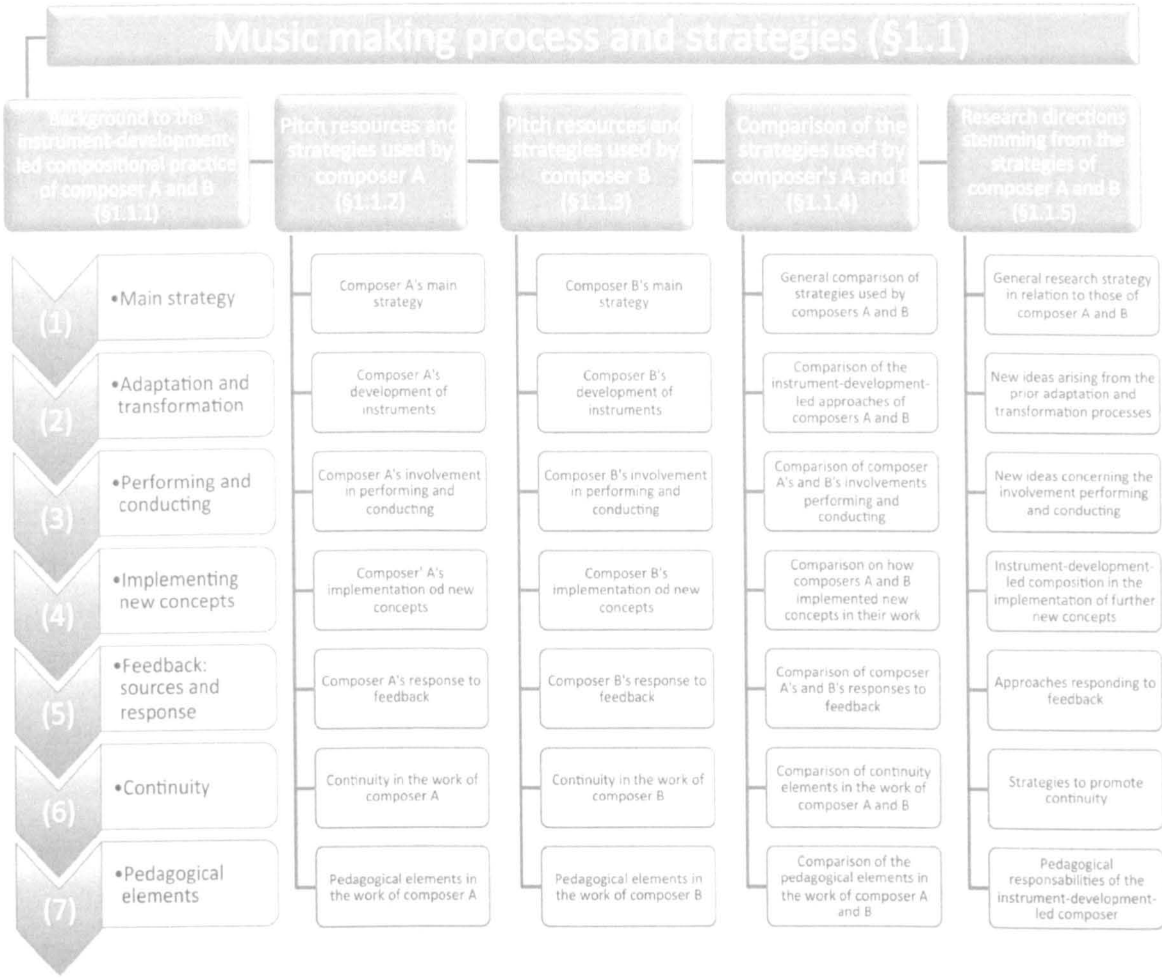

Fig. 6. The seven principal aspects of music-making processes considered in sections 1.1.2-1.1.5 (Stage II).

1.1.1 Background to the instrument-development-led compositional practice of Carrillo and Partch

Carrillo was deeply concerned about the practicability and continuity of his work. He realised his microtonal compositions primarily by applying extended playing techniques to existing orchestral instruments, by adapting several existing instruments, and by developing a small number of essentially new instruments. Partch's innovation, in contrast, was more focussed on the development of new instruments from scratch, and he abandoned 12-et from the outset. In a few cases he also substantially transformed existing instruments. At a later stage in his career, Partch extended his regular instrumentation to include folk and traditional orchestral instruments, primarily using extended techniques to achieve his preferred microtonal scale, but in some cases adapting or redesigning the instrument.

Carrillo was one generation ahead of Partch (he was 26 years older). As Carrillo lived in New York between 1926 and 1930, it is conceivable that the two composers might have been in contact and exchanged ideas, but there is no known evidence that they were influenced by each other's work. Although Carrillo reviewed the tuning theory of several contemporary theorists from the USA,[9] he did not acknowledge Partch's work in print. It appears that the two composers worked remarkably independently of one another.

1.1.2 Pitch resources and strategies used by Carrillo

This section examines the foundations of Carrillo's instrument-development-led approach to microtonal composition, and his consequent use of sliding and microdiscrete-sliding pitch.[10]

1.1.2.1 Carrillo's main strategy

According to David Espejo,[11] Carrillo's approach to composition was based on three main ideas: to expand the musical vocabulary and thus the sound of his compositions; to devise and work with a new notation system that substitutes staff notation easing the sight reading process; and in practice, to realise his theoretical awareness of the harmonic nature of sound by using micro-intervals.

The musical vocabulary that Julián Carrillo employed in his composition brought to light a unique sound attributed to his exploration of: (1) pitch, though frequent use of microtonality and microdiscrete-sliding pitch; and (2) musical instruments, using his new instruments, adaptation of existing instruments, and extended techniques.

Carrillo's numerical notation, *Sound 13*, reduces the five lines found in staff notation to one line, while it allows flexibility to represent the different divisions of the tone (from 1 to 16).

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[9] *STTWJC*. See Abbreviations. pp. 481-540 (translated from: Carrillo, J. 1946. *Dos leyes de física musical: I. Escala de los armónicos*).

[10] See Glossary.

[11] Personal communication, 9 August 2013, from Milton García to the author (Appx 5). David Espejo was a pupil of Carrillo, in his late life. This report was written by Milton García, who studied with Espejo and is the director of the organisation *Julián Carrillo y el Sonido 13*, which promotes the legacy of Carrillo. Espejo observes that the work of Carrillo is built on three principles: simplification of the notation system, enhancement of sonorities, and approximation to the intervals of the harmonic series.

An example illustrating *Sound 13 notation* for the 96-et (16th division of the tone) is available on p. 164 (Fig. 91; here used to represent an excerpt one of my works).

By exploring equal divisions of the 12-et tone, from the semitone to the sixteenthtone, (with a focus on sixteenthtones), Carrillo was closely able to approximate intervals of the harmonic series, as he states in his essay *Dos leyes de física musical.* In this essay Carrillo relates the interval constituting each equal division of the 12-et tone (from 1 to 16) to a ratio from the harmonic series.[12] Although the criteria for choosing the ratios from the harmonic series seems unclear,[13] his perseverance improving his compromise approximating to the intervals of the harmonic series had a profound impact on the work of two pupils in the late period of his life, David Espejo and Oscar Vargas. Oscar Vargas devised zither-'s using the intervals between harmonics 100 and 200, a system devised by David Espejo. [14]

1.1.2.2 Carrillo's development of instruments

Carrillo wrote microtonal music for all the normal instruments of the Western orchestra and incorporated additionally several instruments of his own invention. The most original of these, the *'Carrillo' harp* or *sixteenthtone harp* (a zither-like harp in sixteenthtones) and the *octavina* (a large lute, fretted in eighthtones), resemble existing traditional Mexican folk instruments. While most of the *'Carrillo' harps* are in sixteenthtones, one is in quartertones. That he produced only two essentially original instruments to widen the available sound spectrum for his microtonal works (the *sixteenthtone harp* and *octavina*), alone would not have changed the overall sound of a large ensemble greatly; however, it was Carrillo's use of microtonality and sliding pitch with mainstream instruments which were crucial to his ensemble and orchestral works from 1925 onwards. If each alternative tuning adopted for each instrument of the orchestra (whether achieved by a new fingering system or by adaptation or redesign of the instrument) considered a new instrument, the total number of alternative instruments to the regular orchestral instruments for which Carrillo wrote is thirty-seven. Most significantly, he substantially transformed the upright

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[12] *STTWJC.* p. 527 (translated from: Carrillo, J. 1946. *Dos leyes de física musical: I. Escala de los armónicos*).
[13] pp. 235-296.
[14] Personal communication, 9 August 2013 from, Milton García to the author (in Appx 5). Milton García explains in the letter, that David Espejo and Oscar Vargas were asked by Carrillo in his last years to complete the only aspect of his theoretical foundation that he could not explore in depth: the purification of intervals. García also reports that Espejo formulated a tuning of 100 notes per octave. The tuning extends from the 100th to the 199th harmonics.

piano in fifteen distinct ways, in order to realise different equal divisions of the tempered tone. Since composing for an existing instrument in a new tuning may involve as much additional effort as composing for a new instrument, Carrillo's achievement in overcoming challenges in this area was a significant one for his time.

Between 1922 and 1925 Carrillo, already in his late forties, prepared his first microtonal compositions for a prominent concert, which took place on 15 February 1925. During this period he had instrument makers working under his guidance on several adapted instruments: the addition of a quartertone key to the flute (depressing the key opens an additional hole which raises the pitch by a quartertone); a guitar with quartertone frets; and four brass instruments (trumpet, trombone, horn and tuba) with quartertone, eighthtone and sixteenthtone valves. Although not all of the instruments were used in the initial 1925 concert, by the end of that year Carrillo had composed for all of them. Contemporaneously, his students developed fingerings and new techniques to play quartertones on the violin, viola, cello (for which eighthtone fingerings were also developed), double bass, clarinet, oboe and bassoon.

Carrillo's adaptation and design of microtonal instruments occurred primarily in two distinct periods: in the mid-1920s, when he adapted the orchestral instruments and created his sixteenthtone zither and eighthtone lute, and in the 1940s, when he designed fifteen different microtonal pianos under the generic name of *pianos metamorfoseadores 'Carrillo'* (*'Carrillo' metamorphosing pianos*).[15] Carrillo's conception of the *'Carrillo' metamorphosing pianos* encompasses fifteen upright instruments, all with essentially normal-looking keyboards (with seven white and five black keys per octave), using from 1 to 16 equal consecutive steps to reach a 12-et tone, but excluding the existent 12-et piano. Thus, for example, on the *sixteenthtone 'Carrillo' metamorphosing piano* (*'Carrillo' metamorphosing* is omitted from here onwards), the notes sounded by the adjacent C and the C# keys are separated not by a semitone but by only a sixteenthtone. Carrillo's fifteen new pianos represent his most radical adaptations of existing instruments. That he composed for them a decade after they were designed and patented, at and shortly after the time at which they were being built (see composition list below), suggests that it was essential for him to have the instrument itself, and feedback from playing and hearing it, in order to compose for it; and that this was more important to his composition process than

[15] See Figs. A1.51-A1.106 on pp. 272-294.

the initial conception of the instrument. This observation raises the question whether an instrument-development-led composer can or should rely on an initial conception to advance composition, or whether it is necessary to experience the actual instrument and to interact with it in order for compositional ideas to be prompted. According to *CIAJC* (see Abbreviations, pp. 75-78), Carrillo wrote the following works for the *metamorphosing pianos* built in 1958:

> *Prelude for the 'Carrillo' quartertone metamorphosing piano* (1957) (C45)
> *Concertino for thirdtone piano* (1958) (C46)
> *Prayer without words for the 'Carrillo' metamorphosing piano in tones* (1959)
> *Babbling for the 'Carrillo' metamorphosing piano in sixteenthtones* (1959) (C47)
> *Studies for the 'Carrillo' metamorphosing piano in fifthtones* (1959) (C48)
> *Caprice for the 'Carrillo' metamorphosing piano in quartertones* (1959) (C50)

Apart from the pieces for the quartertone and thirdtone pianos, all of the other pieces were composed after the International Universal EXPO'58 in Brussels, where the *'Carrillo' metamorphosing pianos* were first exhibited (12 June 1958).[16] The other works were completed for a 1959 exhibition in Mexico City. As Carrillo had only composed works for two of the fifteen *'Carrillo' metamorphosing pianos* by the time of the EXPO'58, it is possible that he might have used sketches (not registered in his portfolio of completed works) or improvisatory works to demonstrate the pianos for which he had yet to compose. With the exception of a late composition for seven-string guitar in thirdtones (which also was not a new tuning), he chose, especially between 1960 and 1965, to work instead mainly in quartertones (see compositions M51-M65).

Carrillo's most influential contributions to instrument development were his *sixteenthtone piano*, his use of microtonal valves (for quartertones, eighthtones and sixteenthtones) on brass instruments, and the addition of a quartertone key (opening an associated hole in the head joint) for the flute. The *sixteenthtone piano* is currently manufactured by Sauter, and has been used by several contemporary composers such as Alain Bancquart.[17] Donald Bousted's works for quartertone trumpet where originally written for a trumpet with a custom-made quartertone valve;[18] the performer Samuel Stoll's F and Bb French Horns with

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[16] Oscoy-Cárdenas, M. 1959. *Exposición de los Pianos Carrillo.* pp. 12-13.
[17] Pröve, Bernfried E. G. 2003. Liner notes to *'The Carrillo 1/16 Tone Piano'* (CD).
[18] Bousted, D. 2007. *The Microtonal Trumpet. 24 Microtonal Studies.*

eighthtone valves (pp. 255-256) are in current use; and Eva Kingma has developed and patented the *key-on-key* mechanism in order more securely to achieve quartertones on a variant of the Boehm-system flute.[19]

1.1.2.3 Carrillo's involvement in performing and conducting

Carrillo was an experienced conductor and violinist before he became a microtonal composer, and he conducted rehearsals and performances of his own music extensively during his microtonal period. These roles were mutually beneficial and supported his composition practice. His experience as a violinist informed and gave him assurance in his microtonal writing for string instruments; and his involvement playing and conducting his own microtonal works was also crucially significant in the development of his appreciation of very small micro-intervals.

1.1.2.4 Carrillo's implementation of new concepts

Carrillo's first inventions, the *octavina* and the *sixteenthtone harp*, influenced by traditional Mexican instruments, were developed contemporaneously with is composing three works that included both instruments:

> *Prelude to 'Christopher Columbus'* (Op. 1) (C1) (1922-1925)
> *Ave Maria* (Op. 2) (C2) (1922-1925)
> *Quartertone cello prelude No 1* (for ensemble) (Op.4) (C4) (1922-1925)

A further work employing the *sixteenthtone harp* with voice, *'Tepepan', rural scene* (Op. 3) (C3) (1922-1925), was also composed during this period. As Carrillo used microtonal instruments to train the musicians from whom he gained feedback which informed his composing, it is likely that he had developed them before starting the composition process, but not necessarily the before initially conceiving of the compositions. In several of his works Carrillo seems initially to have used a chosen concept, which in some cases was to influence not only the composition but also the instruments developed. For example, in his microtonal work *Prelude to 'Christopher Columbus'* (Op. 1) (C1), the concept implied in the title may have prompted him to refer to the Mexican folk harp in designing the *octavina* (comparable to a bass lute with a soundboard similar to a Mexican harp), and the

[19] Fether, D. C. 2005. *A discussion of Contemporary Flute Design.*

sixteenthtone harp (with sound-holes similar to the harp), which not only visually but also conceptually blend European and Mexican traditions, apparently referring to and emphasising the Western colonisation of the Americas. By dedicating this work to Columbus, Carrillo not only acknowledged the contribution of Western culture to Mexican culture but also aimed to reflect the loss suffered by the pre-Columbian inhabitants of the American continent;[20] he explains in his autobiography that although this composition is dedicated to Columbus, acknowledging his bringing European civilization to Mexico, he regrets the conquistadors' destruction of pre-Columbian American cultures.[21]

In 1949 Carrillo had a Steinway grand piano adapted by Federico Buschmann, in Mexico City, following his 1940 patent for the fifteen *'Carrillo' metamorphosing pianos*. In the same year his daughter Lolita (nickname for Dolores Carrillo Flores) played it for first time in a concert in Mexico City on the 29th of September.[22] For this event he wrote a prelude for the instrument, which was also played by Lolita, who subsequently performed the work in Paris.[23] Unfortunately this work is not in the Carrillo Archive catalogue, so it may have been a draft for demonstration purposes. Soon after these concerts, Carrillo drew the detailed plans of his fifteen *'Carrillo' metamorphosing pianos* and, following his 1940 patent, he approached European piano builders and arranged for them to be manufactured by Carl Sauter in Spaichingen (Germany).

That Carrillo's *metamorphosing pianos* were designed and patented in 1940, before any compositions for them had been completed, suggests that he waited to hear and play the instruments before composing for them.[24]

The most important of Carrillo's works for a *metamorphosing piano* in the development of microdiscrete-sliding pitch was that for his *sixteenthtone piano* and ensemble: *Babbling for the 'Carrillo' metamorphosing piano in sixteenthtones* (1959) (C47). Dated two years after

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[20] A cry-like passage for soprano at the beginning and ending of the work seems to imply such pain and loss.
[21] Carrillo, J. and Carrillo, D. 1965. *Julián Carrillo*. p. 231.
[22] Carrillo, J. 1955. *Conferencia pronunciada por Julián Carrillo*. p. 19.
[23] Carrillo, J. and Carrillo, D. 1965. *Julián Carrillo*. pp. 264-265 and p. 275.
[24] Carrillo might have already started drafting some of his works for *metamorphosing pianos* any time after he completed the patents in 1940, as an expansion of his compositional theory, *Law of Musical Metamorphosis*, which allow you to transform the tonal proportions of a work by changing the size of the intervals proportionally to a chosen ratio so as to produce a harmonic metamorphosis (e.g. changing semitones for quartertones or whole tones). It is also possible that this obsession with using the word 'metamorphosis' might reflect the changes that the pre-Columbian inhabitants of Mexico went through after the invasion of the Spaniards to the American continent in 1492, since this was the subject that first inspired Carrillo to work with microtonality and to incorporate design elements from Mexican folk musical instruments.

the piano was built, it is likely that the impression made by playing chromatic passages on the instrument influenced Carrillo's decision to write undulating microdiscrete-sliding-pitch contours in a 'babbling' manner. We may ask whether Carrillo was perhaps making an analogy between the sound of a baby babbling and the rebirth of a new culture in the Americas after the Spanish invasion;[25] or was this title simply indicative of his compositional use of microdiscrete pitch to simulate sliding pitch. This symbolism of birth can be traced back to his 1926 work, *Babbling for muted string quartet in quartertones, with exceptional use of eighth and sixteenthtones* (C10).

1.1.2.5 Carrillo's response to feedback

Carrillo worked closely with the members of his ensemble and orchestra. From 1923 until 1925, when preparing his first microtonal concert, the performers ended up being largely his composition students, which allowed him to explore and experiment openly during rehearsals. During these three years he designed new instruments and instrumental adaptations, realised under his guidance, in parallel with his composing. His students also were involved in composing music for these instruments, and brought him additional feedback not only regarding composition but also on how to write and notate music for the instruments.[26] After these initial microtonal works, Carrillo worked very closely with members of an ensemble that he directed while in New York, between 1926 and 1930. Upon his return to Mexico, he worked with other orchestras, and continued adapting monophonic instruments of the orchestra that could not readily achieve the microtones he required when using extended techniques.

1.1.2.6 Continuity in the work of Carrillo

In adapting instruments to have microtonal properties, Carrillo made a fruitful contribution to the field of musical instrument design. He collaborated with instrument makers and with several performers who worked out alternative fingerings and techniques to achieve microtonal intervals on orchestral instruments. In his theoretical writings he devised yet

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[25] Having the tittle of the work referring to the happy sound of a child (rather than its crying) could symbolise how the pre-Columbian inhabitants of the American continent assimilated European culture and looked forward positively to the future challenges of human kind as a one body using the potential of the piano (as a symbol of European music), unlike the nationalists, whose domination of politics at the time frustrated many of his efforts.

[26] Carrillo, J. 1962. *Sonido 13: Recorrido histórico.* pp. 10-11.

more tunings, for which he eventually developed instruments, and for which he spent forty years devising and composing. Alongside his composing, the continuity of his theoretical work and its application was also important to him. Carrillo's expansion of music theory and practice according to his new microtonal conception, and his persistent attempts to reform music education using his notation and instruments, were repressed as a result from the political situation in Mexico at the time.

1.1.2.7 Pedagogical elements in the work of Carrillo

Most of Carrillo's microtonal works are available in numerical notation,[27] and their availability in recordings is also of great value for the study and understanding of his music.

Carrillo's interest in advancing not only his compositions but also his wider commitment to the practice of microtonality led him to compose several studies for solo instruments. The first of these were written in 1927, to promote the practice of quartertone technique on bowed string instruments: the violin, 3-string violin and double bass. He had by then already written *Prelude to 'Christopher Columbus'*, Op. 1, (1925) (C1), using the quartertone violin, and as he was himself a violinist he presumably felt that it was important for string players to practice quartertone techniques, which might have led him to compose the following studies:

> *70 exercises for double bass (new techniques for quartertones)* (1927) (C15)
> *70 exercises for violin solo* (1927) (C16)
> *3 quartertone studies for the 3-string violin (in 'sonatina' form)* (1927) (C18)

Soon after composing these studies, Carrillo composed the first and second *Colombia Symphonies*, which include quartertone string parts, and then a set of five studies for quartertone guitar. These studies help the player to build technique and confidence in preparation for playing Carrillo's ensemble's works. Only two of the five guitar studies have survived (*CIAJC*, pp. 63-64):

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[27] The full list of Carrillo's microtonal works on p. 295, specifies which are available in numerical notation and which in staff notation with microtonal symbols. On this list, numerical notation (*Sound 13*), is referred to as 'NUM'. Author's translations of Carrillo's microtonal compositions are shown on p. 296.

Quartertone guitar study No 1 (1931) (C35)
Quartertone guitar study No 5. 'Midnight at the Oriental' (1931) (C33)

Carrillo's *Studies for the 'Carrillo' metamorphosing piano in fifthtones* (1949) (C48) is the only work for this instrument. Its purpose may have been to demonstrate the instrument's sound in lectures and exhibitions. The same can be said of the *Study for 7-string thirdtone guitar* (1962) (C56).

Although specifically didactic works do not exist for the *sixteenthtone harp*, Carrillo wrote solo and duo works for the *sixteenthtone 'Carrillo' harp*, which efficiently demonstrates a wide range of dynamics and textures possible on this instrument. Carrillo only used the *octavina* for ensemble works, which are more representative of his musical style rather than the pedagogical value of his writing.

In his microtonal compositional work, Carrillo achieved a balance between creative and pedagogical output. The theory underlying his compositional processes was constructively documented in his publications. This outstanding pedagogical dedication was strongly motivated by his vision to create a music education institution based on his theories.[28]

1.1.3 Pitch resources and strategies used by Partch

As sliding pitch was a major element of Partch's early compositions, and microtonality and micro-discrete sliding pitch became highly important to him later on in his career, the advancement of the frontiers of pitch organisation had a crucial bearing on his instrument designs.

1.1.3.1 Partch's main strategy

Partch's compositional practice was suffused by his interest in mythology, history, dramaturgy and sculpture. It is difficult to isolate the influence of these elements, which he

[28] Carrillo, J. 1955. Conferencia pronunciada por Julián Carrillo. p. 19.

skilfully wove into a unique art form, which is often unfortunately mislabelled as 'exotic'. Three facets of Partch's philosophical approach to composition pertain closely to my own compositional concern with microtonality, sliding pitch, and instruments: firstly, he was a self-taught acoustician who developed a refined taste for beatless intervals and devised a theoretical system to reconceive music theory using the harmonic, and the subharmonic series; secondly, he often wrote sliding pitches for the voice, and instrumental parts characterised by microdiscrete-sliding pitch, inspired by the inflections of spoken North American English language (and occasionally borrowing intonational elements of Jewish recitation);[29] and thirdly, he developed new musical instruments for his compositions, to achieve just intonation and sliding pitch (continuous or microdiscrete).

1.1.3.2 Partch's development of instruments

If Partch's small percussion instruments are considered as one set, then he created twenty-five new instruments. This instrumentarium includes only three adaptations of existing instruments (viola, guitar, and koto), all of which adaptations are substantial enough to be considered as new instruments. Most of his new instrument ideas stem from an existing instrument that is radically transformed, often to the point where the origins of the instrument are almost unrecognisable. Partch was very creative with his microtonal instrument designs, and his approach to instrumentation was highly innovative for his time. If the various prototypes of each instrument, and the existing instruments – all of which required adjustments of pitch (by means of alternative fingerings or embouchure adjustments) to yield just intonation – are considered, the number of microtonal instruments for which Partch composed would be more than double the number of new instruments he created.

Partch's work in developing instruments spanned most of his career, but it was not evenly distributed. He started in 1928 – soon after Carrillo and at a much younger age – by adapting a viola to receive a longer (cello-like) neck, thereby lengthening its strings and lowering its pitch; and in 1934 he provided just intonation marks for a guitar. He then redesigned the ancient *kithara* (1938), in order to support his theory of just intonation with fixed pitches, and retuned several reed organs (1941), slightly transforming their keyboards.

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[29] Hansen, L. 1998. *Harry Partch Biography.*

Between 1945 and 1946 he entered one of the most productive periods of his life, inventing a total of 4 new musical instruments (the Adapted Guitar II, Harmonic Canon I, Diamond Marimba and Bass Marimba), while improving three other instruments (the Adapted Guitar I, Kithara I, and Chromelodeon I).[30] As these new instruments were gradually incorporated into his instrumentation, his music became predominantly instrumental. Partch's early composition work, shaped by the inflections of the speaking voice (inspired by the musicality of the spoken North American English language),[31] must have had an impact on the instruments that followed the Adapted Viola, since they all have microdiscrete sliding-pitch capabilities, if not sliding pitch capability. Although by the mid-1940s Partch had enough instruments to be able to compose for varied ensembles, he continued to develop new instruments. This activity reached a second peak of productivity between 1963 and 1965, during which three-year period Partch invented seven new instruments (the Boo II, Zymo-xyl, Mazda Marimba, Eucal Blossom, Gourd Tree with Gongs, Harmonic Canon III and Quadrangularis Reversum). By this point, his designs had become much more eccentric and innovative than before, as he sought both visual beauty and new sounds.

The chronological spread of Partch's output (see Appx 2) shows that he continued developing instruments in parallel with his composition throughout his career; but he, rather like Carrillo, had two remarkably productive periods – one between 1944 and 1946; the other between 1963 and 1965 – which, like Carrillo's, were separated by about two decades.

1.1.3.3 Partch's involvement in performing and conducting

Partch was always involved in rehearsals and performances, either performing or conducting. Having his compositions rehearsed and performed was an important part of Partch's preparation of a new work, and of the instruments made for it. He learnt how to play his new instruments to be able to compose for them more effectively, and to teach others how to play them. He also developed his conducting skills, mainly through conducting performances of his own works.

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[30] These instruments were developed in parallel to Partch's composing, mostly as part of a unified music making process.

[31] Hansen, L. 1998. *Harry Partch Biography.*

1.1.3.4 Partch's implementation of new concepts

At the age of 25, in 1926, Partch decided to abandon the piano, which he had been studying on and off for several years, and began learning the violin and viola in order to familiarise himself with variable pitch. His theoretical research into just intonation, started two years earlier, continued to develop throughout this period;[32] and his interest in the development of new instruments began when he transformed his viola into a longer, monochord-like instrument, which he could support between his legs to control intonation:[33] his initial idea was to use the instrument as much for theory demonstrations as for musical performance. The adaptation of the viola had been planned since 1928 (when he initially prepared cello fingerboards for the purpose) and was completed in 1930, when Partch asked an instrument maker to fit one of his cello fingerboards (with bradheads marking the stops for a just intonation scale which he named 'monophony') to a viola body. This instrument, initially called the Monophone, was later on renamed the Adapted Viola.[34] This invention could have resulted from combining the ancient Greek monochord (used to study musical scales) with the features of an instrument that Partch had chosen to enable him to imitate speech patterns using his voice. The new instrument, which had a speaking length of 20-inch (Partch used cello strings, apart from the highest, which was a long first or second violin string), descended a fourth below the viola (to G), and thus had an ideal range to match his voice (*GM,* see Abbreviations, p. 198).

At this early stage, Partch aimed to develop an instrument that could imitate the voice in order to evoke a peculiar dramatic use of it.[35] His study of ancient Greek dramaturgy and Greek music must have influenced the conception and creation of his just intonation scale. If Partch was already thinking about composing a setting of Chinese poetry at the time he conceived the Adapted Viola, then it is possible that image of a portable *erhu*-like instrument (bowed and held between the legs) might have appealed to him, and also as a way of alluding to or symbolising the itinerant Chinese poet who wanders through nature carrying as little as possible. These are merely personal suggestions of concepts and ideas that might have shaped Partch's first instrument, the Adapted Viola, and his first work for that instrument (and voice), the *Seventeen Lyrics by Li Po* (1930-33) (P1).

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[32] Gilmore, B. 1998. *Harry Partch: A biography.* pp. 53, 61.
[33] Gilmore, B. 1992. *Harry Partch: The Early Vocal Works 1930-33.* p. 73.
[34] Gilmore, B. 1992. *Harry Partch: The Early Vocal Works 1930-33.* p. 41.
[35] Hansen, L. 1998. *Harry Partch Biography.*

Partch's interest in imitating the voice shaped posterior compositions and instruments too. A relatively simple example is the Bloboy (*GM*, pp. 249-251), an instrument blown by pressing bellows to create air pressure to blow four autohorns and three organ pipes. This sound resembles the whistling of a steam train.

1.1.3.5 Partch's response to feedback

At several stages, the specific needs of Partch's compositions prompted or dictated the development of new versions of some of the instruments he had already created, as for example in *Oedipus* (1950/1952-4/1967), which uses the Chromelodeon II (1950), and *The bewitched* (1952-55), which uses the Harmonic Canon II (1953) (p. 327). The case of *The bewitched* is remarkable for the extent to which it occasioned the creation and adaptation of further instruments: it calls also for a Surrogate Kithara (*GM*, pp. 231-235), which was initially created in 1953 due to technical limitations experienced in writing for the Harmonic Canon II (*GM*); the Boo (1955), another instrument developed for *The bewitched*, half way through the composition of the work; and the Kithara II, invented in 1954. That the Harmonic Canon II, Surrogate Kithara, Kithara II and Boo were all devised while composing *The Bewitched*, to meet the specific needs of that work, affords a clear example of composition – and of composition-led instrument development – in which the instrument development process worked in parallel with the act of composing.

In 1958 Partch wrote *Windsong* for a documentary about his music,[36] in which he played all the instrumental parts for the Harmonic Canon II, Kithara II, Adapted Viola, Surrogate Kithara, Chromelodeon, Boo, Diamond Marimba, Cloud-Chamber Bowls, Spoils of War and Bass Marimba. Demonstrating the separate parts one by one for a documentary,[37] he explains:

> In performing the music that I wrote for Madeline Tourtelot's film *Windsong*, I played ten different instruments. After recording a few measures on one instrument, I used headphones to listen to these, while adding the sound of a second instrument. No more than four are used simultaneously...

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[36] *Harry Partch: Enclosure 1* (video).
[37] *Harry Partch: Enclosure 1* (video).

With the recording technique already employed in his composing at this stage, Partch was able to correct the scores obtaining feedback from the cumulative recording. To this experience he added the feedback from the performers he had worked closely with, and the multiple experiences of performing and travelling with his instruments, all of which informed the design of the instruments and the compositions.

1.1.3.6 Continuity in the work of Partch

Partch's most lasting contribution to the field of instrument development was a substantial instrumentarium, used to perform his music periodically at Montclair State University as part of a continuing microtonal ensemble named *Newband*.[38] This ensemble is now conducted and directed by Dean Drummond, who formerly played in Partch's ensemble and also composes for these instruments. Although Partch was not very interested in his instruments being used by other composers, they are nonetheless used in this way now, and his works are still being regularly performed alongside works by other composers.

1.1.3.7 Pedagogical elements in the work of Partch

There is no record of Partch writing technical studies for the instruments he developed, but the substantial body of works for adapted viola and voice from the early part of his composing career (1930-1933) demonstrates his systematic manner of composition at this early stage of his career. These works have great pedagogical value as demonstrations of sliding pitch simultaneously played with sustained just intonation. In general, most of Partch's works demonstrate his use of just intonation and compositional theory with prime number limits, and they afford several examples of instrument layouts, which serve as physical illustrations of his tuning theories, as in the case of the Diamond Marimba and the Kitharas.

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[38] Drummond, D. *Newband* (http://www.newband.org/aboutnewband.htm).

1.1.4 Comparison of the strategies used by Carrillo and Partch

Aspects of Carrillo's and Partch's pitch resources and methods, previously treated separately, are here compared.

1.1.4.1 Comparison of the main strategies used by Carrillo and Partch

Carrillo and Parch were interested to expand the sound qualities of their compositions through microtonality informed by the harmonic series, Carrillo approximating through equal temperaments and Partch favouring and notating low prime number ratios. These theoretical concepts were also incorporated into their development of instruments.

Carrillo used 12-et and the instruments of the orchestra as a starting point, while Partch rejected them almost from the outset. Carrillo started microtonal composition with a tuning encompassing ninety-six pitch classes and gradually introduced microdiscrete sliding pitch elements to his compositions, inspired by the instruments concerned. Partch started by using sliding pitch in combination with his just intonation scales (which were later on consolidated and rationalised with forty-three notes to the octave), and then substituted sliding pitch for microdiscrete-sliding pitch as instruments with these capabilities were developed. In both cases, the use of sliding and microdiscrete-sliding pitch happened naturally during the composing process, probably prompted by the capabilities of the instruments employed, since no theory was previously devised using these concepts.

Carrillo's obsession to simplify staff notation using numerical notation for pitch degrees and one single line accommodating this way several divisions of the tone, contrasts Partch's notation practice mainly using ratios and always adaptable to suit each instrument and composition to ease the sight-reading.

A comparison of the strategies used by Carrillo and Partch is summarised in the diagram showed in Fig. 7, where the boxes filled with grey show the aspects that are specific to the corresponding composer.

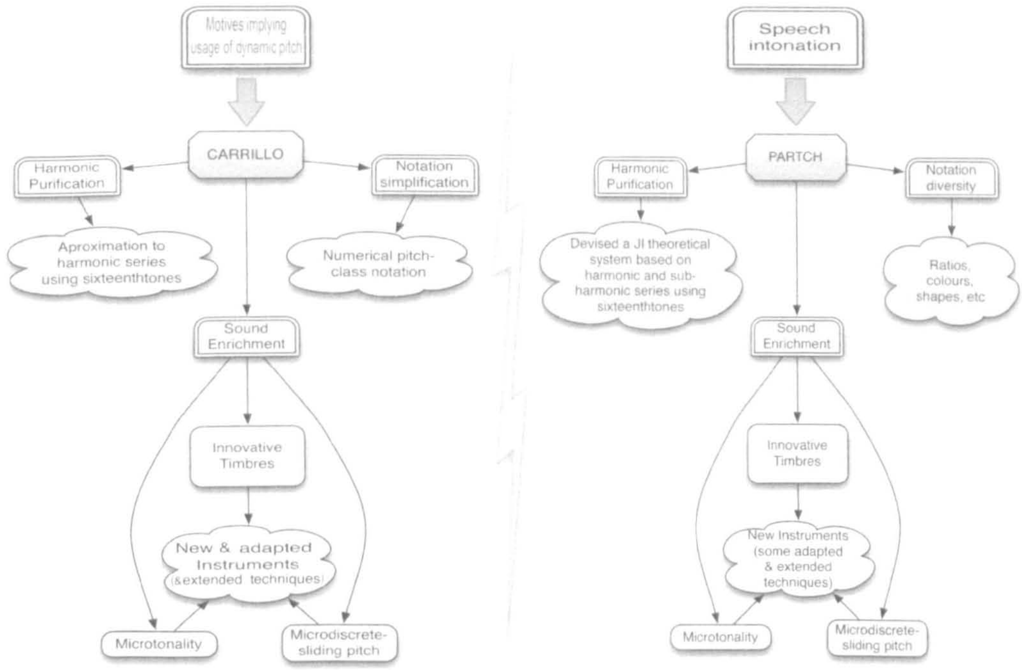

Fig. 7. Strategies followed by Carrillo and Partch compared.

1.1.4.2 Comparison of the instrument-development-led approaches of Carrillo and Partch

Carrillo adapted instruments when no fingerings were possible for the alternative tunings, but also developed some instruments from scratch, as in the case of the sixteenthtone zithers, named *'Carrillo harps'*.

Carrillo made an almost two-meter tall lute (the *octavina*), which had a fingerboard long enough to enable very fine gradations of tuning. There is a parallel between this and Partch's extension, only a few years later, of the neck of a viola to achieve precise pitches at a deeper pitch than that of the instrument with which he started. After that, most of the instruments developed by Partch resulted from transforming one or two characteristics of an existing instrument, to allow the layout to match his microtonal theories, while also bringing unique timbres to the ensemble. Carrillo on the contrary, mainly adapted existing orchestral instruments or employed extended techniques to facilitate successive subdivisions of the tempered semitone in his search for new sounds.

Partch's radical transformations and inventions of instruments allowed him to bring a fundamentally new range of sound quality and experience to the listener; while Carrillo's successive divisions of the tone using orchestral instruments (some of them slightly adapted) demonstrates how, by implementing microtonal theory rigorously, the instruments of orchestra can produce a myriad of new and refreshing sound qualities. Partch and Carrillo mostly developed instruments with the immediate aim of using them in their compositions. The ten *metamorphosing pianos* for which Carrillo did not compose, are extraordinary exceptions, since the initial idea behind their development was the realisation of a systematic division of the tone, as he had previously described in theory. However, the works that Carrillo composed for *metamorphosing pianos* (only for the *tone*, *thirdtone*, *quartertone*, *fifthtone* and *sixteenthtone pianos*) were composed within a period of three years (1957-1959) – the first half of this period coinciding with the construction of the pianos.

1.1.4.3 Comparison of Carrillo's and Partch's involvement performing and conducting

Both composers were involved in conducting performances of their music. Partch particularly developed his conducting skills through working with his ensemble. Carrillo, though he was an exceptional violinist, was not involved in performance when he started composing his microtonal works. Partch not only played the instruments as part of his composition process, he performed on most of them as well, and taught other players how to play them. The involvement of both composers in the performance and conducting of their works was facilitated by their very different approaches.

1.1.4.4 Comparison of how Carrillo and Partch implemented new concepts in their work

The work of Carrillo and Partch in developing instruments was influenced by their cultural backgrounds. Carrillo was influenced by both his pre-Columbian Mexican origin and national folklore, and by his European cultural and musical education. Among many factors, Partch was mainly influenced by his lonely youth in Arizona, by his interest in ancient cultures (mainly Chinese and Greek), and by a period in his mid-thirties in which he decided to travel around the USA as a homeless person.

Partch's creative process occasionally led him to improve and modify his existing instruments at the same time as he was composing for them. A clear example is the Kithara I, invented in 1938 and reconstructed in 1941, 1948 and 1959, on each occasion for a new work. These improvements involved substituting several soundboards for a single one (one for each row of strings), which not only improved the appearance of the instrument but also its acoustical properties, and furthermore resolved problems of unwanted noise in the original resonance box. While Carrillo at times had a team of specialists working on his designs, Partch worked alone in his workshop, or with not more than one assistant; while Partch documented his reconstructions and improvement of instruments, no information has been found about the extent to which Carrillo's team of instrument makers improved the instruments he adapted and invented.

For Carrillo, a compositional concept allowed him to explore aspects of compositional theory aided by the development of instruments. Partch, in most of his works used a text to carry a dramatic message. This not only influenced his search especially in his earlier compositions for instruments, which could imitate speech, but later on influenced his conception of instrumental layouts that favoured microdiscrete-sliding pitch. This was also the case for Carrillo, particularly in the *sixteenthtone harp* pieces and his music for the *sixteenthtone piano*.

Carrillo and Partch were both initially interested in exploring microtonality through instrument development as part of their compositional processes, and for both this led to their adopting pitch slide simulations, by means of small chromatic-step glissandi, as part of their compositional language. In both cases, the original concept not only affected the instrument but also vice versa.

1.1.4.5 Comparison of how Carrillo and Partch responded to feedback

Both composers worked closely with performers, using feedback obtained in rehearsals and performances, most of which they directed themselves. That Carrillo worked with his students, who also performed his music and composed under his guidance, placed him in a privileged position. Partch also had to teach his theories to his performers.

Partch played all of the instruments that he developed and was able to record them separately. Carrillo, once he embarked on microtonal composition in 1924, though an accomplished violinist, devoted himself to composing and conducting.

1.1.4.6 Comparison of the continuity in the work of Carrillo and Partch

Despite Carrillo and Partch having made extensive contributions to the fields of microtonal instrument design and microtonal composition, principally in the second quarter of the twentieth century, performances of their work were mainly carried out under their personal direction and ensembles. Since the decease of Carrillo and Partch (1965 and 1975 respectively) up to date, performances of their works have been rare. An exception is the annual local performances of Partch's music by Newband at Montclair State University (NJ, USA), using the original instruments. To date, very few mainstream composers have adopted Carrillo or Partch's tuning theories, or used their instruments. Partch's instruments are not commercially available and if his compositions were arranged for orchestral instruments, in order to achieve just intonation, exhaustive training would be required. The obstacles to performing Carrillo's music have not been widely overcome. His microtonal music in 96-et requires a specially trained musician to sound seven extra tones (sixteenthtones) between each of the familiar semitone steps of the 12-et scale. Regardless of the difficulty of achieving absolute precision, the performer does not have aural training to perceive these seven intermediate tones as distinct from one another. Most of Carrillo's microtonal music is thus difficult for players of adjustable-pitch instruments, and his adapted orchestral instruments are not in good condition or commercially available.[39]

Partch and Carrillo's involvement in the rehearsal and direction of performances helped them to understand the entire music-making process, and allowed them to learn from their experience in creating new works. That Partch trained himself to play most of the instruments he developed made him fully aware of their capabilities and properties.

Carrillo, who seems to have been more concerned than Partch about the continuity of his work, was not as efficient as Partch in this regard, partly due to his all-or-nothing project to institutionalise the teaching of his theories at conservatory level.[40] Partch did not share his theories and instruments with other composers. He chose to stay away from academia for

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[39] An exception is *sixteenthtone piano* manufactured by Sauter (Mikroton Piano), an upright model following Carrillo's patent, which is not ideal for concert halls.

[40] Carrillo did not plan on an alternative option, promoting an ensemble and regular performances of his music in the late period of his career, leaving most of his instruments stored in an archive up to date. The Conservatorio Nacional de Música (Mexico) and cultural Mexican authorities have not shown much interest in the promotion of Carrillo's work to date since Carrillo stopped working for this institution.

most of his life, although in the final part of his career he was closely associated with a university-based ensemble, several of whose members have managed to continue using his instruments and playing his music to the present. In both cases, at least some of their publications are widely available; and while all of Partch's compositions are recorded on CD, only about half of Carrillo's microtonal works are commercially available in that form. Although the original works are preserved and copies can be obtained for research purposes upon request, only a few scores by each composer have been published.

1.1.4.7 A comparison of the pedagogical elements in the work by Carrillo and Partch

The pedagogical value of Carrillo's and Partch's compositional output has supported the survival of their theory, compositions and instruments. The solos and duets with most pedagogical value are found at the start of Partch's career, in his extensive works for adapted viola and voice.[41] In contradistinction, Carrillo's solo studies for string instruments in quartertones are mostly concentrated towards the end of his career. While Partch systematically explored a wide range of sliding techniques for voice and viola, and intervals in just intonation, Carrillo wrote for violin, viola, cello and double bass, using the quartertone system. In both cases, the techniques used were significant for the training of musicians.

1.1.5 Research directions stemming from the strategies of Carrillo and Partch

Having analysed and compared the music-making processes and strategies of Carrillo and Partch, this section explains how these were apprehended and interpreted in this research, and how my own music-making processes and strategies stem from theirs.

1.1.5.1 General research strategies in relation to those of Carrillo and Partch

In general, Carrillo and Partch shared the desire to find new and unique sounds in their compositions by means of pitch resources beyond the capabilities of existing instruments.

[41] These works in particular are mainly masterworks but can also be approached by their pedagogical value unlike Carrillo's studies, which had the main functionality of practicing.

My research incorporates compositional practice and instrument development, whose aims (see Fig. 2, p. 6) are informed by their practices, which have profoundly influenced my strategies. These strategies are as follows:

(1) An interactive and open-ended methodical approach

Unlike the more intuitive approaches shared by Carrillo and Partch, my strategy in this study is method-based. However, this research followed an initial intuitive period inspired by Carrillo and Partch, encompassing a wide range of trial-and-error experimentation, from which a method was then formulated. The reason for choosing a methodical approach was to induce and coordinate beneficial interaction in several ways: between the composition and instrument development processes; between instrument-development-led composition projects which overlap in time; between instrument prototypes and the feedback from alternative designs, and in general; between theory and practice (see Fig. 3, p. 8).

The study and analysis of the way Carrillo and Partch used pitch (microtonality, sliding and micro-discrete sliding pitch) categorises the treatment of pitch into two groups: microdiscrete and dynamic. The research strategy and its derived method were developed such that in the future they can be utilised for four other compositional parameters, in addition to pitch, which can also be approached statically and dynamically: duration, amplitude, timbre, and spatial projection.

(2) Innovative use of microdiscrete-sliding pitch

Microdiscrete-sliding pitch, being the area of convergence between static and sliding microtonality takes an important role in the strategy. This capability of some of the instruments adapted and invented by Carrillo and Partch,[42] had a strong impact in their compositional practice. In this research the concept of microdiscrete-sliding pitch is incorporated into the compositional theory responsible for determining the capabilities of the instrument. Therefore, in my strategy, the demands of the

[42] In the case of Carrillo this capability is shared by all of his *'Carrillo' harps* (zithers) and *'Carrillo' metamorphosing pianos*; and in the case of Partch, by the Harmonic Canons, Boos, Eucal Blossom, Chromelodeons and Kitharas.

composition inform the microdiscrete-sliding pitch capability of the instrument being developed, and vice versa. Other microtonal considerations behind the chosen tuning chosen to support microdiscrete-sliding pitch (using 96-et) are the use of those scales that do not include octaves, unlike the octave-based systems adopted by Partch and Carrillo.

(3) Development of accessible notation systems appropriate to the music and instruments created.

I propose additional notation systems here as close scrutiny of existing systems. My experience has led me to conclude that microtonal notation and the notation for new instruments needs diversity to let performers have the choice to decide which one works better in practice. Partch's experience adapting notation to ease performance has a similar motivation. Carrillo's notation system is easy to learn and it has the potential to apply the numbers (standing for pitch degrees) to graph paper, which would be ideal to represent sliding and micro-discrete sliding pitch. In *Glissando study* (*Study No 3*, Sc. 3), as an alternative to using graph paper, I adapt Carrillo's *Sound 13* numerical notation by heightening the numbers according to the required pitch contour, while indicating the rhythm with regular noteheads beneath.

(4) Development of a conceptual approach to instrument development that is informed by and integrated with compositional practice and theory.

The instruments invented and adapted by Carrillo and Partch were mostly developed before compositional practice (see instrument and composition dates in Appx 1 and Appx 2). In my strategy, concepts of instrument capabilities and characteristics are informed by and integrated with compositional practice and theory, in order to allow composition not to be limited by the capabilities of the instrument but to determine them when required, while also reinforcing the interaction between instrument development and compositional practice. This is mainly induced by arranging a prototype development plan in parallel to the composition (see details in Fig. 29, p. 73), which is arranged in stages determined by the compositional theory.

A reinforcement of the research's conceptual approach to instrument development is incorporated to the method applied, by instructing the use of feedback obtained from a supplemental prototype evaluation process as part of the instrument development and compositional practice. In this process alternative instruments to each prototype are defined at a conceptual level, so as to compare with the corresponding prototype evaluative data.

The diagram in Fig. 8 shows details of a comparison between the common elements of the compositional strategies used by Carrillo and Partch, and those considered in this research.

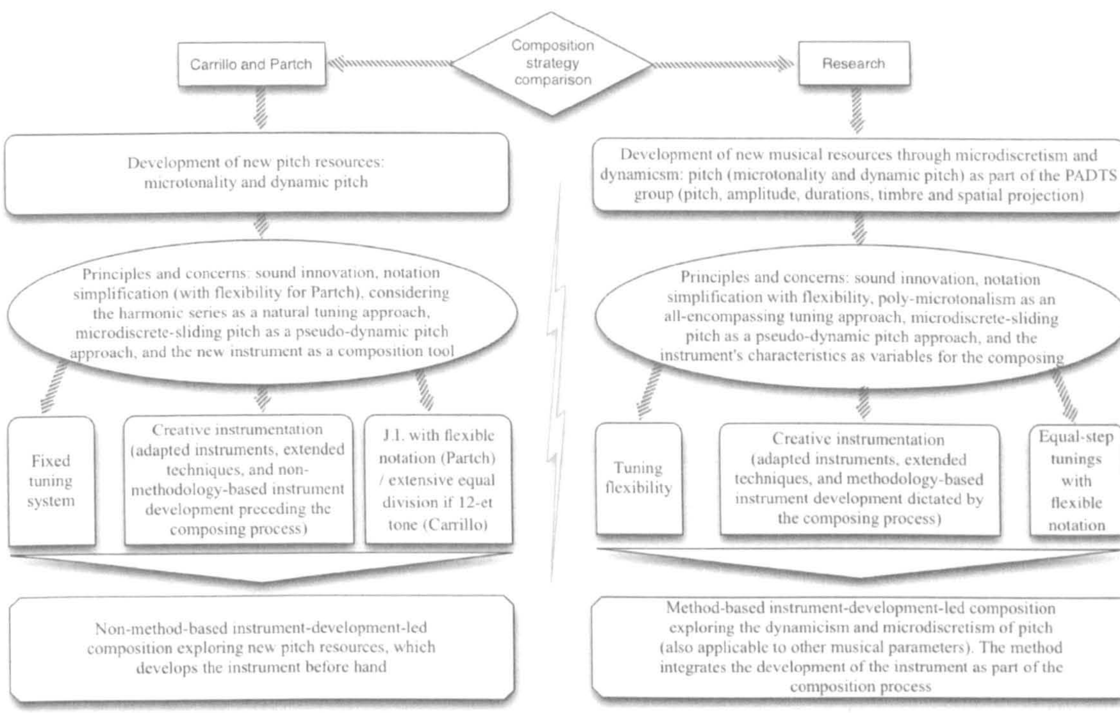

Fig. 8. Carrillo and Partch shared main strategic elements and those of this research.

1.1.5.2 New ideas arising from the prior adaptation and transformation processes

In order to introduce new sounds, an effective, gradual evolution of the orchestra as a whole is as important in refreshing the listener as developments in timbre arising from transformations of the instruments individually. Both lines of change are considered as part of the instrument development-led method applied in this research. In this, the instrumentation of existing instruments (adapted if necessary), using extended techniques for sliding pitch and alternative tunings, works in parallel with composing for a newly developed instrument. Partch and Carrillo are here treated as exemplars.

The method followed and exemplified by

this research promotes the documentation of compositional work in progress and allows for a fruitful extrapolation of approaches. For this reason, the stages of the musical instrument's development need to be defined. Carrillo and Partch did not have computer technologies available to them to allow them to simulate musical instruments by audio-visual means. They had analogue recording technologies available to them late in their careers, which Partch used to aid his composition, recording his playing and superimposing tracks so that they could be heard together. The availability of audio-visual and computer technologies to simulate musical instruments enables the stages in which a concept takes shape as a musical instrument to be simulated to obtain feedback from prototypes (CD-tks 1-7 are computer-sampled versions).

Several stages of development, informed by the work of Carrillo and Partch and by my own recent practice, have been identified (their names are abbreviated here as initials), as follows:

(1) Musical instrument characteristic(s) (MIC). This is a characteristic or array of characteristics chosen. In the present research, pitch (dynamic pitch and microtonality, which are further subdivided into more specific characteristics) is the foremost characteristic chosen.

(2) Evaluated MIC (EMIC). The present research evaluates the chosen characteristics of pitch together with the sound and form of the instrument.

(3) Sketched EMIC (SEMIC). This is the first creative step for the instrument-development-led composer, who has already thought about and evaluated the required instrument characteristics. A rough sketch is made to accommodate a wide variety of prototypes.

(4) A prototype. The term prototype is used here to mean a sketched and evaluated musical instrument characteristic (SEMIC) for which basic measurements of a

sound-producing body and structure (in this case a supporting frame) have been specified. When a prototype is conceived of as having complex internal mechanisms, it is not until the instrument is built (prototype 8) that precise definitions need to be resolved and improved, if necessary, after testing. Their construction, testing and improvement (if necessary) are parts of prototype 8, involving the construction of the physical instrument.

(5) A visual musical instrument (VMI) is a virtual simulation of the instrument playing, generated by means of computer software.

(6) An audio-visual musical instrument (AVMI) is a VMI with sound. Ideally it would highlight the sounding bodies, as they are sounded by means of manipulating sound samples through sequencing technology.

(7) A MIDI instrument with AVMI (MAVMI). Instead of attaching a MIDI file to the virtual model, the programming involved in the AVMI can be extended, linking a live MIDI input attached to the virtual model in the computer. This allows a MIDI interface (keyboard, touch-screen, etc.) to be attached to the virtual model, so that it can be played in real time, not only visually simulating the instrument being played, but also reproducing the sensation of playing the instrument. The closer the MIDI instrument is to the virtual instrument, the closer the sensation should be. Preparing a transformable MIDI instrument would allow the exploration of desired compositional parameters by means of improvisation to introduce new ideas to the design of the instrument. Unfortunately there are very few devices as such commercially available and they are also very limited.[43] As a clear example of MAVMI that can be used with a computer mouse, Partch's instruments are now available to be played interactively on-line.[44] The hosting of on-line MAVMI improves access while also promotes awareness and continuity, especially if sites are made easy for children to use.

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[43] The design and realisation such MIDI instruments for each sound-producing action – potentially an interesting research project in its own right – would expand the field of instrument-development-led composition.

[44] Vogeli, T. 2003. *Harry Partch's Instruments.*

(8) A built musical instrument (BMI). This refers to the physical instrument being constructed. As the cost (including time) of physically building a new musical instrument normally exceeds that of preparing a MAVMI. It is normally more efficient to have experimented with a MAVMI version before building the instrument.

(9) A (built and) performed-on musical instrument (PMI). Performing on several layouts of the instrumental design using MIDI instruments can bring us very close, in an almost effortless way, to the physical instrument, and can help inform the layout of the instrument. Having the physical instrument performed on, ideally in an ensemble context with other instruments as appropriate, confirms that what was initially simulated in this research also works in a physical instrument. Although there is a possibility that further improvement may be required, such modifications are likely to be relatively minor. To follow these stages regularly becomes a discipline, which can improve ergonomic and other aspects of the instrument-development-led composer's work.

(10) A (built and) performed-on musical instrument with extended mechanised-MIDI capabilities (PMI with EMMC). A musical instrument per se has the potential of incorporating a mechanised system, attached to a computer and a MIDI interface, so the capabilities of the instrument can be extended. This is an emerging area which offers unlimited possibilities, while still providing the acoustic sound of the instrument and integrating the movement of the performer to provide visual expression to the performance and a touch of human element to the mechanised system.

An existing example is a piano assisted by a mechanised-MIDI system (e.g. the Yamaha Disklavier), which could for example be used to play two parts with two hands and add a third part (for a sequencer to play with a MIDI file) be impossible for a performer to realise. In this case the pianist still can lead the tempo of the MIDI file for that part with a pedal programmed to control the tempo (attached to the sequencer). Since we are playing and sounding a standard piano (built and performed musical instrument) and then execute additional sounds with the aid of a mechanised-MIDI device, which we are also leading (in this case through the tempo parameter), this musical instrument would then be used as a BPMI with EMMC.

Fig. 9 is a diagram of the stages of musical instrument development. The terminology presented is that used for the instrument development process throughout the thesis. The timeline of the instrument design process proceeds from bottom to top of the diagram. Starting with a conceptual instrument at the foot of the diagram, its development may be followed ascending through the diagram, as it becomes a virtual or a physical instrument.

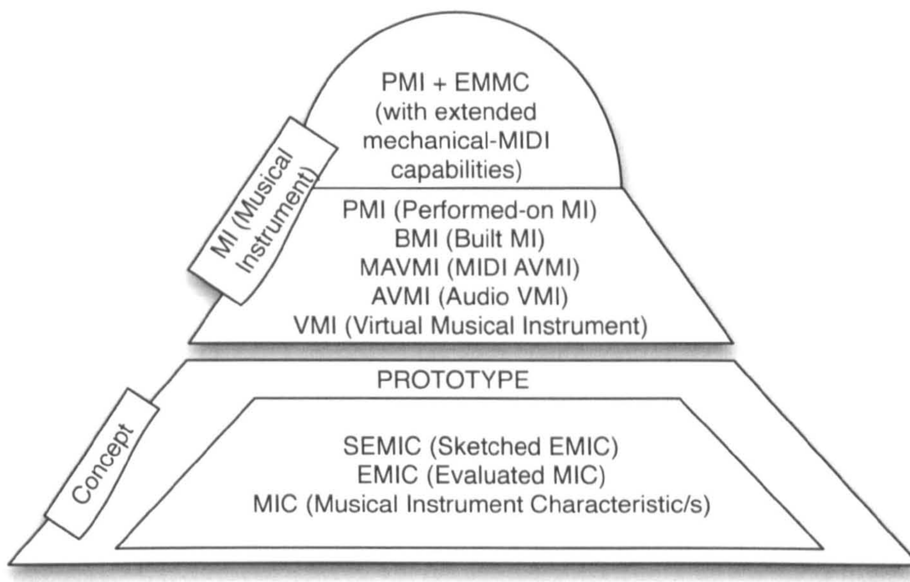

Fig. 9. Instrument development stages (from bottom to top).

1.1.5.3 New ideas concerning the involvement performing and conducting

Carrillo's and Partch's involvement in conducting and rehearsing, greatly benefited their understanding of instrument capabilities, techniques and pitch theory. This shows how relevant it is for an instrument-development-led composer to be directly involved in these practices in order to gain a comprehensive command. However, where the costs of live rehearsal and performance are prohibitive, the provision of a computer-generated track with clues for practice, or the use of MIDI-run virtual instruments, allowing the player to practice with visual clues is considered here. Such a system can also be used to substitute players in rehearsal, in this case using a MIDI tempo controller to run the virtual instrument(s). A PMI with EMMC, can substitute performers at rehearsals if the conductor can control their tempo in case of absence, or for the conductor to practice without the players. Also at the performance scenario, and in the case the written parts are not executable, the conductor can control with a tempo-controller device attached to a sequencer, the pace at which the MIDI instrument plays. In this case the conductor's controller device and the instruments attached become a single PMI with EMMC played by the conductor, who takes two roles. Since the present research does not allow for the development of a mechanised version of the bellophone, this idea is discussed but not tested in practice. As recent technology affords the potential to allow instrument-development-led composers to conduct a MAVMI or a PMI with EMMC, to improve the development of the composition, the composer may then conduct, record and step back to hear the result, while still composing, without assistance. A conceptual prototype exemplifying this idea, consisting of a baton for the conductor with a MIDI tempo controller, is proposed in Chapter 4 (see *dynamic baton,* p. 211).

Another application of PMI with EMMC would be writing for a single performer who also controls a PMI with EMMC with a tempo-controller pedal (pp. 152-154). In such case it would also be easy to compose the part for the PMI with EMMC first and then compose the part for the other instrument by improvising while playing the PMI with EMMC instrument with a MIDI pedal set to control tempo.

1.1.5.4 Instrument development-led composition in the implementation of further new concepts

New, overlapping compositional projects and revisions and expansions of previous works, allow revision and improvement of the musical instruments developed. They can also trigger the development of new instruments that complement the characteristics of the already developed instruments to please the composition's demands.

As a general guideline, the instrument development process should interact as often as possible with the compositional process. Since an appropriate vocabulary for communication between the two disciplines is required, the devising of music theory and notation is almost unavoidable. Therefore, it is good to keep a record of the theoretical developments both in chronological order and by subject so that they can be easily accessed during the instrument-development-led compositional process.

New terms, notation charts and symbols are normally derived from development of the music theory and a glossary must be maintained for reference (in this thesis kept in the Glossary section).

An instrument-development-led composer can find inspiration in life experience, and historical and cultural interests. It is beneficial to consider any surrounding sounds (and especially those found in nature) as a musical instrument or source for new concepts, ideas within the instrument development-led composition process.

Exploring pitch with electronic equipment has provided a wide range of resources applicable to this research. For example, samples of the instrument being developed have been used to explore the pitch accuracy perception limits while composing, determining this way the ideal equal division of the tone to be consider for the instrument being built.

Regular practice composing thinking about sounds rather than instruments can easily lead to instrument characteristics and also designs being imagined simultaneously as part of the creative process of composition. Therefore instrument development-led practice a discipline notating and documenting as part of a pre-established method promotes an efficient instrument-development-led practice.

The method employed in this research, can be enhanced compiling a database of musical instruments with fields for physical properties and sound capabilities (§4.2.5, p. 214).

The involvement of the instrument development-led composer in the instrument-making workshop (as in the case of Partch) is another beneficial possibility to consider. If a wide range of new musical instruments developments are being explored it is preferable to have a team of people, specialised in each area, backing up the instrument-led composer (in much the same way as Carrillo coordinated different instrument makers).

1.1.5.5 Approaches responding to feedback

Informed by the interaction that Carrillo and Partch had with players, this research method includes a compositional stage in which collaborating players improvise within a range of patterns (see for example the improvisatory duet for prototype 8 in Fig. 5). This experimentation is intended to provide feedback to inform the development of the prototype and concurrent composition.

The creative ideas that Carrillo and Partch initiated can be developed further by gradual assimilation into compositional practice, incorporating new instruments and adaptations when desired, without limiting the imagination. Offering audiences the opportunity to hear changes of tunings within a single piece should increase awareness of and demand for music with alternative tunings. Incorporating instruments of the Western orchestra into such performances, thereby exploring further what Carrillo initiated, is a viable way of exploring novel possibilities.

Playing the instruments developed and also conducting the works written for those instruments has proven to be positively beneficial to the music making process (as observed in the cases of Carrillo and Partch). This could be taken a step forward by documenting the feedback obtained from these processes and drawing conclusions upon it, on a regular basis, so as to carry a systematic process of gradual improvement of the open-ended instrument-development-led method proposed and followed in this research project. The method encourages this practice but does not impose it. However, if future applications of the method were to be conducted by myself, the time that I would not have to use to devise it (already done in this research project) from scratch would give extra time in which to be involved in these activities, or in reporting and analysing feedback from performers.

1.1.5.6 Strategies to promote continuity of the research

Twentieth-century mainstream composers, such as Xenakis, Ligeti and Nono, adopted the language of quartertones and exceptionally of eighthtones. In terms of twenty-first-century concert repertoire, further gradual acceptance of increasing subdivision of the tempered semitone, including sixteenthtones, is more likely to happen before widespread acceptance of just intonation. Once players of variable-pitch instruments have learnt to play fluently in 96-et, achieving just intonation from the closest sixteenthtone degree, when beating partials are appreciated, will be but a minor challenge. Consequently, acceptance of just intonation might follow a hypothetic acceptance of 96-et. In the light of this, it is proposed here that compositional practice for the 96-et bellophone includes a task in which just intonation is approximated in sixteenthtones (see *Glissando study*, Sc. 4). Such practice helps both to link concurrent traditions of microtonal music making, and to establish historical continuity.

Other elements supporting continuity of the research are: (1) the use of an open-ended method which may be customised to suit a specific pitch investigation, and also transposed to another musical parameter; (2) the creation of a new instrument intended for use in Western ensembles, and development of technique, compositions and demonstrations illustrating its capabilities; and (3) the introduction of a way of combining composition and instrument development, which is applicable to both existing and new instruments.

1.1.5.7 Pedagogical responsibilities of the instrument-development-led composer

Systematic composition, notably of solos or duets, at particular periods in Carrillo's and Partch's careers aided their adoption of new instruments and tunings and helped performers to acquire new techniques. Carrillo's approach to composing microtonal solo studies for existing instruments as a way to explore their limitations, can be expanded to accommodate instruments newly created and even to interact with their design process. Solo studies are here used to guide the devising of alternative techniques, and thereby to nurture the development of the instrument itself.

1.2 Compositional theory context

As Carrillo and Partch are the main sources of inspiration for this research, relevant theoretical aspects of their treatment of pitch are classified and discussed here. The ways in which these two composers treated static and dynamic microtonality are considered and compared, and ideas arising from their practice, which are relevant to my own, are discussed.

Fig. 10 shows the hierarchy of the compositional theory context of the general method used in this research. The classification system devised provides the vocabulary required to analyse and compare the compositional theories and strategies of the composers considered. Reflection upon these leads to new ideas, which are proposed and acquired as the research method is revised and refined.

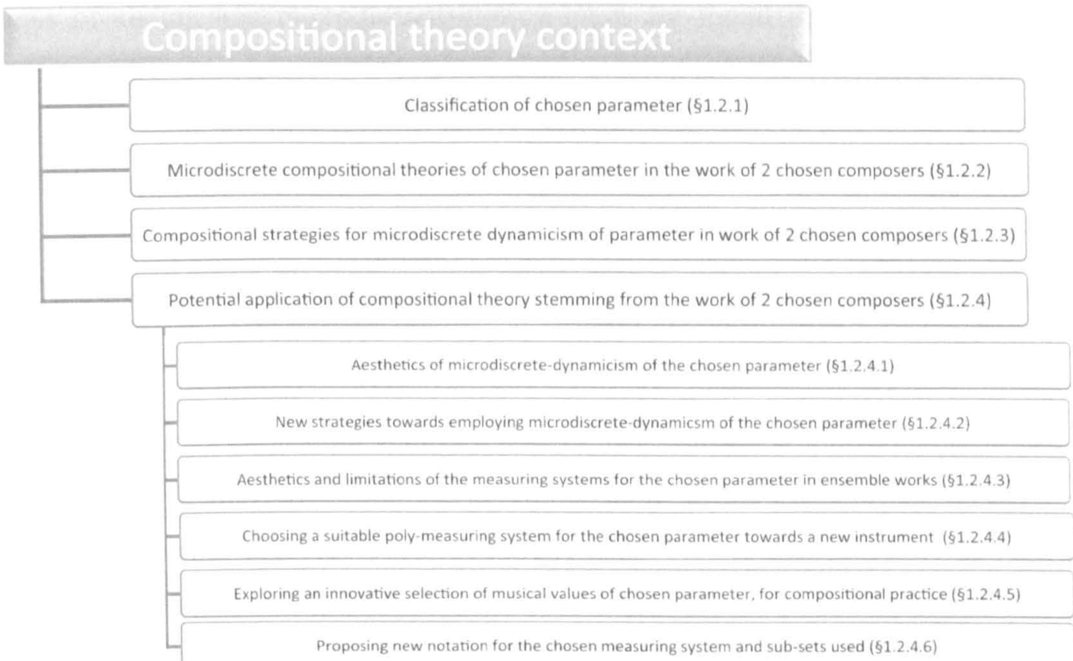

Fig. 10. Compositional theory context hierarchy for the method.

1.2.1 Pitch classification

Pitch resources can be classified as static or dynamic: static referring to pitches which do not change in time regardless of the sustained nature of the tone, and dynamic to pitches which do change in time implying the use of sustained tones. Sustained pitches are a necessary basis of modern harmony and modal theory. Microtonality can be divided into two categories, both of which are considered useful here: one for microtonal systems that include the 12-equal temperament (like Carrillo's) and the other for systems (like Partch's) that do not.

From the point of view of Western music theory, sliding pitches are difficult to classify, since only the melismas of Gregorian chant (represented by *neumes*) and straight (linear) sliding pitches (gradual, constant changes of pitch, denominated by pitch slides from note to note) are largely present in the Western repertoire. In order to notate Indian classical music, for example, from the point of view of Western theory, a very sophisticated method of sliding pitch notation would be required. Devising such a system is beyond the scope of this research, but the work presented here may be considered as a small contribution to such development in the future (see §4.1.12 on p. 208).

Elements of sliding and microdiscrete-sliding pitch are found throughout Carrillo's and Partch's outputs. Partch's output is consistently microtonal (the only aspect of sustained pitch of central interest here), while only approximately half of Carrillo's works are of microtonal nature.

1.2.2 Microtonal compositional theories in the work of Carrillo and Partch

Carrillo developed a compositional theory, named *Metamorphosis*, in which the value of the 'chromatic' step employed throughout a composition is varied, shifting between tone, semitone, quartertone, eighthtone and sixteenthtones. This is clearly a way of controlling the thickness of the texture, since this process either places pitches closer together, or further apart, maintaining the proportion of the pitch spacing in the texture.[45] Partch using his theory of 'limits' in just intonation found a way to control the consonance or dissonance of the intervals employed (*GM*, pp. 109-173).

Carrillo reviewed and compared ratios of the harmonic series from the perspective of 96-et (sixteenth equal division of the 12-et tone), and from the perspective of other divisions of the 12-et tone from one to fifteen (see pp. 265-271). Though for practical reasons he saw a pure realisation of the harmonic series as remote, he considered that the successive division of the tone (semitone, quartertone, eighthtone and sixteenthtone) would gradually lead to an approximation of the harmonic series that would not be substantially differentiated from the ideal equal temperament.

Partch considered the ratios of the harmonic and subharmonic series to be means of realising just intonation. The predominance of harmonically rich instruments, such as tuned percussion which typically have short sustain, suggests that his just intonation theory was essentially a starting point for composing, and that producing non-beating partial frequencies was an aesthetic aim when composing for sustained-pitch instruments. This is the case with the Chromelodeons, which produce reed sounds identical to the melodeon from which they derived.

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[45] Carrillo, J. 1927 (pub.1949). *Leyes de metamórfosis musicales*. pp. 12-64.

1.2.3 Sliding and microdiscrete-sliding pitch strategies adopted by Carrillo and Partch

Using the intonational patterns of American speech, turning poetic recitation into music, led Partch intuitively to introduce pitch slides for the voice and the Adapted Viola into his microtonal structures at an early stage of his career. Later on, his music became predominantly instrumental; consequently microdiscrete-sliding pitch contours were used for ornamentation and tone colouring. For example, instrumental tone colouring is used in *The waterfall* for fast gliding passages for the Diamond Marimba, in which the effect of the quantised pitch continuum (in this case with relatively large intervals) can be associated with the sound of water striking the rocks.

Carrillo obsessively produced microdiscrete-pitch instruments (employing varied divisions of the tone) to achieve both microtonality and microdiscrete-sliding pitch. Although his microtonal theories prompted his design of his first instruments, it must have been his auditory and haptic experience of the instruments that showed him their potential for the execution of microdiscrete-dynamic pitch progressions. Carrillo did not write theoretically about how to apply sliding pitch, though his theory of metamorphosis is gradually applied in his compositions. Carrillo's composition *Babbling for piano solo (in sixteenthtones) and chamber orchestra* (see Fig. 11, p. 50) is a significant and unique example of a thematic solo instrumental part (for the piano) using microdiscrete-sliding-pitch contours.

Carrillo's technique of using zigzag patterns in quartertones as used in his *Quasi-sonata No 6*,[46] and the speech imitation in Partch's works for Adapted Viola and voice are good examples of their use of sliding pitch induced by microtonality. The incorporation of new microtonal instruments with microdiscrete-pitch layouts into their works and a consequent search for new instrumental techniques led both composers to augment their use of sliding and especially of microdiscrete-sliding pitch.

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[46] Carrillo, J. *Seis casi sonatas en cuartos de tono para violonchelo solo* (CD).

1.2.4 Potential applications of compositional theory stemming from the work of Carrillo and Partch

Within my compositions, consideration of microdiscrete representation and a realisation of the pitch continuum support gradual changes of textures and the use of microdiscrete-pitch contouring rules. Ideas derived from Carrillo and Partch, which are directly applicable to my research, are explained in this section, while further extensions of these lines of thinking, which have potential for further development, are set out in Chapter 4.

1.2.4.1 Aesthetics of microdiscrete-sliding pitch

Although the piano and pitched mallet instruments cannot perform portamenti, glissandi effects are possible. Carrillo, in his work *Babbling for piano solo (in sixteenthtones) and chamber orchestra*, creates the effect of an undulating portamento by means of fast chromatic glissando passages in the *sixteenthtone piano* part (see Fig. 11). In my own compositions I use undulating portamenti executed by sixteenthtone bellophone. It is also useful to establish the speed at which microdiscrete-pitch slides are satisfactory on a specific instrument, and the studies are ideal minor works for the exploration of new instrument developments at a preliminary stage. Microdiscrete-sliding pitch can be used effectively with parallel and contrary motion movements and in general to produce gradually changes of texture (see Autumn, Sc. 10).

Fig. 11. *Babbling for piano solo (in sixteenthtones) and chamber orchestra* (Carrillo, 1959): 16th-tone piano part (bars 121-124). Courtesy of the *Carrillo Archive*.

That mallet instruments can perform glissandi faster than keyboard instruments when the sounding bodies are laid in chromatic sequence in a linear pattern. This is as taken into consideration in the compositional processes adopted here, and in the development of the *conic bellophone*. The use of struck glissandi is extended to the timpani in *Autumn* (pp. 174-192). In this work, microdiscrete-sliding pitch progressions of bells guide parallel and contrary motion glissandi on the timpani (see Fig. 103 on p. 180).

1.2.4.2 Compositional strategies for the use of sliding and microdiscrete-sliding pitch

The practical elements of this research focus primarily on melodic applications of sliding and microdiscrete-sliding pitch, realised in both the composition portfolio and in the parallel development of the instrument.

Four different compositional approaches to the use of sliding and microdiscrete-sliding pitch are employed in my compositional practice here: (1) smooth melodic progression from the middle of one note the start of the next (portamento), as in *Autumn* (Sc. 10); (2) simultaneous, parallel progression, at a set interval, as in *Glissando study* (Sc. 3); (3) brief ornamental glissandi and grace notes, as in the sequences preceding sustained tones in *Prelude No 1* (Sc. 11); and (4) other melodic progressions and undulations, such as the vibrato-like microdiscrete-slides of *One row study* (Sc. 1).

1.2.4.3 Aesthetics and limitations of tuning in ensemble works

Musical works conceived for non-equal tunings and temperaments (including most European music before the nineteenth century) are perceived differently when performed in 12-et, although the differences in tuning may be small. Such tuning adjustments affect the sound of the intervals, since they produce different partial-beating effects.[47] The subtlety of this aesthetic difference was an initial stimulus to my adopting microtonality, and particularly for exploring very small tuning steps – as far as dividing the tone into 9600 steps (see p. 206).

The apparent timbre of an instrument can be affected by small tuning adjustments when playing dyads or chords. These adjustments substantially change the beating between partials from different notes sounding simultaneously, especially when these partials happen to be contained within the same critical band.[48] Since most orchestral instruments have

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[47] Sethares, W. A. 2005. *Tuning, Timbre, Spectrum, Scale*. pp. 40-41.
[48] Sethares, W. A. 2005. *Tuning, Timbre, Spectrum, Scale*. p. 44.

relatively few partials which are outstandingly prominent (those which chiefly characterise the timbre of the instrument),[49] dyads and chords played on these instruments produce a wide range of beating effects when using 12-et. Enhancing or abolishing the beating produced between two or several simultaneous tones are two of several possible approaches to substantially changing the sound of an interval by means of small pitch adjustments.

The beating between two partials can be increased or decreased by respectively increasing or reducing the interval between the beating partial-frequencies contained within the same critical band. The beating can be abolished matching the partial frequencies that produce the beating. For most orchestral instruments, their simple harmonic spectrum allows controlling the beating to be achieved by placing their fundamental frequencies in a low-number ratio relationship with each other, and by using spectral scales.[50] William Sethares particularly refers to strings and tubes, and argues that 12-et has little to do with reducing the beating of intervals when employing instruments of such spectra.

> Recall that most musical instruments based on strings and tubes are harmonics; their partials are closely approximated by the integer ratios of the harmonics series. Such spectra are related to the just intonation scale, and yet are typically played (in the West, anyway) in 12-tet. Although this is now considered normal, there was considerable controversy surrounding the introduction of 12-tet, especially because the thirds are so impure. [51]

With both harmonic and inharmonic instruments in equal temperament (in contradistinction to just intonation), the beating between simultaneously sounding notes can be controlled, and also abolished, thus manipulating the spectra of the sounds. Not all instruments allow spectral manipulation, but a good example of this is the tuning of harmonics in Western bells. Sethares describes how the spectra of a harmonic instrument can be changed to match 12-et: '...the consonance of 12-et can be increased by moving the partials away from the harmonic series to a series based on $s = 2^{1/12}$, an example being the set of partials f, $s^{12}f$, $s^{19}f$, $s^{24}f$, $s^{28}f$, $s^{31}f$, $s^{34}f$, $s^{36}f$, s^{38}.'[52] Minute adjustments of the pitches in a chord can also be made so that all the possible intervals produce the same beating, thus enhancing the beating effect.[53] These beating or non-beating effects can only be appreciated with timbres containing a few partials which are substantially louder than the others. For control to be

[49] Fletcher, N. H. and Rossing, T. D. 1991. *The Physics of Musical Instruments.*
[50] Sethares, W. A. 2005. *Tuning, Timbre, Spectrum, Scale.* p. 66.
[51] Sethares, W. A. 2005. *Tuning, Timbre, Spectrum, Scale.* p. 250.
[52] Sethares, W. A. 2005. *Tuning, Timbre, Spectrum, Scale.* p. 250.
[53] Jorgensen, O. H. 1991. *Tuning.* p. 325.

exercised over the beating desired, as an aesthetic decision in composition, the tuning and spectra of the instruments must be considered, and at the least one or other of them must be easy to vary.

These phenomena may be taken account of in designing instruments to satisfy specific compositional objectives. It is desirable for performers to be trained to adjust the tuning of notes – and thus to control the rate of beating – and in such circumstances it is helpful to have stable-pitch instruments to refer to, particularly during the training of players of variable-pitch instruments. When composing for adjustable-pitch instruments with simple harmonic spectra a stable-pitch instrument that is easy to distinguish, ideally with a distinctive harmonic spectrum, can be used to provide reference pitches for the instruments of adjustable pitch. Instruments not receiving the reference pitch have to tune by listening to the beating of their instrument and comparing it with those that did receive it (assuming that both have relatively simple harmonic spectra, as most orchestral instruments apart from the tuned percussion do). In that case, notes that require fine adjustments but have no reference tones need a brief moment in which they can adjust, which may only be achievable in relatively slow passages.

1.2.4.4 Choosing a suitable tuning for the new instrument allowing polymicrotonality

Having examined the just intonation work of Harry Partch, and keeping in mind Carrillo's intention to approximate the harmonic series using the ninety-six-equal temperament, a just intonation system was the first option considered for the tuning of the bellophone. However, having chosen to build a steel idiophone from the outset, it was necessary to consider the inharmonic spectrum that such an instrument would have, and the possible beating frequencies that might be present in the sound of a single bell. Irregularities of the metal or irregularities arising from the construction method have to be borne in mind.

The use of successive divisions of the equally tempered semitone, as favoured by Carrillo, is a more suitable option if one keeps in mind the objective of polymicrotonality and an equal exploration of the intervals with and without beating frequencies, to allow some degree of control over beat rates. Prompted by Carrillo's example, and with the aim of realising very close approximations to low-number ratio intervals using equal pitch increments, the 192-et, using a thirtysecondtone (6.25 ¢) as chromatic step, was initially considered as a further subdivision of his sixteenthtone division. In practice, however, it was found that the presence of irregularly beating partial frequencies within the sound of each steel bell made it difficult to perceive such a small interval (a thirtysecondtone), especially when adjacent notes are sounded sequentially.[54] The use of 192-et was therefore rejected, and 96-et was adopted, since sixteenthtone steps (12.5 ¢) are easily to recognise when playing ascending and descending sequences with steel bells. When playing two such bells a sixteenthtone apart there is a substantial difference in the perceived pitches though not when playing a thirtysecondtone apart.

1.2.4.5 Exploring non-octaval scales

All 96-et equal-step scales having steps comprising an odd number, from 5 to 23, of 96th-octave increments (which do not include the octave) are systematically introduced in the work *Seasons* (Sc. 12) in order to explore an interaction between microtones and the rich harmonic content (characterised by stretched octaves) of the steel bells. Reinforcing partials of the bells, in specific stretched octaves, using a non-octaval scale brings consonance (in a manner analogous to the gamelan) to the overall sound of the composition, without needing to use just intonation intervals between notes. Non-octaval scales are also used in *Autumn* (Sc. 11) and *Mollienaire* (Sc. 8). *Mollienaire,* written for an early, thin-walled version of the bells, which had particularly rich harmonic content, initiated experimentation with sequences of steps not totalling 96, which influenced *Autumn* and its expansion in *Seasons*.

1.2.4.6 A new notation for 96-et: extended Stein-Couper notation

Although in 1917 Carrillo strongly supported the simplification of staff notation for music in equal temperaments from 12-et to 96-et,[55] his later numerical notation – in which pitches are only distinguished vertically in relation one to another in bands encompassing one octave – lacks bi-dimensional pitch perspective. This need not be a problem once enough time has been devoted to pedagogical matters arising from Carrillo's multiple treatises. Since addressing this problem was beyond the scope of this research staff notation was

[54] An initial experiment with sampled cone-shaped bells tuned in thirtysecondtones and playing sequentially in zigzag patterns, 2 steps up and one down, was difficult to appreciate.
[55] Carrillo, Julián. 1957. *Sistema General de Escritura Musical.*

chosen as a starting point. However, Carrillo's notation proved to be effective for his regular ensembles and could also function as a complementary way of reading and writing music using graph paper. Having chosen staff notation for this research, a system of accidentals has been developed for this purpose, in addition to the standard five accidentals used in staff notation (Fig. 12).

Fig. 12. The five accidentals used in normal staff notation.

Gardner Read surveyed the alternative notations in use for quartertones up to 1990.[56] After due consideration, the quartertone sharp and three-quartertone sharp symbols most widely used by twentieth-century composers, according to Read,[57] which were first proposed by Stein,[58] were adopted (Fig. 13) here. These two signs have the advantage that they are nowadays accepted by most score-editing software as the standard.

Fig. 13. Quartertone sharp and three-quartertone sharp accidentals.

In Reed's survey, the most popular quartertone flat accidental among twentieth century composers interviewed,[59] was the reversed flat (Fig. 14). Since it is often adopted by score-editing software, it is adopted here. This accidental was first proposed by Stein.[60]

Fig. 14. Quartertone flat accidental.

[56] Read, G. 1990. *20th-Century Microtonal Notation.* p. 24.
[57] Read, G. 1990. *20th-Century Microtonal Notation.* p. 24.
[58] Read, G. 1990. *20th-Century Microtonal Notation.* p. 41.
[59] Read, G. 1990. *20th-Century Microtonal Notation.* p. 25.
[60] Read, G. 1990. *20th-Century Microtonal Notation.* p. 41.

The use of three-quartertone flat accidentals mentioned in Read's survey,[61] differed substantially amongst those composers interviewed. An accidental combining the flat symbol with the quartertone flat previously referred to (𝄳♭), is widely accepted among score editing software in the first decade of the twenty-first century, although a simplified version is sometimes available as a substitute. This simplified version shares the stem of both flats (Fig. 15), which takes less space in the score while still symbolising the addition of the regular flat with the quartertone flat. It was used first by Mildred Couper (1887-1974) (see the example in Fig. 16). Reed refers to Couper's use of this three-quartertone accidental in her composition, *Xanadu* (1930).[62] She was the first composer to use it.

Fig. 15. Three-quartertone flat accidental.

Fig. 16. *Dirge* (Mildred Couper, 1937) excerpt: violin part. Courtesy of Greta Couper and UCSB Library.

Since three of the accidentals represented for quartertones were first used or proposed by Stein and Couper, the whole set is referred to in this chapter as the Stein-Couper quartertone accidentals (Fig. 17).

Fig. 17. The Stein-Couper quartertone accidentals (also referred here as Stein-Couper notation).

A logical extension of the Stein-Couper quartertone accidentals is suggested here. The eighthtone sharps proposed are built by adding a horizontal line to the closest quartertone to raise it an eighthtone, and by subtracting a horizontal line to lower it an eighthtone. Fig. 18

[61] Read, G. 1990. *20th-Century Microtonal Notation*. p. 25.
[62] Read, G. 1990. *20th-Century Microtonal Notation*. pp. 41-42.

shows the horizontal line build up for one, two and three eighthtones, while Fig. 19 shows the horizontal line build up for five, six, and seven-eighthtones, bearing in mind that two-eighthtones is the same as a quartertone and six-eighthtones is the same as three-quartertones.

Fig. 18. Accidentals for eighthtone, 2/8th-tone (quartertone) and 3/8th-tone.

Fig. 19. Accidentals for 5/8th-tone, 6/8th-tone (three-quartertone) and 7/8th-tone.

The proposed eighthtone flats add to or subtract from the Stein-Couper accidentals, although not as consistently as the eighthtone sharps. The eighthtone flat resembles the two-eighthtone flat (regular quartertone flat) but with the lower part of the stem removed (Fig. 20), in the same way that the three-eighthtone flat resembles the four-eighthtone flat (which is the regular flat) with the lower part of the stem removed (Fig. 21). The five-eighthtone flat accidental resembles the four-eighthtone flat accidental (regular flat) filled in black, while the seven-eighthtone accidental joins the two-eighthtone flat (regular quartertone flat) with the five-eighthtone flat (Fig. 22).

Fig. 20. Accidentals for 2/8th-tone flat (quartertone flat) and eighthtone flat.

Fig. 21. Accidentals for 4/8th-tone flat (regular flat) and 3/8th-tone flat.

Fig. 22. Accidentals for 7/8th-tone flat and 5/8th-tone flat.

The sixteenthtones are represented by adding upward arrows to the previously denoted sharps in order to raise the pitch an extra sixteenthtone and by adding down arrows to the previously proposed flats to lower the pitch an extra sixteenthtone (Fig. 23).

Fig. 23. Accidentals proposed for the 96-et.

1.3 Instrument development context: observations arising from comparison of the instruments used and developed by Julián Carrillo and Harry Partch

Fig. 24 shows how the instrument development context, the work of Carrillo and Partch, informs the creation of a classification system in order to analyse aspects of the instrumentaria used by these two composers. This leads to the definition a feedback mechanism for the development of prototypes relying on conceptual instrument models.

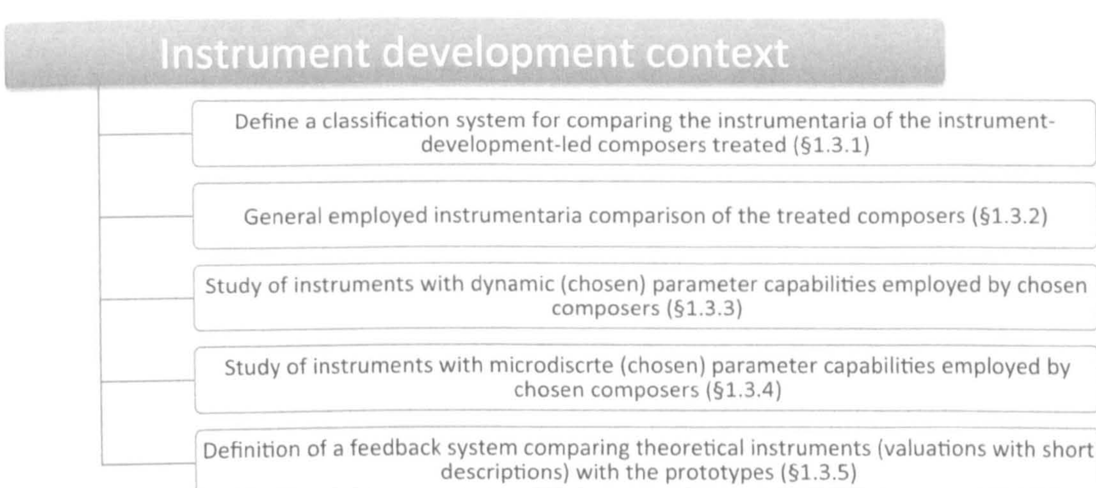

Fig. 24. Instrument development context hierarchy for the method.

All of the instruments developed or adapted by Carrillo or Partch (or developed under their supervision) have micro-intervallic capabilities. Carrillo's instruments were developed or adapted to achieve equal divisions of the tempered tone (200 ¢), and Partch's to achieve just intonation. Both composers made extensive use of both sliding and microdiscrete-sliding pitch though neither addressed this in their compositional theory. It seems that they used sliding pitch without reference to prior theoretical reflection. This was also the case with microdiscrete-sliding pitch. The following sections analyse the instrumentaria of both composers, and compares their microtonal, sliding pitch, and microdiscrete-sliding pitch capabilities.

1.3.1 A classification system for comparing the instrument designs and instrumentaria of Carrillo and Partch: extended K-H-S

This classification has been proposed (explained in detail on pp. 338-363) in order to allow a simplified code to represent all the instrument characteristics necessary to this research; to ease visualisation of the whole of Carrillo's and Partch's instrumentaria; and to allow the calculation of statistics required to make an effective comparison of the two composers' instrumentaria.

This research has the potential to be utilised for four parameters other than pitch: amplitude, duration, timbre and spatial projection. An acronym for pitch and those four facets, *PADTS* parameters (see Abbreviations), is used to refer to all five – all of which are here considered an advantage to the exploration of instrument development-led composition. In the classification system proposed, the initial 'P' is used for the coding to recall pitch, but the other letters of the acronym would be used if we were dealing with the other four parameters. The potential for expanding this research to treat the other four compositional parameters proposed, is examined on pp. 216-219.

The taxonomy proposed here is an expansion of the K-H-S classification system, used by Toshie Kakinuma (which departs from the Hornbostel-Sachs system) to classify Partch's instruments (*MIHP*, see Abbreviations). The extended classification code starts with the K-H-S code (including a few new categories in special cases for instruments by Carrillo), and is followed by '-P' with 2 subindexes explaining the sliding and micro-intervallic properties respectively.[63] The 'P' with subindexes is followed by another hyphen and symbol enclosed in parentheses, explaining the origin of the instrument, and concludes with a hyphen followed by the initials of the composers who used them (in chronological order and

[63] The extended K-H-S code can accommodate other parameters, to be considered in future research.

separated by forward slashes). The first composer indicated after the hyphen is responsible for the development of the instrument. If the instrument was not developed by a composer, this last hyphen is followed by a forward slash. Thus any composer whose initial follows a forward slash was not involved in the development of the instrument referred to.

1.3.2 A general comparison of the instrumentaria of Carrillo and Partch

It is necessary first to consider the percentages of instruments with definite pitch used by Carrillo and Partch for each of the main groups from the Hornbostel-Sachs system (Fig. 25).

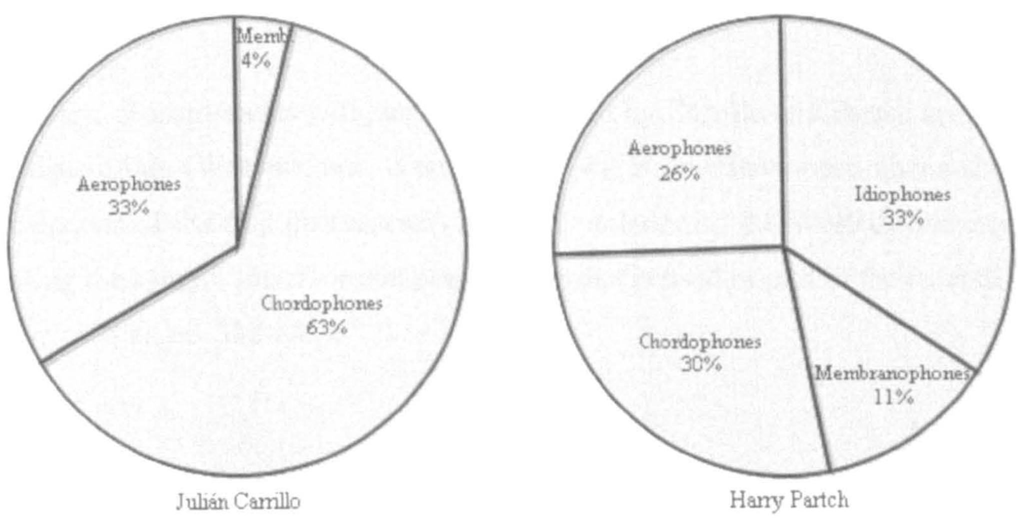

Fig. 25. Instrumentarium (definite pitch) by Carrillo and Partch under H-S's main groups.

The pitched instruments used by Carrillo were mainly chordophones (approx. 2/3), some aerophones (approx. 1/3), and two membranophones (quartertones tom-toms, and timpani). Partch used instruments from the four main groups of the H-S system to an almost equal extent: there is a slight increase in percentage from instruments with less definite pitch, including the less stable membranophones (which do not provide a distinct pitch centre), to the instruments with more stable pitch, including the idiophones (which have the most stable tuning). In this progression, the aerophones and chordophones, which are tuned before performance and may require fine adjustments during performance, are situated in the middle.

Partch's logic in choosing instruments (from the H-S system groups' perspective) seems to emphasise his desire, mainly for instruments with stable fixed micro-intervallic capabilities, while Carrillo preferred to use instruments with fixed micro-intervallic properties, though only those that can be finely tuned before the performance. Most of the idiophones cannot be retuned without damaging them and they can be troublesome after many years if they have not been properly maintained, while most of the chordophones can always be slightly retuned without damage. Carrillo required his new instruments to play with different orchestras that might have required a different concert pitch, while Partch did not since he relied mainly on his own ensemble.

Both Carrillo and Partch used a substantial number of aerophones to produce microtones (33% and 26% of their instrumentaria respectively) and they both adapted several of them to have fixed micro-intervallic capabilities.

The percentage of instruments with definite pitch used by Carrillo and Partch are examined showing their origin (Western, non-Western or New), if they have been changed (new or adapted versions of existing instruments), and their relation to the Western orchestra (Fig. 26), by using the symbol (black or contoured shape that is used as part of the extended K-H-S code proposed on pp. 338-343).

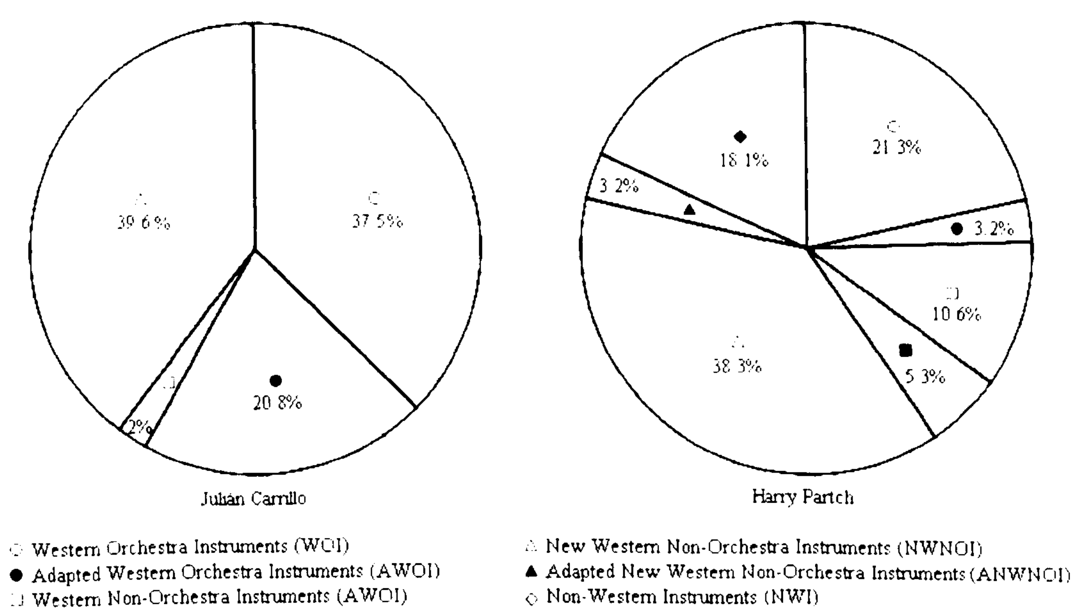

Fig. 26. Percentages of definite pitch instrumentarium used and developed by Carrillo and Partch in their microtonal works.

The highest percentage of pitched instruments considered by Carrillo for his micro-intervallic compositions belongs to the new Western non-orchestral group. This group happens to consist of all the new chordophones that he invented, and includes the fifteen *'Carrillo' metamorphosing pianos*. These pianos were not all used for compositions but since the intention was there and the legacy for other composers to use them, they are considered relevant and included in the graph. Although the *'Carrillo' metamorphosing pianos* were derived from an original orchestra instrument, their transformation was substantial enough for them to be considered as new and original instruments.[64] There is a possibility that Carrillo's invention of new instruments could have been aimed at achieving microdiscrete-sliding pitch rather than sustained micro-intervallic capabilities. If so, the concept of achieving sliding pitch by means of microdiscrete divisions of the tone must have been conceptualised in his mind before he decided which type of instruments he wanted to invent. However, there are no theoretical writings that elucidate this.

Very close in percentage to the NWNOI used by Carrillo (39.6%), are the Western orchestra instruments in their original form (37.5%), which he expected to play at least quartertones (if not eighthtones or sixteenthtones), through extended techniques and fine adjustments during performance. Most of the microtonal instruments of the orchestra that Carrillo adapted were fixed-pitch instruments allowing precise sustain of microtonal pitch values. The adapted and non-adapted instruments of the Western orchestra amount to 58.3% of Carrillo's microtonal instruments (or instruments used to play microtones). This proportion allows us to understand Carrillo's approach to instrumentation by means of exploiting the already standard orchestral instruments. This is understandable since his ambitions to replace the standard notation system and to introduce microtonality as part of the curriculum of a new music education institution was already challenging enough to also introduce many new instruments too. He still invented new instruments that could have the capabilities not achieved by the orchestra, and adapted several orchestra instruments.

As Fig. 26 shows, Partch (38.3%) and Carrillo (39.6%) wrote for similar percentages of NWNOI. Both composers invented close to 40% of the instruments for which they wrote. Carrillo incorporated most of his new inventions at the beginning and towards the end of his

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[64] The mandolin and mandola are considered instruments that have been used in the orchestra (by other twentieth century composers), and in the case of Carrillo, frets for quartertones were placed respecting the ones that were already there, therefore they are considered adaptations of orchestra adapted instruments.

career. While Partch incorporated his new inventions at the beginning and throughout the middle of his career and only incorporated orchestral instruments into his late major works.

A remarkably high proportion (18.1%) of Partch's pitched instruments were his own versions of non-Western instruments. This enhances to the already unconventional nature of his invented musical instruments.

Partch used a substantial number of non-orchestral Western instruments (10.6%) from a wide range of periods and backgrounds: folk instruments, historical instruments, and also new instruments that were not commonly used in the orchestra – at least at the time at which he used them. Carrillo also incorporated instruments that were not accepted as part of the orchestra, notably marching band instruments, but they represent a very small percentage of microtonal instrumentarium (2%).

1.3.3 Instruments with dynamic pitch capabilities used by Carrillo and Partch

Both composers simultaneously developed instruments and composed music using micro-intervals and gliding tones. Studying the sliding pitch capabilities of the instruments Carrillo and Partch developed helps to understand their compositional strategies. Fig. 27 shows the percentages of pitched instruments employed by Partch and Carrillo according to their sliding pitch capability.

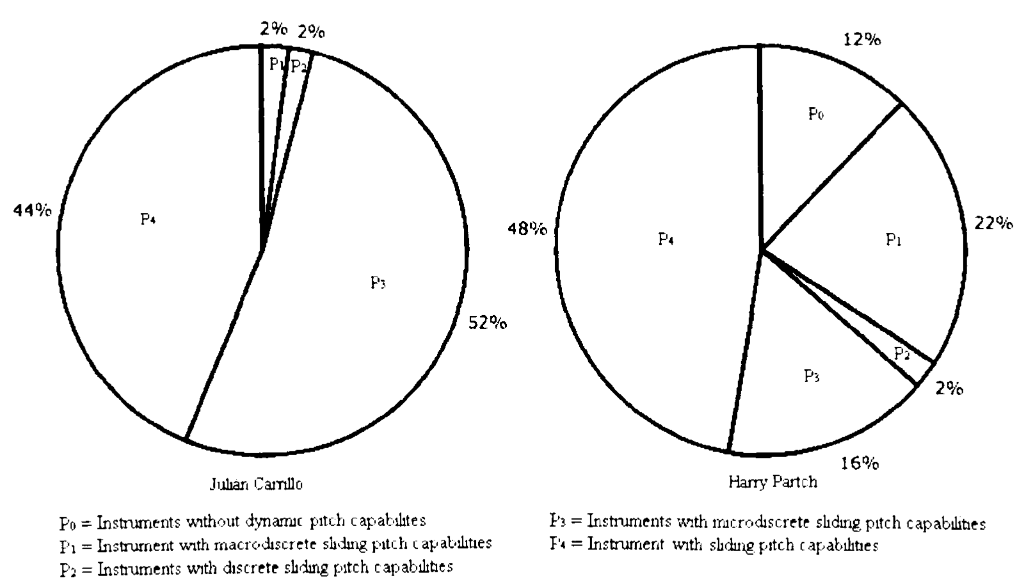

Fig. 27. Percentages of instruments used by Carrillo and Partch according to their sliding pitch capabilities.

Slightly over half of the pitched instruments employed by Carrillo had microdiscrete-sliding pitch capabilities (52%), while almost the rest (44%) had pure sliding pitch capabilities. However, when he used sliding pitch, Carrillo mainly employed the instruments with microdiscrete-capabilities, which were the chordophones developed under his supervision. Therefore Carrillo's way of conceiving the gliding tone was to quantise it into small microdiscrete pitch values, similar to the approach he used for his micro-intervallic theories. Initially Carrillo simply ornamented his compositions with microdiscrete-sliding tones using plucked chordophones (the *Carrillo harps*), but as he incorporated struck chordophones (*'Carrillo' metamorphosing pianos*, and in particular the *sixteenthtone piano*), which provided a louder tone, he was able to use microdiscrete-sliding pitch passages as a leading solo part (for *sixteenthtone piano*).

That almost half of the pitched instruments employed by Partch (48%), used in most of his works, had sliding pitch capabilities shows that he must have been highly conscious of this specific potential. It is noteworthy that the 16% of the pitched instruments with microdiscrete-sliding capabilities that Partch regularly used were his own inventions. The sound producing bodies of those instruments are mainly from bamboo or have strings which require amplification if they are to be clearly heard in ensemble. The microdiscrete-sliding pitch effects were mainly ornamental rather than structural (providing a referential tone in the ensemble), and in some cases they took small leading rolls. Of the 22% of the pitched instruments used by Partch which had macrodiscrete-sliding pitch properties, most are idiophones of metal or wood (not bamboo). The heavy weight of metal or wood used for the sound producing bodies of these instruments may explain why Partch did not design them to cover the full 43-notes-per-octave scale. It could also be that these instruments, which are distinctively heard due to their inharmonic nature, were ideal for rhythmic parts rather than for microdiscrete-pitch contours. A peculiar aspect of Partch's compositional work is the use of fast macrodiscrete-sliding pitch and prominent arpeggio passages, especially for wooden idiophones, in such a way as to suggest that the compositional concept might have dictated the tuning and layout of the instruments' sound-producing bodies, or vice versa.

There are several techniques in which Carrillo and Partch achieved gliding tones with their instruments, which can usefully be considered when designing a musical instrument:

(1) Changing the length of the vibrating body or changing to different vibrating bodies with different lengths: Sliding fingers (one finger technique) on string instruments; sliding plectrums over chromatic sets of strings (Carrillo's zithers; and Partch's Kitharas, Surrogate Kitharas and Harmonic Canons); sliding Pyrex rods on top of metal strings (the following Partch's instruments: Adapted guitars A and C, all Kitharas, Surrogate Kitharas, Harmonic Canons I and II and New Harmonic Canon I), and; extending tube length on brass instruments (mainly using the slide trombone).[65]

(2) Changing the tension of strings: Pressing and depressing them at the other side of bridge (Partch's Koto, Surrogate Kitharas and Harmonic Canons) or pressing attached parts (Partch, with the handle of the Crychord, with the bamboo flanks of the Ektaras, and with the bar attached to the string of the Gubagubi).

(3) Bending flexible sounding bodies (Partch's Whang Guns and *flex-a-tone*).

(4) Changing the shape of resonator (Partch's Drone Devil does this when imitating the singing voice of the chorus in *Revelation*, and the speech in *Delusion*) and shifting resonators (Partch's Ugumbu, played close to bare chest or belly or shifted away).

(5) Playing chromatic scales on keyboard instruments. The gliding tone produced in step-wise motion by Partch's instruments using the 43-note chromatic layout (Chromelodeons, Harmonic Canons, Boos and Eucal Blossom), which sounds like a smooth gliding tone due to the micro-intervals (*MIHP*, p. 184). Carrillo uses the *sixteenthtone piano* to write melodic passages drawing tiny pitch contours by also using chromatic movements in the keyboard.

Other composers who used gliding tone and new instruments worthy of consideration are: Varèse, who used the siren for *Ionization* (1930-33) or the *Theremin* and *Ondes Martenot*

[65] Neither Carrillo nor Partch considered placing slides on brass instruments other than trombones.

for *Ecuatorial* (1934), and Percy Grainger who used the *Theremin* for *Free Music No 1 and No 2*. However, these instruments are electrophones that are outside the scope of this research that only considers acoustical instruments for performance purposes. That Partch and Carrillo, who composed only for acoustical instruments, were also involved in developing most of those instruments illuminates their uniqueness in the area of instrument development-led composition while also enhances their results exploring microtonality and sliding pitch.

1.3.4 Instruments with microtonal capabilities used by Carrillo and Partch

The whole of Partch's compositional output and the second half of Carrillo's rely on micro-intervallic theories supported by instruments that were newly invented, adapted, or played using extended techniques. Partch also used folk, historical, new non-orchestral and non-Western instruments (either adapting them, changing the tuning or using extended techniques to achieve just intonation). The use of micro-intervals was mainly a theoretical challenge that led Carrillo and Partch to adapt and produce new musical instruments, while the use of sliding pitch was for them an aesthetic consideration most likely inspired by the capabilities of the instruments they composed for. In order to understand the overall application of these theories into the instrumentarium employed in their compositions it is necessary to examine the percentages of instruments used for each group of micro-intervallic capabilities (see definition on pp. 340-342). These percentages are shown in Fig. 28. Starting from the lowest percentages and with Carrillo, the 2% (result of rounding to whole number the 2.12 %, and calculated from the 47 stable-pitch instruments used or simply built by Carrillo), refers to the *'Carrillo' metamorphosing piano* in semitones, which in this case is a subset of the 12-et, for which no records of a microtonal composition where this instrument is also used has been found. Since at least it was built and it is a legacy left for future generations it is here included in the chart. As for the 12-et piano that Carrillo envisaged as part of the 16 *'Carrillo' metamorphosing pianos*, since it has not been found in the Carrillo Archive under the Sauter tag, neither in pictures, it is assumed that it might not have actually been built, but simply used as part of the 16 *'Carrillo' metamorphosing pianos* concept to cover the semitone among the 16 different divisions of the tone considered. Consequently since it was not built, or written for, it is not included in the diagram in Fig. 28, which shows the percentages of pitched instruments that Carrillo and Partch used in their compositions,[66] according to their microtonal capabilities.

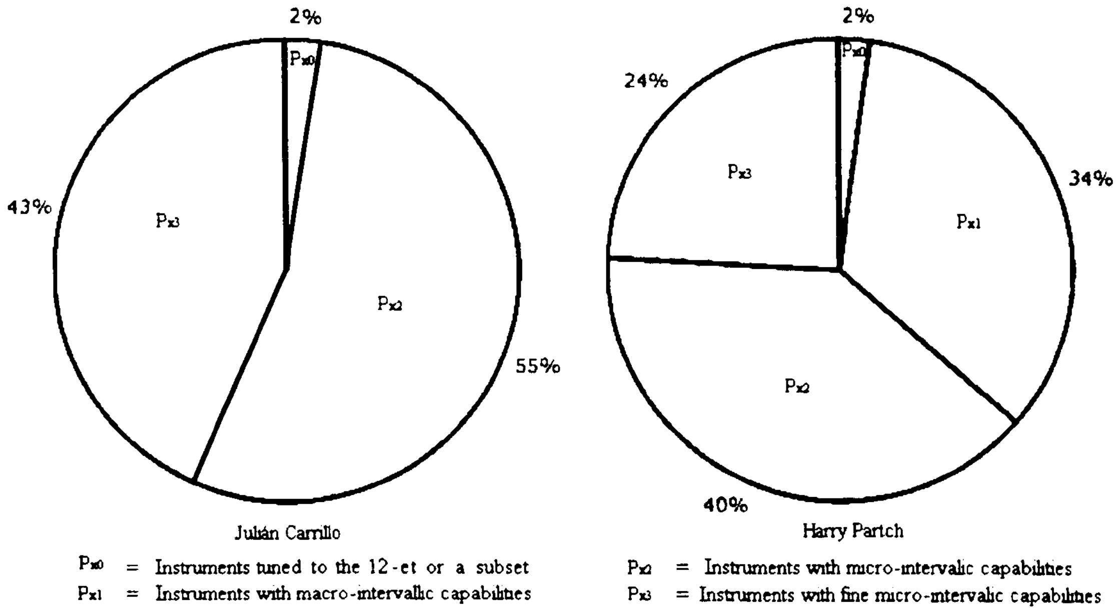

Fig. 28. Percentage of pitched instruments used by Carrillo and Partch according to their microtonal capabilities.

According to Toshie Kakinuma, Partch used a 'guitar' (probably referring to a metal string acoustic guitar) and a 'Spanish guitar' (probably referring to a nylon string classical guitar) (*MIHP*, p. 347). Due to the fact that she did not specified any adaptation nor transformation of these instruments it is here assumed that they were fretted to 12-et. The 2% corresponding to Partch in Fig. 28, is the result of rounding to whole number the 2.19% of the 12-et stable-pitch instruments that Partch composed for (*MIHP*, pp. 345-348). In the case of Carrillo, also a 2% of the pitched instruments used for his microtonal works, were exclusively used employing the 12-et.[67]

Having defined macro-intervals as the non-12-et intervals that are larger than a 12-et semitone, it comes to a 34% the pitched instruments with macro-intervallic properties (implying that the instruments do not have micro-intervals in the tuning used) that Partch

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[66] The *metamorphosing pianos* that Carrillo built but did not composed for, are also included.

[67] In the case of Carrillo, instruments that he did not composed for, but that he built envisaging using them for compositions, have been taken into account for the diagram in Fig. 28.

wrote for. However, Carrillo did not write for pitched instruments with macro-intervallic properties.

Having defined micro-intervals as non-12-et intervals that are smaller than a 12-et semitone not smaller than 12 ¢, it comes to a 55% the pitched instruments considered by Carrillo that had micro-intervallic properties, while to a 40% in the case of Partch.

Having defined fine micro-intervals as the non-12-et intervals that smaller than 12 ¢, it comes to a 43% the pitched instruments considered by Carrillo that had fine micro-intervallic properties, while to a 24% in the case of Partch.

The reason for choosing 12 ¢ as the limit for the instruments with regular micro-intervallic properties was to exclude any equal temperament that had more than 100 notes per octave, since that being slightly above the 96-et mostly used by Carrillo it corresponds to the limit of pitch classes that can be represented with two digits as in the notation system proposed by Carrillo. A just intonation system of 100 notes was proposed by Carrillo's student Espejo, and another student, Vargas, made zithers, based on Carrillo's *sixteenthtone harp* (p. 251), using that system.

Only 24% of the instruments that Partch employed had fine micro-intervallic properties, and these were only achievable at restricted speed. These were mostly Western orchestral wind instruments, which he incorporated in his major works towards the end of his career.

Although Partch did not use scales with more than 43 notes, these instruments were required to adjust the pitch during performance with great accuracy (to achieve beatless intervals). Since this accuracy expected is more than what it would be required to roughly play 12 ¢ steps to achieve (100 notes per octave) these instruments are considered fine micro-intervallic instruments (according to the definition on p. 341). These instruments with fine micro-intervallic properties used by Partch did not require adaptation to achieve precision since Partch wrote slow passages for them in most of the cases, which do provide the required time for the performer to adjust the pitch with precision. The Chromelodeons are an exception. They are adapted instruments, which might require a slight fine-tuning (or change of reeds) before a performance, but they cannot be adjusted during performance. However, they do not rely on the performer's ear to give the right pitch, and they keep sustained pitch reliably without needing much retuning, making them the most reliable source of accurate just intonation within Partch's instrumentarium.

The 40% of the instruments employed by Partch that had regular micro-intervallic properties were idiophones tuned to the 43-note scale, providing great accuracy; and chordophones also tuned to the 43-note scale, but more likely to lose some of the accuracy required by just intonation during the performance although they allow fine adjustments beforehand. These instruments, unlike most of the instruments from this group can play rapid micro-intervallic passages, which do not require the just intonation scale to remain precisely in place.

34% of the instruments used by Partch have macro-intervallic capabilities. These instruments are mainly membranophones and idiophones. The idiophones have subsets of the 43-notes scale and many offer a unique timbre ideal for Partch's melodic writing within dense textures. The membranophones, due to the lack of pitch clarity are more often used for rhythmical passages.

Partch employed macro-intervallic solo passages often in his music, and also developed a wide range of instruments with this capability, ergonomically designed to suit this writing style. Carrillo conceived most of his musical instruments at different levels of scales, starting from the whole tone scale and then subdividing the tone into semitones, thirdtones, quartertones, etc., according to his theories. Partch's development of instruments with macro-intervallic properties constitutes an important element in the materialisation of subset scales derived from his 43-note just intonation tuning.

Carrillo's and Partch's contrasting ways of realising microtonal theories by developing musical instruments and using extended techniques still have many things in common. While Partch does not use as many tones per octave as Carrillo, he requires higher pitch accuracy. However, the most precisely pitched instruments developed by both composers are Carrillo's *metamorphosing pianos*, which are struck chordophones, and Partch's Chromelodeons, which are reed aerophones. Both are non-adjustable-pitch keyboard instruments which can be tuned prior to performance.

1.3.5 A creative and comparative prototype feedback mechanism

Partch's instrumentarium contains a large percentage of pitched instruments, which occur in increasing proportion as successive groups of the H-S system afford more stable pitch: membranophones 11%, aerophones 26%, chordophones 30%, idiophones 33%. As it is vital to the exploration of pitch resources in this research to rely on stable-pitch instruments, the development of a microtonal idiophone is favoured. Having at this stage a need to explore a wide range of materials, forms and sound-producing actions, a creative-comparative feedback system incorporating these characteristics is introduced. Having adopted a preference for idiophones, sounds of relatively undefined pitch are also considered. Although some of the resulting sounds might not be ideal for providing stable reference pitches, the unique nature of their timbre potentially contributes to the overall aesthetic value of the composition. Therefore they are not necessarily excluded, since they provide contrasting feedback, and additional or alternative instrumental resources. This interest in instruments that can substantially contribute to a unique overall tone colour led to considered also feedback from instruments that produce sounds based on the vibration of liquids (e.g. struck water). The feedback system devised involves proposing eight variant conceptual instruments to each prototype. The variant instruments are systematically conceived to explore three sound-producing actions (struck, plucked, blown) and a wide range of sounding bodies (bells, plates, solid bars, solid tongues, shallow bars, strings, water, membranes, tubes, air columns, and reeds). One of the eight groups, 'new vibrating bodies or hybrids', is kept for experimenting with the concepts of sounding bodies and actions.[68] The compositional practice for each prototype is transposed to each of the eight variant conceptual instruments and when positive feedback is obtained is documented and used to inform the design of the corresponding bellophone prototype. An evaluation system of instrument capabilities and properties help to define the variant conceptual instruments and to evaluate the prototype. The data obtained is compared and analysed to informing the prototype development. The feedback obtained from transposing the compositions and from comparing evaluations is documented in Chapter 2.

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[68] See p. 108, where these eight groups are defined, for more details.

The feedback approach followed studies the characteristics of each prototype by means of transposing ideas to parallel scenarios through original alternative sketches. This allows vast amounts of effortless experimentation, and provides a broader view of the possibilities available in the decision-making process of the instrument design.

1.4 Method refinement: relation to research aims and objectives, and stage-by-stage description of method application

As the result of a cyclic review of the first method stage group,[69] the method developed for this research is refined (process documented here in §1.4 as part of method Stage V), which has a substantial contribution to its final form.[70] This refinement process aims to reinforce the method, assuring that: (1) it accommodates the potential exploration of other *PADTS* parameters other than pitch, (2) the research aims and objectives are backed up by the strategies adopted, and; (3) an effective plan of action for its application in this research is settled and explained stage by stage explaining how it was applied in Chapter 1 (method stage group A), and how is going to be applied in Chapter 2 and 3 (method stage groups B-F).

With the aim of increasing the suitability of the method to explore musical parameters other than pitch, two strategies are initially considered. It is important systematically to check that all the method stages are applicable to the other parameters; and a reflective approach allowing the method be reviewed as appropriate. Consequently, the method refinement process documented here, provides: (1) a rationale for application of the method in relation to the research aims (§1.4.1, pp. 72-76); (2) a rationale for the application of the method in relation to the research objectives (§1.4.2, pp. 76-77); and (3) a stage-by-stage description of the application of the method in the thesis (§1.4.3, pp. 77-86). The last one can be used both as a detailed guide to apply the method in this project, and as a summarised example illustrating its application.

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[69] This is method stage group A.
[70] The final form of the method is outlined in Fig. 5 (p. 13).

1.4.1 Rationale for application of the method in relation to the research aims

The main research aim is systematically to explore microtonality, and particularly sliding pitch, in historical and theoretical context and, by composition and the development of instruments, in practice. The historical and theoretical contexts analysed and reflected upon in this chapter (as part of Stages II-IV) are supported and informed by an annotated chronological review of relevant work by Julián Carrillo (Appx 1) and Harry Partch (Appx 2). Arising from the reflection process, new instrument-development-led composition ideas, involving strategies, compositional theory, notations, and instrument development theory, are proposed at the end of sections 1.1, 1.2 and 1.3. These ideas are brought to fruition through the instrument development process and compositional practice (treated schematically in Stages VI-XXVII), which are presented in Chapters 2 and 3 respectively. However, at particular stages, the instrument development process or compositional practice may inflect the method, which is open to potential change throughout its application.

The consequent research aims (see Fig. 2, p. 6) shape the overall strategy. The relation between four of the aims and the method employed is as follows:

(1) The interactivity, flexibility and systematic approach of the method

Interaction between the research contexts, instrument development and compositional practice occurs throughout the method (indicated by double-direction arrows in Fig. 5, p. 13). This interaction is intense in stage group D of the method, which was responsible here for instrument prototypes 3 to 8. This stage group is characterised by a multi-layered compositional practice, three works having been composed simultaneously throughout most of the time (see Fig. 29). The completion period of each of the first four studies was planned to coincide with the initial period of the following study. This overlapping process allows the prototypes corresponding to each study to interact with each other sequentially, producing smooth transitions between them.

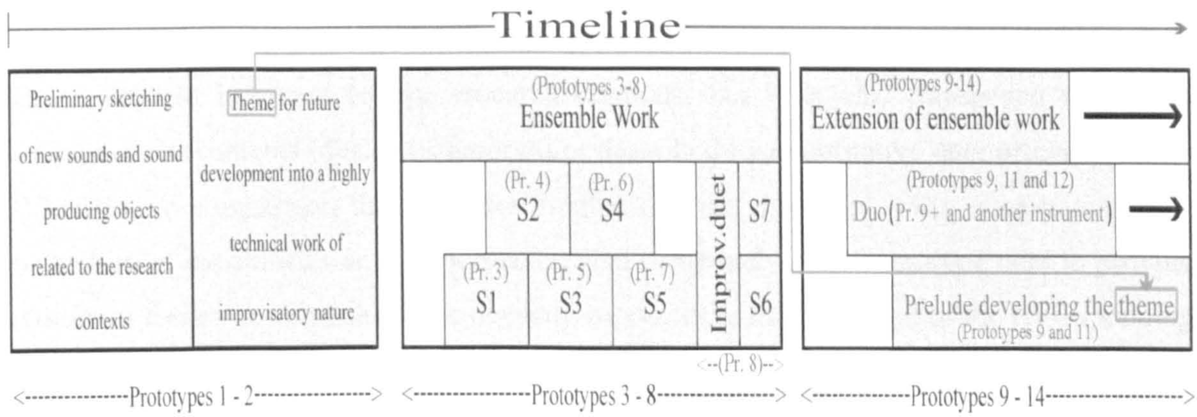

Fig. 29. Timeline diagram, showing compositional projects and the development of prototypes.

In the case of the first solo studies (S1-S4) the completion period of each of has to overlap the start of the composing for the next study, in order to prepare the composition materials that will inform the design of the new prototype to be considered. The studies are also to be composed at the same time as the ensemble composition to inform it with new technique vocabulary. The ensemble work also overlaps a '4-hands' composition of improvised nature, which allows the players to adjust the curvature of an experimental version of bellophone prototype 8. This prototype provides feedback to inform: (1) a final prototype designed and built for the performance of the ensemble work and studies 6 and 7 (prototype 8); and (2) potential expansions, additions and adaptations of prototype 8 leading to prototypes 11-14 and the three last works presented here. One of these three compositions, an expansion of the ensemble piece, provides time continuity to the compositional practice, plus there is a solo work developing a theme composed at an early stage reinforcing this continuity, which is strategically planned to provide a smooth and progressive development of the instrument and the related compositional practice. The expansion of the ensemble work aims to extend what was previously achieved at a larger scale in terms of structure, and to incorporate new ideas. The solo work (in prelude form or similar) for a prototype 8 with the range extended (prototype 9) is responsible for demonstrating the musicality that can be achieved by using the techniques previously revealed by the studies to the limit of virtuosity.[71] This work also informs the two simultaneously developed works, an expansion of the ensemble work and a duo for bellophone with another instrument. These three concluding compositional projects interact with the prototypes shared, as informing tools.

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[71] Which is why the mechanised version of prototype 9 (prototype 11) is also applicable to this work.

The compositional practice for each of the prototypes, not only interacts directly with their design process informed by the research contexts, but it is also transposed to variant conceptual instruments (designs supported or described by quantitative data placed in Appx 3) to allow a comparison that provides feedback to the prototype. The quantitative data, evaluation of capabilities and properties, is also compared to the prototype data to provide additional feedback. This feedback not only supports the improvement of the corresponding prototype but also the progress from prototype to prototype.

The method induces interaction between the theory and the practice, by suggesting parallel developments in most of the stages (as previously illustrated in Fig. 3, p. 8). Consequently, the compositional and instrument development theory proposed ends up being reviewed as the compositional and instrument development practice progresses that also informs back to these practices.

(2) The innovative use, in theory and practice, of microdiscrete-sliding pitch as an area of convergence between static and sliding microtonality

The corresponding aim behind the method is to achieve an innovative use of dynamic microdiscretism (pp. 216-218) of the musical parameter chosen, pitch. In the application of the method conducted by this research, microdiscrete-sliding pitch (see Glossary) is studied within the work of the two chosen composers on method Stage II, and new consequent compositional theory is proposed as part of Stage III, which is to guide the research's instrument development from the beginning. An ideal layout of the sounding bodies for the achievement of microdiscrete-sliding pitch is the first one proposed (prototype 1) and then compromised in further prototypes (prototypes 2 to 8) to also incorporate sight-reading fluidity for individual sustained notes (microtones) as a second additional capability, and two additional properties of interest, sound distinctiveness and audio-visual expressiveness (see corporeal expressiveness in Glossary). In other words, dynamic microtonality is the starting point in the instrument design process, and static microtonality is gradually incorporated through further developments.

(3) The development of accessible notation systems appropriate to the music and instruments in the method

Stage III requires choosing the tuning for the instrument that is going to be built for a future performance as part of the overall music making process, or at least deciding the criteria behind the tuning to consider. In Stage X, when studying the acoustics of the sounding bodies, further subdivisions of the intervals considered within the chosen tuning are to be experimented with, in case it proves to have some relevance considering them, which leads to confirming what the final tuning for the instrument would be. From Stage XI onwards, existing notations for that tuning, which were reviewed and proposed in Stage III (and consolidated in Stage X) are suggested to performers as the compositions for the prototypes are being completed. The feedback provided by the performer and the conductor informs which notation systems work for each kind of technique, and implied work. This feedback leads to proposing additional alternative notations, so in the end the performer and conductor have a wide range of choice. The method induces this approach that makes the composer work closely with the performer and the conductor.

(4) Conceptual approach to instrument development, integrated with compositional theory

When describing the interaction between instrument development and the compositional practice, instrument capabilities are referred to in compositional theory throughout the formulated method, starting with Stage VI and intensified from Stage XVII onwards. This interaction is achieved mainly by demanding parallel processes between compositional practice and prototype development projects, and secondarily by using an evaluative feedback process for each prototype.

The process of composing *Study No 3* (*Glissando study*, Sc. 3) exemplifies the strategy of simultaneous composition and prototype development. Whereas the rows of the square-layout prototype 4 were too long to play smooth glissandi by sliding the mallets over the bells, this work was intended to result in a new layout improving such capabilities according to the results, since capabilities are accumulated in the prototype development. The rectangular layout of prototype 5 was developed in parallel with the composition. At later stages of the composition process, curving the rectangular plane of bells was introduced as a way of improving the sliding of mallets over bells. This idea informed the following layout (prototype 6, *concentric conic bellophone*) which adopted a rectangular frame with curved support bars. Although prototype 6 was not developed simultaneously with a glissando technique study, it kept the glissando capabilities of the previous prototypes and even improved them together with additional techniques explored.

An additional strategy of the method, a creative-comparative analytical approach which integrates instrument characteristics and capabilities with compositional theory (especially that relating to dynamic and microdiscrete dynamic pitch), reinforces the main conceptual approach to instrument development.

1.4.2 Rationale for the application of the method in relation to the research objectives

The main research objectives; to create a portfolio of compositions and to develop a new musical instrument closely integrated with the compositional practice, are achieved through six subsequent objectives defining each section of the resulting method structure they inform. Each section contains several method stages, which is why they are also called stage groups (A to F). The relation between each of the six consequent objectives and the corresponding method stages are explained by stage groups as follows:

Stage group A (Stages I-V): General considerations and first visions. The objective behind this group is to define the research strategy and to refine the application of the research method devised (Stage V). It involves parallel sketching and notating of vivid, abstract, mental images of how the research aims might be achieved, in terms instrument development and composition. The strategy is defined by reflecting upon a systematic comparative study of the strategies, compositional theory and instrument developments (respectively in Stages II, III and IV) of two relevant composers.

Stage group B (Stages VI-X): Sounding bodies. The objective behind this group is to define the geometries-proportions and materials (Stage VII) of the instrument created.

Stage group C (Stages XI-XVI): Layouts. The objective behind this group is to consider the musical and ergonomic implications of alternative dispositions of sounding bodies, so as to determine the laying out of sounding bodies.

Stage group D (Stages XVII-XIX): Prototypes. The objective behind this group is to make and compare several prototype instruments and related compositions.

Stage group E (Stages XX-XXIII): Additions. The objective behind this group is to propose MIDI-activated versions of the instruments created.

Stage group F (Stages XIV-XXVII): Derives ideas, Sketching and documentation. The objective behind this group is to propose further concepts and projects for further future development.

1.4.3 Stage-by-stage description of the application of the method in the thesis

The development of a composition portfolio and new musical instrument, being the main objectives of the research, involve six subcategories (groups A to F) containing 27 stages (I-XXII) (see method outline in Fig. 5, p. 13 and from here onwards whenever might be required for this section). Some of the stages do not necessarily have to be completed before moving to the next stage. Most of group A has to be reviewed once when completed and then when necessary once moving to other groups. Group D has a cyclic nature and it should be repeated as many times as the instrument prototypes can be improved by choosing different layouts. The method is set out with reference to the sections in the thesis in which it has been applied. The 27 stages are sequentially described under their corresponding group as follows:

1.4.3.1 Group A. General considerations and first visions

Within the preliminary stages in this group, the composer defines the research field; looks into the work of prominent composers in the area; defines the instrument development aspects of interest, and attempts to compose by visualising and hearing an ideal instrument with preconceived characteristics.

In parallel to the stages of this group (I-V) a preliminary phase of the compositional practice is conducted at a particularly abstract level. It consists of brainstorming ideas, sketching images and improvising with sounding objects. It is important that the instrument-development-led composer constructs a preliminary image of what the ideal instrument would look and sound like, exploiting the desired compositional parameter fully. These materials will provide intuitive ideas to the instrument design that will complement the thinking process and development practice to come in future groups, and also to the improvisations with sounding objects will support the envision of an instrument being played, and the creation a theme using the sounding bodies considered (to be developed in the next stage group). This experimental phase is sketched but not documented in the thesis apart from prototype 1 that reviewed on group D.

Stage I: Musical parameter, aims and objectives

This research primarily explores pitch resources, although other compositional parameters or combination of compositional parameters are indirectly implied at times. This method has been developed to also accommodate the other *PADTS* parameters (amplitude, duration, timbre and spatial projection), in order to support future research. The aims and objectives have been defined in Fig. 2 (p. 6).

Stage II: Review of the work of two leading and contrasting instrument-development-led composers who have done pioneering work in the field of pitch, the chosen compositional parameter (Julián Carrillo and Harry Partch being the chosen composers). Part I: strategies

The work of Partch and Carrillo has been reviewed, compared and reflected upon earlier on this chapter and within the appendices. In doing so, it has been useful to treat musicological aspects, compositional theory, and instrument developments separately. Section 1.1 (pp.

14-46), reporting on Carrillo's and Partch's historical practice and strategies, shapes most of a method proposed to suit the nature of the *PADTS* parameter treated, in this case pitch.[72] Stages II-IV include the sketching of sound-producing objects, the annotation of their capabilities, and a preliminary compositional exercise.

Stage III: Review of the work of two leading and contrasting instrument development-led composers who have done pioneering work in the chosen compositional parameter. Part II: Compositional theory and notation

The compositional theory here treated and also proposed aims to identify the tools necessary to accommodate the ideas resulting from the reflection process.

Stage IV: Analysis of the instrument development context for a broad study of static and dynamic microtonality

The instrument development review and ideas derived aim to extend the classificatory system adopted in order to manipulate the data of the instrumentarium used by the reviewed composers and to make conclusions which will influence the instrument development approach followed in the application of the method. According to the method, the preliminary research-based instrument-development-led compositional practice initiated in Stage II is to be completed in Stage IV, to allow a first bellophone prototype to be defined.

Stage V: Method refinement and application

The instrument, as seen and heard through this imaginative process, might result in a clear image or sound, or it might simply lead to further thinking about the sound and form of the instrument and music to be conceived. In this research project, a basic approximation of an ideal instrument is envisaged in Stage IV, providing extra guidelines important to defining the parameters to be explored within the instrument development process (see group B).

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[72] This proposed method is not only the skeleton of this research but also intends to provide a model, guidelines and a starting point to build up a customised methodology to match different *PADTS* parameter(s), and also the same but using different interests (see Fig. 1, p. 4).

1.4.3.2 Group B. Sounding Bodies (see §2.2.1, pp. 91-105)

This group looks into a basic definition of the desired sounding bodies informed by an interaction between experimentation and classification of the different options considered.

In parallel to the work involved in Stages VI-X, this group looks into a preview of prototype 2 (to be completed in group D) as an improved version of the previous prototype, and a theme based on previous improvisations, that is to be extended into a prelude for the instrument developed at a concluding stage of the research.

Stage VI: Possibilities within the geometric group considered for sounding bodies, and compared

The geometric group used for the application of the method comprises the cylindrical symmetric, if the two mouths of a perpendicular-sectioned cone are the same (p. 91-96).

Stage VII: Choosing the material(s) for the instrument

British mild steel and aeronautic steel (if necessary) are to be experimented with. The selection process among several considered metals is discussed in detail on pp. 96-97.

Stage VIII: Practical trial I: experimenting with geometries, sizes and proportions and defining the measurements of the sounding bodies

From the beginning this process is kept in parallel with other stages to follow until the end of group D, by the time a performance on the instrument completed is expected, since decisions can be made in the last minute, including methods, tools and coating required for each shape and size of cone-shaped bell considered.

Stage IX: Practical trial II: sound producing actions and sound activators

This also requires a period of experimentation, mainly achieved through composition, performance, and feedback obtained from the overall music-making process.

Stage X: Initial acoustic observation

The acoustical implications of the proposed sound-producing bodies are explored at this stage. Since the sounding bodies might change as the musical instrument develops, it may be necessary to come back to this stage as many times as is needed before a basic acoustical report can be provided (p. 104-105)

1.4.3.3 Group C. Layouts

This group studies the layouts to be considered and their implications, complementing the previous group to inform the strategies and processes of instrument development practice that schematically starts with the following group (D). In parallel to this theory-based section, the preparation of the structure for a major ensemble work employing a prototype 3 aiming a layout implying an easy to sight-read system are to be conceived.

Stage XI: Comparison of spatial and formal disposition of sounding bodies: shapes

The shape from which the sound-producing bodies (or the sound activators) evolve is one of the most important considerations in deciding the layout design of a musical instrument (pp. 106-107).

Stage XII: Angular disposition of contact surfaces

The angle at which the sound producing bodies (or sound activators) are placed in relation to the player are here determined by whether the performer stands up or sits down and how they might move around within the performance space (p. 107).

Stage XIII: Supporting framework and mountings

In this stage, ideas later on to be used to keep adjustable framework and mountings ideal for the considered disposition of sounding bodies are provided (p. 107).

Stage XIV: Variant designs for comparison

Eight variant conceptual designs to each prototype are to be created for comparison, methodically incorporating a full range of musical instrument characteristics. The process is here drafted and reviewed when necessary, for an application in Stage XIX (pp. 108-109).

Stage XV: Psychoacoustic implications: sliding pitch and tuning perception

In this stage a comparison of the acoustical properties of the sounding bodies throughout the range is performed. The ideal range and psychoacoustics characteristics of the instrument are also defined. This is mainly treated on p. 109.

Stage XVI: Choice of main instrument characteristic to determine future prototypes

Having already designed two prototypes (1 and 2), this section decides the main instrument characteristic that guides the following 12 prototypes to consider (p. 109).

1.4.3.4 Group D. Prototypes.

The three stages that follow are repeated for each type of instrument design aspect considered. Group D is repeated a total of 14 cycles: 2 cycles treating the materials previously sketched for prototypes 1 and 2 (here reviewed); 8 cycles (prototypes 3-8) leading to a built musical instrument (prototype 8) and consequent performance, and; 4 cycles (prototypes 10-14) involving three compositional projects (one to be completed and two to be sketched), in parallel with Stages XX to XV. The compositional practice for this group D, E and F is clearly outlined in fig. 29 (p. 73) in relation to the prototypes, and therefore this diagram is implied from here onwards when mentioning the compositional practice 3 to 14.

Stage XVII: Prototype design

The design process of each prototype is guided by a new characteristic of the aspect considered (in the Case Study the aspect is the shape followed by the spatial disposition of sounding bodies, or keys) and this follows full interaction with the layered compositional processes for prototypes 3-14.

Stage XVIII: Feedback from parallel compositional practice

The compositional practice for prototypes 3-14 occurs in 3 layers of simultaneous projects that inform each other, and continuity is also pursued in the ensemble work.

Stage XIX: Feedback from the variant conceptual instruments

In this stage, the composition of music is fully integrated with instrument development. While visualisation is the main aim, the physical development of the instrument is also to be considered. Eight conceptual instruments are to be for each of the 14 prototypes which are to be informed by evaluative and creative feedback (looking into the instrument development practice from method stage groups A to F). These conceptual variants adopt the main property of the corresponding prototype, and normally the layout (or shape adopted by disposition of sounding bodies), while considering eight alternative characteristics of interest (eight combinations of sound producing actions and sounding bodies). Each prototype is evaluated and then compared with evaluations of the eight corresponding variant conceptual instruments. The compositional materials for each prototype are then tested in relation to the variant conceptual instruments, such that these comparisons reciprocally inform the prototype and composition. This conceptual, instrument-development-led approach to composition avoids the limitations imposed when the instrument is conceived prior to composing. This process is essential to the formulation of compositional theory in this research.

The conceptual variants of the first bellophone prototype which were considered are elaborated on pp. 372-434, with detailed descriptions of the resulting instruments; and the conceptual variants considered for the second and third prototypes are developed into shorter, initial instrument descriptions (pp. 434-450 and pp. 450-460 respectively). These descriptions illustrate how the conceptual variants of each instrument (bellophone) prototype can be extended (at two levels of detail) and documented. This process can be further extended, to produce designs that can be documented in a database describing instrument physical properties and sound capabilities. These designs could then be used, in future instrument-development-led composition projects. The sketching and description in more detail of the conceptual instruments defined by title descriptions and evaluations (the variant instruments to prototypes 4-14), has not been found absolutely necessary for the creative-comparative feedback process followed by this research, and therefore are not included in the thesis.

The evaluated instrument characteristics used for the creative-comparative process (and also to define prototypes 4-14) are: two instrument capabilities (static and dynamic microtonality), and two custom predefined concepts of either strategic or aesthetic interest (distinctiveness of timbre, and the expressiveness of the instrument's audio-visual form, which is also referred to as corporeal expression).[73]

1.4.3.5 Group E. Additions

With the bellophone already being completed and the ensemble composition performed, this group and the one to following (F), sketch prototypes 9-14 without physical development being conducted. This group reports on an extension of range (prototype 9), additional instruments covering further ranges (prototypes 10a and 10b covering lower and higher ranges), a MIDI mechanised version (prototype 11), MIDI controllers (prototype 12) and potential additional resonators and sounding bodies (prototype 13). This is all produced in parallel with the consequent 3-layer compositional practice.

Stage XX: Extended range

At this stage the final prototype of this research has already been built. From this stage onwards prototypes for future possible extensions of the instrument are proposed. In Stage

[73] See 'corporeal expression' in Glossary

XX an extended version with slightly wider range is to be proposed for future consideration (prototype 9).

Stage XXI: Other ranges and mechanised version

This stage describes potential instrument development work, consisting of conceiving two additional instruments to expand the lower and the higher ranges of instrument already built (prototypes 10a and 10b). Then this stage also explores the possibility of using a MIDI mechanised version of the main instrument (prototype 11).

Stage XXII: MIDI controls, frame, safety, coating and finishes

This stage explores potential MIDI controllers (prototype 12) for the previous mechanised prototype. It also treats the processes that may be essential for preservation, and make the instrument look presentable and finished, for a possible commercialisation.

Stage XXIII: Resonators, additional sounding bodies, maintenance and flight case

This stage explores the incorporation of resonating bodies and additional sounding bodies (prototype 13). The development of a maintenance manual and flight case (essential for regular use and commercialisation of the instrument), can be considered at this point, once all the additions and extensions described have been tested.

1.4.3.6 Group F. Derived ideas, sketching and documenting

This group considers the proposal of further concepts, ideas and projects pertaining to *PADTS* parameters other than pitch, for potential future development (prototype 14). In its final two stages, it concludes with documentation and reflection processes, which are essential to support the further development of the instrument already built, and, in the bellophone Case Study, of compositional practice left in progress at the completion of this research.

Stage XXIV: Spatial considerations

Especially for instruments with extensive numbers of sounding bodies, it is worth considering how they are to be assembled and disassembled and distributed around the performance space, especially with regard to possible future research projects focused on spatial projection either on its own or in combination with other compositional parameters.

Stage XXV: Other derived ideas

Every time a different prototype or instrument is designed, heard or visualised in combination with the compositional process, new compositional and design ideas, which arrest the flow of the work, can arise. In such instances, writing down the musical ideas and sketching instruments is a good practice, so that when reaching this stage, they can be addressed, expanded and documented for future consideration. This concept of continuity is treated in more detail in Stage XXVI; and is recapitulated in Ch. 4 under two categories: applications of the research; and future projects following the research.

Stage XXVI: The on-going work of an instrument-development-led composer: documentation, notational development, and flexible, open-ended method.

It is essential for its continuity, systematically to document everything related to the music-making process. New notations are propped as necessary; they are documented on pp. 54-58 and discussed in relation to specific compositions in Chapter 3. When this method is applied in another research project, the documentation process should be revised in accordance with the requirements of the project.

Stage XXVII: Reflection and conclusion

This stage reflects upon and summarises the overall result of the research.

Chapter Two: Instrument development

This chapter traces the main stages in the development of the tuned percussion instrument envisaged, a bellophone (basics defined on pp. 87-91), with reference to the original musical works submitted in the accompanying portfolio, whose compositions played a substantial and significant part in the design process. The foundations of the instrument development process are first defined and treated separately from the compositional practice in the interests of clarity of exposition, providing ready access to the elements considered within each process (pp. 91-114). This is followed by a detailed explanation of the main development of the bellophone (pp. 114-160).

The six research method stage groups (A to F) could also be described as four major processes: (1) The first, is the formulation-in-context process treated in stage group A, and supported by the literature review and derived thinking process in Chapter 1, together with the instrument development Case Study definition (pp. 87-91), process in which the strategy behind the instrument development process is detailed; (2) The second, the setting out of the foundations of the development process of the bellophone (stage groups B and C), where sounding bodies and bellophone layouts are treated separately (pp. 91-114); (3) The third process, the actual development of the bellophone including two early prototypes (1 and 2), six prototypes intensifying the interaction with the compositional practice (prototypes 3 to 8) and leading to the construction and performances (using prototype 8), and another six prototypes exploring range, playing mechanisms linked to a controller (with MIDI decoder) using MIDI to relay interface, additional sounding bodies, resonators, and derived ideas (prototypes 9 to 14, treated in method stage groups D, E and part of F), which involves composition in parallel with a feedback strategy in which variant conceptual instruments inform each bellophone prototype, and; (4) the drafting of derived ideas and the exposition of future projects (Ch. 4, pp. 201-218), which conveys the second half of stage group F, although it shares content with the rest of the group and stage group E (considering additional elements relevant to the bellophone prototypes) where some of these concepts were first formulated.

2.1 A basic definition of the instrument development Case Study

The Case Study here proposed sought to create a stable-pitch instrument with microdiscrete-sliding pitch (see Glossary) properties, tuned in small equal steps. Individual sounding bodies are required for each pitch class rather than adjustable-pitch bodies, so as to achieve microdiscrete-sliding pitch. For this reason, an idiophone was considered more suitable than an aerophone, chordophone or membranophone, due to its pitch stability. The development of the sounding bodies themselves, the selection of their layout, and analysing considering the bilateral implications of variant conceptual instruments employing similar layouts, were first experimentally conducted. Gradually as a method was consistently devised the Case Study was also defined in its finalised form.

Following the classification of instruments according to interval size as proposed (pp. 340-341), the instrument to be developed belongs to the *micro-intervallic instrument* group, but very close to the next group, *fine micro-intervallic instruments*. Two-digit equal divisions of the octave different than 96, but close, would have resulted in an impractical number of notes per octave, thus the 96-et is preferred. Microdiscrete-sliding pitch capabilities, without noticeable restrictions, are required. Therefore, the extended K-H-S classification code describing the pitch capabilities (pp. 338-346), should have the subindexes 3 followed by 2. The classification code to describe the ideal instrument envisaged would be 111.242.222.X1-P_{32}-(△).[74] Simply by comparing the classification code with those for the instruments by Carrillo and Partch, it is straightforward to recognise the instruments that have the closest characteristics to the ideal, and how the design could be improved to get closer. The closest instrument from the instrumentaria already classified, is Partch's Gourd Tree (p. 349, 330-331). Carrillo's instrumentarium does not apply here since he did not develop idiophones. However, his *sixteenthtone piano* was initially considered, since it is now commercially available (p. 294). Since this instrument is a chordophone, a slightly sharper metallic tone colour is required, to provide reference tones clearly distinguishable from strings, woodwind and brass instruments. Using metal hammers would have been a solution, but pianos have the inconvenience of needing regular tuning. Also, the speed at which chromatic passages can be played on the piano keyboard layout – as used by Carrillo in the *sixteenthtone piano* – can be improved upon by using a mallet instrument in linear chromatic layout. Designing such instrument would be an easier task than redesigning the keyboard of the piano to have linear chromatic layout. However, the commercial availability of the *sixteenthtone piano* makes it a perfect candidate for future

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[74] Set of suspended bells; with/without resonators (X=1 or 2 respectively); struck from the outside.

works, which might explore both micro-intervals and microdiscrete-sliding pitch in conjunction with the bellophone here developed.

Returning to Partch's Gourd Tree, and considering the neighbouring instruments in the extended K-H-S taxonomy (p. 348-349), there is a group of six analogous idiophones with micro-intervallic properties and chromatic linear layout in the first four of the cases from the following list (all incorporating 'P_{32}', as defined on p. 338 and p. 341):[75]

> Boo II (Bamboo Marimba): 111.232.125-4-P_{32}-(△)-P.
> Boo I (Bamboo Marimba): 111.232.225-4-P_{32}-(△)-P.
> Eucal Blossom: 111.232.315-4-P_{32}-(△)-P.
> Zymo (The Zymo-xyl): 111.242.441.2-4-P_{32}-(△)-P.
> Gourd Tree: 111.242.222.26-4-P_{32r}-(△)-P.
> Brass Shell Casings (Spoils of War): 111.242.242-4-P_{32r}-(△)-P.

The short sustain of struck bamboo tubes makes the first three instruments, (extended K-H-S group 111.232), unsuited to produce clear microdiscrete-sliding pitch contours with a distinctive sound that can be effectively used as a reference pitch; and the only glass instrument from the list, the Zymo (a set of glass percussion vessels), which does not have the desired pitch clarity is also discarded. This leaves only two instruments, each consisting of a set of metal percussion vessels (H-S group 111.242.2):[76] the Gourd Tree and the Brass Shell Casings. Although the Shell Casings are made of brass, their cylindrical shape does not allow them to ring as long as bells do (with shoulders and a waist). This makes the Shell Casings ideal for producing distinctive referential microdiscrete-sliding pitch, since their sustain sound does not build up to the point where it overlaps the perception of the sliding tone. However, working with brass would have been prohibitively expensive, and although the ringing time of these metal vessels is close to that of the ones envisaged, the idea was discarded. Using the shape of Shell Casings with steel and experimenting with slight variations to get the appropriate sound is considered as part of this review of Carrillo's and Partch's instrumentaria.

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[75] Notice that the Chamber Cloud Bells have not been considered here since they can easily break. Similarly the Cone Bells supported by poles, which are very inconvenient for microdiscrete-sliding pitch since they are placed individually in stands, have not been considered.
[76] H-S stands for the Hornbostel-Sachs musical instrument classification system.

Before defining the Case Study, Stages II-IV include creative visualisation of an instrument that produces the desired sound as part of a preliminary composition process (pp. 78-79). This provides a creative perspective to the previous rationalising process. The chosen instrument characteristics for this exercise cannot be very precise so that the creative process is allowed to take shape by itself without too much preconception. A mid-range pitch sound with pitch clarity and mid-range sustain capability was imagined. An extensive set of agogo bells with microtonal capabilities was also visualised and imagined to have a distinctive metallic tone colour when sounded with an orchestra. Short melodic sequences of notes were written without clearly specifying the pitch and later on, with hands on the first sounding bodies produced, they were transformed into a melodic motive used in *Prelude No 1* (pp. 163-165, Sc. 11/ CD-tk 11/ DVD1-tk 11). The instrument imagined had a large amount of agogo bells with no particular layout, in a chaotic display resembling a bush rather than a musical instrument, but the almost conical idea of these bells and the material used in their constructions, steel, was envisaged. At this point, the instrument Stage IV was completed.

At this point it was envisaged that cylindrical symmetry would provide uniformity of pitch across the whole surface of a metal instrument similar to an agogo bell, but a slightly longer sustain could be achieved by using a different alloy or thickening the walls.

Both of the shapes considered so far for the metal idiophone were cones (closest geometrically to the agogo bell) and cylinders (as the geometric shape for Partch's Brass Shell Casings).

Visual aesthetics are here considered to be important; they are explored in succeeding stages through experimentation with geometrical layouts for sounding bodies, which are also required in order to arrange them in chromatic sequence to provide microdiscrete-sliding pitch capabilities.

Having defined the basics of the instrument development Case Study, the Stage V has been fulfilled concluding also the method stage group A.[77]

2.2 Foundations for the bellophone development

This section delineates the foundations of the whole development process of the bellophone as explained on pp. 114-160. These foundations are explored and then defined for both, the sounding bodies (stage group B, pp. 91-105), and the layouts in which these bodies are displayed (pp. 105-109). The ideas behind the potential modifications of the bellophone upon completion (prototype 8) are detailed on pp. 210-213, providing the necessary grounds to formulate prototypes 9-14 as optional future projects.

2.2.1 Sounding bodies (method stage group B)

Having first noticed the agogo bell's piercing sound and its ability to cut through the spectrum of the samba band, similar bells where built and compared. These bells were made using thicker metal sheet than is usually employed in the construction of agogo bells but it provided alongside a similar tone colour to the agogo bell, a longer sustain. The hand hammering technique initially employed to shape sheet metal produced uneven results, while the use of robotic machinery was found to be too costly. At this point, the experimentation was shaping the method. The next section delineates the possible shapes, making techniques, and alternative materials.

2.2.1.1 Cylindrical symmetry shapes (Stage VI)

In producing a wide range of sample sounding bodies for comparison, cylindrical symmetry was mainly used to provide evenness of tone quality and in specially evenness of pitch. The following forms, all having cylindrical symmetry, were first defined as: plates (a), discs and cones (b) and tubes (c).[78] All of these shapes are common among regular idiophones (see Fig. 30)

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[77] At this point the method must be clearly drafted, although it can be reviewed at any necessary point.

[78] There is change when rotating around the axis.

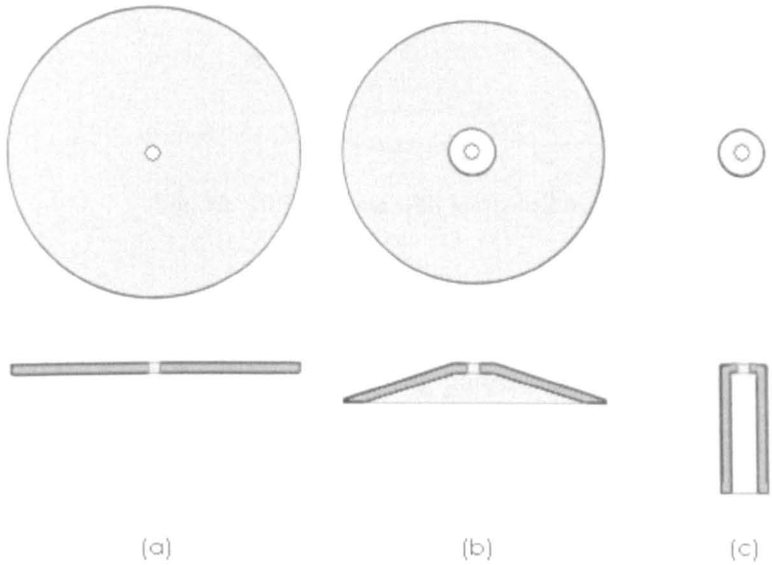

Fig. 30. Examples of shapes with cylindrical symmetry.

A hollow conical figure with the mouth open was first considered, as shown in Fig. 31:

Fig. 31. Hollow cone.

Since indefinite pitch sounds are not the aim here; the area surrounding the vertex of the empty cone with open mouth (Fig. 31) is not immediately useful, especially since this area produces a pitch-less sound when struck. A horizontal cut in the conical shape, slightly below the vertex of the cone, was initially considered since it provides a small circular area where a support for the bell can be attached, as shown in Fig. 32. This shape is relatively close to the shape of a handbell. However it is not ideal for partial tuning, unlike the partials of most handbells (first, second and third harmonics),[79] but instead is thought for the obtaining a distinctive tone of rich harmonic content.

[79] Rossing, T. D. 2000. *Science of Percussion Instruments*. p. 150.

Fig. 32. Hollow cone with horizontal truncation.

The trapezium that defines the contour of Fig. 32 when rotating around an axis is represented in Fig. 33, where all the measuring parameters have been indicated.

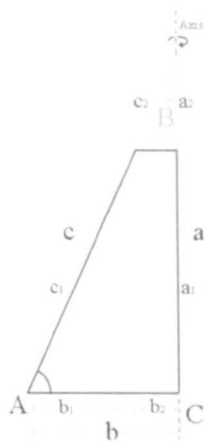

Fig. 33. Rotating trapezium that defines the shape.

The trapezium in Fig. 33 has a fixed angle C of 90 degrees for any of the shapes considered here. Therefore, either the angle A or B is required to define the proportions of the triangle containing the trapezium, since they are complementary angles.[80] In general the Pythagorean theorem,[81] and trigonometry formulas,[82] can be used to deduce the values of the parameters in Fig. 33, if a minimum of three parameters from the diagram are known. By changing the angles and proportions of the trapezium in Fig. 33, six different trapeziums could be represented as in Fig. 34. By rotating these trapeziums around the indicated axes, six shapes were generated as in Fig. 35, five of which resemble the vibrating bodies of familiar tuned percussion instruments; the remaining shape resembling

[80] The addition of both angles is 180°.
[81] Represented with the following formula: "app^2 + adj^2 = hyp^2".
[82] For example: "sinA = a/c, cosA = b/c, tnA = a/b".

a plant pot is rare, though it was used by the experimental instrument maker Barry Hall for his Flower Pot-o-phone.[83]

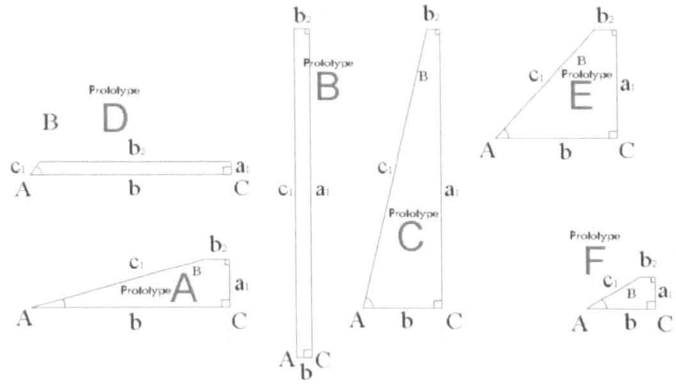

Fig. 34. Six different types of rotational trapeziums considered.

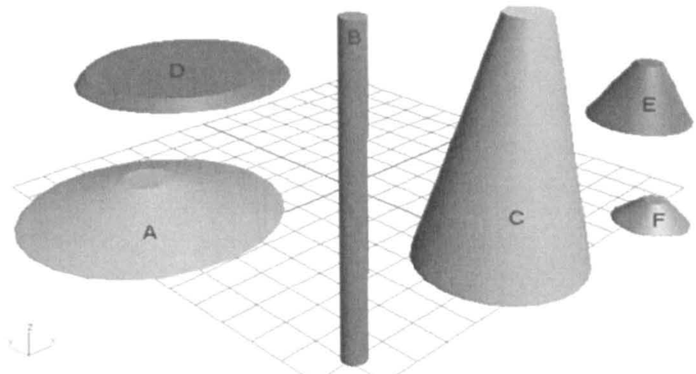

Fig. 35. Six different shapes defined by the previous trapeziums.

Rotating trapezium	angle A	angle B	edge a_1	edge b_2	edge c_1	edge b	Existent instruments
Shape A	1°~10°	80°~89°	$a_1 \ll c_1$	$b_2 \ll b$	$c_1 \simeq b$	$b \gg a_1$	Cymbals
Shape B	90°	0°	$a_1 = c_1$	$b_2 = b$	$c_1 \gg b$	$b \ll a_1$	Tub. bells
Shape C	61°~89°	1°~29°	$a_1 \simeq c_1$	$b_2 > b$	$c_1 > b$	$b < a_1$	*Pseudo* agogo
Shape D	N/A	N/A	$a_1 \simeq c_1$	$b_2 \simeq b$	$c_1 \ll b$	$b \gg a_1$	Crotales
Shape E	41°~60°	30°~49°	$a_1 < c_1$	$b_2 < b$	$c_1 > b$	$b \simeq a_1$	Plant pots
Shape F	11°~40°	50°~79°	$a_1 < c_1$	$b_2 < b$	$c_1 \simeq b$	$b > a_1$	Fing. cymb.

Fig. 36. Ranges dividing the possibilities into 6 categories.

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[83] Hall, B. 1994. Two hardware store instruments. *Experimental Music Instruments*. pp. 20-21.

From the six shape-groups defined in Fig. 36, a sound vibrating body similar to the agogo bell conceived with cylindrical symmetry rather than with an oval-shaped mouth is preferred. These groups are obtained by changing the angles and defining a conical shape as follows:

(1) Shape A: Shallow cones (cymbals and similar shapes). Most cymbals have indefinite pitch. Cymbal-shaped bells with definite pitch could be achieved by using thicker walls, and by using materials, which possess ideal ringing properties such as bronze, rather than brass. They can be placed on a stand on top of one another, slightly separated, to facilitate the performance of glissandi. Definite-pitch cymbals could produce very unique timbres and sound effects when played chromatically, although this would not help to produce a clear sliding pitch effect. In order to create a smooth pitch slide, a wider angle 'A' than that proposed in this prototype, could be employed to improve pitch clarity, especially when playing a chromatic glissando.

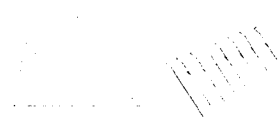

Fig. 37. Thick bronze sliding cymbals.

Chinese opera gongs are pitched instruments with a characteristic sliding tone, which follows the attack. This does not provide a stable reference pitch, nor does it recreate a precise sliding tone by means of microdiscrete-sliding pitch. However, the sliding pitch that is part of the sound quality of each gong is relevant when combining with the bellophone being developed. A Chinese opera gong part was also added suggesting a framed set (p. 194-195).

(2) Shape B: Tubes and cylinders (e.g. tubular bells and wind chimes): For this shape, angles A and B are both right angles. Partch's Brass Shell Cases have this shape but they were discarded. Tubular bells (orchestral chimes), normally made out of brass, are also part of this group. They are made by placing stops on a tube, in order to cancel particular unwanted modes of vibration with the aim of enhancing the fundamental frequency. This has proved to be an efficient way to produce a stronger and clearer tone; but experimenting with this material on an instrument with so many sounding bodies proved to be prohibitively expensive. Electrical Metal Tubing (EMT), which is affordable for experimentation, produces a unique tone colour, although accommodating very many tubes

in the lower range might be problematical, as they would probably need resonators in order to enhance the volume of their fundamental frequency,[84] making the ergonomics of the instrument far from practical.

(3) Shape C: This shape, which has an α angle between 60 and 89 degrees, could be comfortably explored with steel sheet of an appropriate thickness, rather than casting expensive materials which would in any case resonate for too long making the chromatic glissando sound like a simulation of one single pitch slide.

(4) Shape D: This shape includes solid body shapes such as crotales. Though they have a unique tone colour, their attack is too sharp to create a smooth microdiscrete-sliding pitch effect.

(5) Shape E: This shape has been used before, for musical ceramic plant pots, but from the ergonomic point of view it would be problematic to arrange a large number of resonators without using a concentric layout (similar to that in Fig. 37, above), and this would reduce the sustain too severely.

(6) Shape F: This shape has an α angle between 11 and 40 degrees. It would be ideal if working with brass or bronze, as in the case of finger cymbals, but these materials were rejected on grounds of cost.

After considering all of these forms, shape C seemed the most suitable. This corroborated the initial idea of using conical versions of agogo bells made from thicker metal, although the material to be used was not decided. At this point Stage VI was completed.

2.2.1.2 Choosing the material(s) for the instrument (Stage VII)

The main materials considered are arranged according to atomic number as follows:

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[84] Hopkins, Bart. 1986. Conduit Marimba and Glass Marimbas. *Experimental Music Instruments.*

No 6 Carbon (C)

No 26 Iron (Fe, ferrum)

No 29 Copper (Cu, cuprum)

No 30 Zinc (Zn, zink)

No 50 Tin (Sn, stannum)

No 82 Lead (Pb, plumbum)

The alloys initially considered were:

(1) Steel: Its major component is iron, with carbon content between 0.02% and 2.14% of its mass.
(2) Bronze: Its major component is copper, with tin as its main additive (although phosphorus, manganese, aluminium or silicon may be present). It is typically 88% copper and 12% tin. Bell metal has 78% copper and 22% tin. Larger and smaller bells are cast with differing proportions of tin, and some bell, gong and cymbal makers use other materials and elements such as silver, gold and phosphorus.
(3) Brass: An alloy of copper and zinc. Concentrations vary but to enhance the machinability, lead is often added in concentrations of around 2%.

Although thick sheets of bronze, copper and brass were initially considered for acoustical reasons – the casting of those materials also being considered as an alternative –steel was eventually chosen, not on, which does not sustain for as long as the other materials (thus allowing clear microdiscrete-sliding pitch effects). Other factors of interest were its hardness, and its metallic and sharp quality of sound. It produces a sharper attack than most other materials, necessary to distinguish the tone of the instrument from others.

Standard British mild steel sheet was used for most of the experimentation process, though in the end steel with a high carbon (C) content, commercially available for aeronautic purposes, was preferred, since it allowed the bells to be spun on a lathe, which was found to be the most satisfactory technique for shaping them. Using a softer steel also reduced excessive sustain, which also in the case of mild steel was still too long to produce clear microdiscrete-sliding pitch effects.

2.2.1.3 Practical trial I: experimenting with geometries, sizes and proportions and defining the measurements of the sounding bodies (Stage VIII)

Forty-two different cone-shaped bell prototypes, with different proportions and sizes chosen almost randomly, were built within the design limits of the previously defined prototype C (Fig. 38). These prototypes all have different proportions within the prototype C definition (61° to 89° angle between axis and side or 61°-89° angle between side and base of the cone) and received the name of *hammered conic bells*.

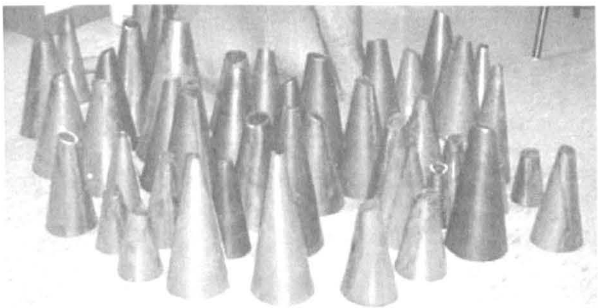

Fig. 38. *Hammered conic bells.*

For this purpose, 1.6 mm British mild steel sheet was cut using a press machine, following the pattern in Fig. 39.

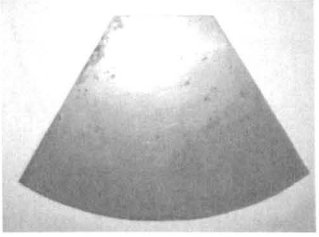

Fig. 39. *Hammered conic bell*: before being hammered.

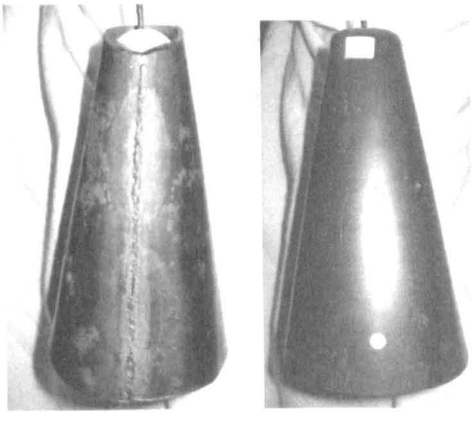

Fig. 40. *Hammered conic bell*: After being hammered and welded (back and front).

The cut sections were hammered on a mandrel and gas welded. Fig. 40 shows that the small mouth of the cone does not have a uniform shape. The curved shape required to represent a sectional cut on the top of the cone, perpendicular to the axis, was difficult to cut and a straight line was used instead since it did not affect too severely the final sound of the bell.

Due to the welding stripe (and also due to irregularities of bending produced by the hammering), the pitch of these bells is very unsettled across its surface: it can vary by up to a semitone according to where the bell is struck. The sound also has beating frequencies, consisting of fundamental pitches very close to each other, coming from the different areas of the bell.

Some sizes of these bell prototypes were more pleasant-sounding than others. Bells that were either too high or too low in pitch to produce a pleasant tone with sufficient pitch clarity were discarded, leaving a set of bells covering a range of an octave and a half. The octave covering the lower area of this range was chosen as the main range of the instrument, since ninety-six bells (covering the ninety-six pitch classes of the tuning used) was already a challenging amount of sounding bodies to work with. The lowest tone in the 1 and ½ octave range happened to be middle C (when using the *hammered conic bells*), which was considered a central and comfortable range to combine with other instruments.

Having made conical-shape bells with a wide range of proportions (Fig. 38 above) within the range of an octave, one bell from the mid-range was selected intuitively, according to its pleasant sound quality and appropriate pitch clarity. The edge of this bell had an angle with the plane of the wide mouth of 78.41 degrees, which is the angle that was adopted, marking an end to the experimentation process with cone sizes and proportions. To differentiate the bell with the 78.41 degrees angle from the others produced, regardless of material and construction method, the term *conic bell* was adopted at this point.

The hammering technique had a pitch inconsistency throughout its surface so a new construction technique was employed: spinning on a lathe. The name *conic bell* was kept since its proportions were not altered. The new technique defines the specific type of *conic bells* produced: they were named *spun conic bells*, but also referred to as *spun bells*. Experimentation with the spinning technique was not possible since it was outside the budget and since the 78.41 degrees would not have changed significantly. Once this angle was adopted the three mandrels required to spin the metal sheet on a lathe were defined as shown in Fig. 41. Although three different mandrels were designed (1 to 3) to spin three different sizes of *spun conic bells* (and then to be finely tuned by means of filing, as demonstrated on DVD2-tk 18), the largest size of mandrel (B3) was found to be sufficient to spin on a lathe three different sizes of sheet plates, matching each of the mandrel proportions (Fig. 42).

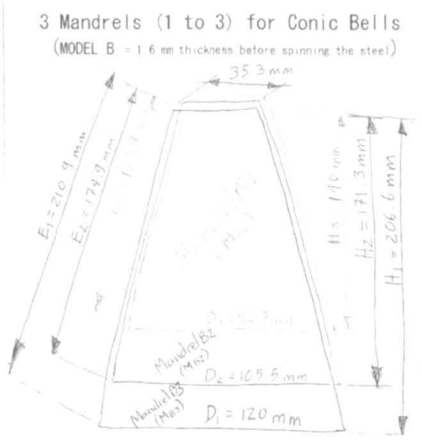

Fig. 41. Sizes for the three mandrels.

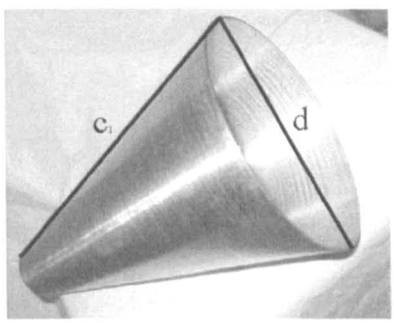

Fig. 42. *Spun conic bell*: side (C_1, or E_1 = 210.9 mm) and mouth diameter (d, or D_1 =120 mm).

The first eight experimental bells produced by spinning were spun in one single operation, which gradually reduced the thickness of the walls. These were found to have a distinctive tone, of rich harmonic content. The name *thin spun conic bell* (simplified to *thin conic bell*) was given to them. In exploratory compositional practice, the use of microdiscrete-sliding pitch was not considered appropriate (although the technique had already been explored), as the bell lacked the necessary clarity of pitch.[85]

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[85] *Study No 6* (*Pasacalles*) (2006) (Sc. 6/ CD-tk 6/ DVD1-tk 6), and *Study No 7* (*Mollienaire*) (2006) (Sc. 7/ CD-tk 7/ DVD1-tk 7).

Consequently, the bells were spun on a lathe in four different sessions so the metal did not have a chance to reach a hot enough temperature to thin the walls of the skirt towards the edge. This process kept the thickness of the metal throughout the skirt of the bell at almost 1.6 mm, and the new *spun conic bells* received the name of *thick spun conic bells* also referred as *thick conic bells.*

During this process of developing and improving the bells, several other processes were considered, such as robotic processing for bending and welding the bells. This robotic processing was found to be prohibitively expensive to experiment,[86] and the cost of having steel bells spun on a lathe was five times lower, which allowed scope for affording corrections (in this case changing from *thin bells* to *thick bells*) and the benefit of equal distribution of the metal around the bell. The use of a punching machine might be a technology to consider for large-scale production.

2.2.1.4 Tuning of the *conic bells* (*thin spun conic bells*)

If the ideal lowest *conic bell* has a mouth of 6 cm radius and the preferred proportions shown in Fig. 41 were retained, an octave can thereby be obtained by cutting a ring so that the diameter of the new mouth is reduced by one third (in this case reduced 2 cm). This is an approximation which can be used effectively to raise the pitch of newly spun bells by slightly less than an octave; but the most effective way to spin and tune *conic bells* is to use mandrel B3 (M_{B3} above in Fig. 41) and the graph in Fig. 44 determines the height of the section to be removed from the mouth of the bell. In practice, 2 mm less than predicted was sawn off, leaving a margin for fine adjustment by filing.

In order to produce a graph showing the relation between the size of the *conic bell* and the tuning (to be used as a reference), one bell was cut four times, providing five sizes and five different pitches as shown in Fig. 43.

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[86] A quotation by Japanese company Kobelco was offered for around £10,000 for 100 *conic bells*, which was close to the price asked by the Whitechapel Bell Foundry for casting the same number of handbells and tuning them.

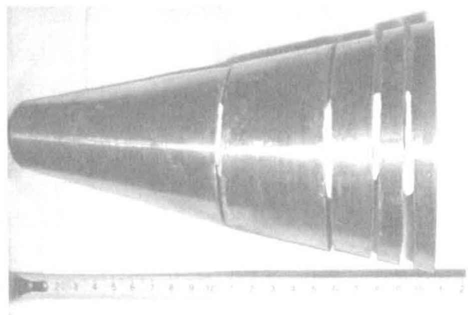

Fig. 43. Successive cuts performed in one single *conic bell* to relate tuning and measures.

The graph produced by joining the five points (0, A, B, C, and D) resembles a slightly curved line (Fig. 44). The horizontal axis represents the height of the conical ring being removed, and the vertical axis the resulting pitch rise in cents, which increases as more rings are removed.

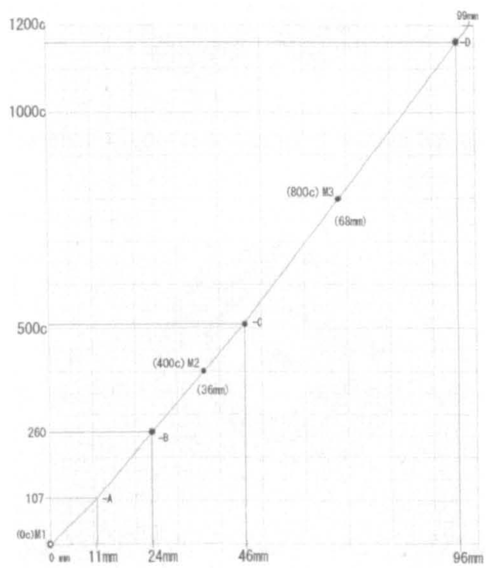

Fig. 44. Graph representing the tuning of the *spun conic bells* at different heights.

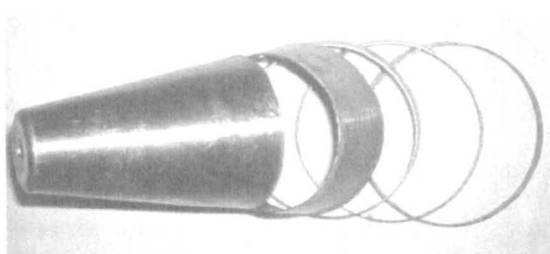

Fig. 45. Another angle of the *spun conic bell* after cutting 4 conical rings, so as to provide five different tuning values for each size.

If the first cut off ring is called A (and the bell that is left in the cut in the case of the graph in Fig. 44),[87] the second B, and so on (Fig. 46). When the 4 conical rings are placed around the small cone left (E) it is observed (from the top view) that the distance between the outer side of conical ring A and the outer base of the small cone E is approximately 1/3 of the radius of the outer ring A (see Fig. 47). The pitch relation between the original *conic bell*, before the cuts, and the *conic bell* E is 1160 ¢. It was found that filing away the rim of bell E by a further 3 or 4 mm, allowed the pitch difference to be raised to reach the octave (1200 ¢). These initial observations were used as a reference guide in tuning the instrument.

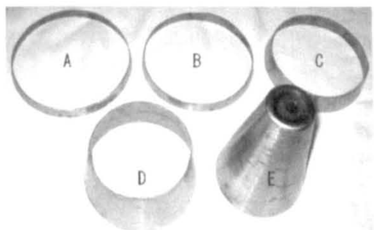

Fig. 46. Four conical rings cut and conical section left on flat surface.

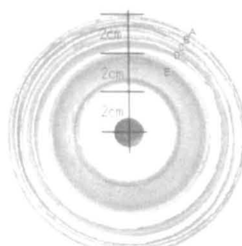

Fig. 47. 1/3 proportion between outer rings of the conical section E and conical ring A, concentrically placed on a flat surface.

2.2.1.5 Coating

The *conic bells* were first coated through the cold blackening process (CuSe), but this resulted in the smoothness of the surface being lost: they also felt sticky, and the remaining odour of this substance made the whole process unsatisfactory. Metal coating (plating) was considered but the struck areas could suffer from this. The cost of this

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[87] The same applies to B, C and D.

process also made experimentation unaffordable. The *conic bells* were initially used without coating and they were then given a silicon spray coating to protect them from getting rusty. This silicon coating is easy to remove, which was necessary since it makes the bells sticky and they smell unbearable. More experimentation is required to produce a professional finish. However, the instrument development of this research stage required no further coating of the bells if kept dry.

2.2.1.6 Practical trial II: sounding producing actions and sound activators (Stage IX)

The bells can be struck with all kinds of media including hard mallets, according to the effect desired. Soft mallets (DVD2-tks 1, 2) can be used to smooth the sharpness of the attack. *Conic bells* are struck on the outside, although hard mallets can be used inside of the bell to produce tremolo effects (DVD2-tk 9). Medium or hard mallets (DVD2-tks 3, 4, 5) can be used to sound microdiscrete-sliding pitch effects and sliding effects across the layout (DVD2-tk 8).

The *conic bells* can be bowed with a cello bow (DVD2-tk 16), isolating the sound of one or two harmonics according to the speed at which they are bowed. Two neighbouring bells from the same vertical or horizontal row can be bowed at the same time.

Friction with a hardwood stick (DVD2-tk 17), similar to the way that singing bowls are sounded, can be used to create long-sustained wind-like sounds. Sliding brushes over the bells produces a very quiet and smooth friction sound of metallic quality. This can be done employing microdiscrete-sliding pitch and also randomly across the whole range, producing a bright sound effect.

2.2.1.7 Acoustic observations: timbre (Stage X)

Only the harmonic spectrum of the *conic bellophone*'s lower register (bells No 0 to 15) has been analysed, since from bell No 16 to 25 the amplitude of the nominal partial was at times not noticeable by basic spectrum analysis software, and never noticeable from bell No 26 to 95. For bells No 0 to 15 the following observations have been noted: (1) the amplitude of the hum partial is on average 16 times the one of the prime partial (sounding an octave above), and five times the value of the tierce partial (a minor third above the prime with a 19 ¢ deviation on average from the pure minor ratio 6/5); (2) the average amplitude of the tierce partial is 6.5 times higher than the average amplitude of the nominal partial and of the superquint partial; (3) the value of the interval between the prime partial and the nominal partial varies from 1230 to 1317 ¢ (except a rare exception on bell No 0 with a value of 1181 ¢); (4) the superquint is located from a range of 12 ¢ below ratio 3/2 above the nominal and 50 ¢ above it; (5) the absolute deviation of the tierce from ratio 6/5 above the prime is of 19 ¢ on average; (6) there is still an abundant high harmonic spectrum of very low amplitude that also contributes to the distinctive sound of the bell.

The broadly stretched octaves found in the harmonic spectrum of the *conic bells*, suggests the exploration of non-octaval scales, and their potential to match and reinforce these partial frequencies. Using the 96-equal division of the octave, any scale using n-steps, where n is an odd number, delivers a non-octaval scale. This exploration is systematically used in the first part of the second movement of the composition *Seasons* (Sc. 12). Employing more than an octave range, the following stretched octaves can be reached with the *extended conic bellophone* (and the extended prototype of the finalised *conic bellophone* drafted in for the work in progress *Seasons*): 1212.5, 1225, 1237.5 and 1250 ¢.

2.2.2 Layouts (beginning of stage group C: Stage XI)

The layout has to compromise the dynamic and the microdiscrete elements of the chosen compositional parameter. Pitch being the chosen compositional parameter, meant that microtonality was the microdiscrete element and sliding pitch the dynamic element.

The study of the movements allowing the performer's hands to draw continuous smooth lines in the space (and smooth continuity from one hand to the other when they alternate the drawing role) is the ideal starting point to facilitate the layout design of a microdiscrete-sliding pitch instrument. Laban notation was initially considered, but due to time limitations an alternative was finally adopted: a study of the different shapes that the hands of the performer (or head of mallets) can draw in the space, was made to organise the different movements that the performer can use to sound microdiscrete gliding tones.

Preliminary work has been done with one single continuous sequence of sounding bodies in the space (see the non-cylindrical helix layout, and the cylindrical helix layout). The sequence was divided into further 10 note sequences (a semitone and an eighthtone or 10 sixteenthtones) for notation purposes, which did allow an easy realisation of 12-et passages (see below the square layout). Since the aim was to achieve microtonality by departing from 12-et this idea has been since discarded. It was necessary to decide whether the tone or the semitone would be the ideal pattern, since irregular patterns such as the diatonic scale complicate the realisation of smooth glissandi and the realisation of parallel glissandi. A sequence of eight bells in sixteenthtones (covering a semitone) has also proven to make fast glissandi passages covering more than a semitone cumbersome (see p. 128). Therefore, tone rows containing sixteen different notes in a sequence were finally chosen followed by experimentation with several prototypes. Any sequence covering a larger interval than a tone would require the performer to move their feet when switching from one sequence to another, thereby losing the necessary agility to perform smooth glissandi passages involving several sequences.

2.2.2.1 Shapes of the layout (Stage XI)

The cyclic nature of the octave and the arched nature of the hand's movement when rotating around the main axis (the spine) initially suggested that curves are preferable to straight lines, at least when producing glissandi (helix shapes). This was also ideal when several octaves and many keys were used, since curve shapes enabled the overall set up to be kept closer to the player. Following this preliminary use of curved shapes, new ideas involving compact shapes of the overall set of notes (trapeziums, squares and rectangles), and straight lines were considered. The instruments derived from these ideas had layouts resembling traditional Western tuned percussion instruments, but the large amount of notes required for one single octave meant that the resulting instruments were limited to an octave range. The square layout was ideal to transpose chords but had too much of a gap in the upper range between the bells to produce smooth glissandi. The trapezium layout was ideal for the glissandi but it was too difficult to transpose the patterns since the distance between the notes changed when the section of the range was changed. Eventually a compromise between a rectangular layout and a half a coil layout was found. These are the main layout shapes that were considered:

- Non-cylindrical helix
- Cylindrical helix
- Trapezium
- Square
- Rectangle
- Concentric (cones)
- Semi-cylindrical arches

2.2.2.2 Angular placement of contact surface (Stage XII)

The ideal angle for the sounding body's contact surface varies according to its height. Since different heights were being considered, the angle placement of the striking surface has been considered adjustable, starting with a horizontal plane when at the performer's waist level (or slightly lower) as in most existing bar instruments (such as the marimba). This then moves up so that ideally the contact (striking) is vertical to the performer's eye level.

2.2.2.3 Framework and mountings (Stage XIII)

The framework has to be portable and easy to set up. Clamp systems are ideal but expensive. Therefore, clamps have not been used for the prototypes within this research, although they are highly recommended for a professional future version of the final prototype.

The safety of the instrument is carefully considered when designing the framework for performances. However, the security required for an exhibition of the instrument, which, for example, involves children playing the instrument, is not considered here for the finalised instrument. However, this problem could be sorted simply by using short bars with clamps on both sides joining neighbour stands with each other to have a solid frame that could stop the stands of the finalised instrument (p. 138) from falling.

2.2.2.4 Creative-comparative evaluation through conceptual variant designs (Stage XIV)

Following upon the method adopted, different prototypes of the instrument envisaged are proposed (pp. 116-160) to accommodate a progressive review of the sounding bodies (in this case steel bells) and the instrument characteristic of most interest considered (in this case the layout). Each prototype of the instrument is compared with variant conceptual instruments, which are formulated using the same characteristic considered for the prototype but using a different type of main vibrating body. These conceptual variants are designed (or at least their characteristics defined), evaluated,[88] and finally compared with the corresponding prototype considered to provide feedback before moving into another prototype. This is done systematically producing eight variant conceptual instruments for each prototype. There is a nomenclature system to define each design, so a roman number with subindex 'a' refers to the prototype, and the eight conceptual variants related to that prototype use the same roman number with other eight different subindexes from 'b' to 'i' representing the following types of main vibrating bodies:

- b = struck bells or plates
- c = struck solid bars or solid tongues
- d = struck shallow bars
- e = struck strings or tongues
- f = struck water or membrane
- g = blown pipes or organs
- h = blown brass or reed instruments
- i = new vibrating bodies or hybrids

The Roman numeral system with subindexes is used to indicate the position among the bellophone prototype group. Bellophone prototypes and bellophone prototype groups are referred to in general using Arabic numerals (1 to 14), so as to avoid confusion with the Roman numbers (without indexes) already used for method stages. This structuring of the creative-comparative design approach of the method has been specially prepared for the Case Study chosen in this research and it demonstrates the openness of the proposed method.

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[88] In some cases these evaluations are also responsible for defining the conceptual instrument in mind if a sketch has not been elaborated.

The subindex 'b' refers to an alternative metal idiophone with cylindrical symmetry. The other subindexes mainly relate to other shapes being also struck, apart from two blown instruments ('g' and 'h') and a final design aiming either the exploration of new materials or a hybrid of previous groups.

Evaluations and comparisons are explained in detail for each prototype of the Case Study in this chapter (pp. 119-159), although more details are provided on Appx 3, pp. 462- 473.

2.2.2.5 Psychoacoustic implications: sliding pitch and tuning perception (Stage XV)

If the perceivable pitch continuum is successively subdivided (see microdiscretism on pp. 216-218), there is a question of how far the process can go so each pitch can be perceived as a different one. There is also a question of how continuous the sliding pitch effect can sound when playing a succession of neighbour tones in ascending or descending order. These aspects are considered later on in practical situations when dealing with the compositional and performance process.

2.2.2.6 Instrument characteristics responsible for the prototype criteria (Stage XVI)

Initially, the smoothness of the performer's movement was considered the most important aspect in achieving an instrument with microtonal and microdiscrete-sliding pitch properties. However, to avoid a complex study of movement notation, the physical disposition of the main vibrating bodies was prioritised as a way of organising the performer's movements; the layout of the bells became the most important aspect of the instrument development process.

2.2.3 Other considerations

How to extend ranges, mechanise the sound activators, amplify and modify the sound was all considered at a posterior stage together with the development of a flight case and maintenance manual. These considerations are treated as possible expansions of the project and they are described under prototypes IX to XIV (pp. 141-160). These elements are here introduced as follows (§2.2.3.1-2.2.3.6):

2.2.3.1 Sound activators

The material and shape of the sounding bodies might suggest the use of particular kinds of sound activators. Although the sounding bodies have already been defined as part of the general considerations, a list of general sound activators for idiophones was initially considered for the experimentation that took place in the late period of the development process. This list is grouped considering the physical action involved, as follows:

(1) Striking action

Mallets: Mallets' heads can be of any desired metal (wood, metal, synthetic, etc.) and they can be covered with soft material such as cloth, felt, rubber, and cork. Mallets can be organised according to their hardness, or the material they are made from. Multi-mallet holders can be custom made to match specific patterns within a layout. The back of the mallets can also be considered an alternative striking point and they can also be custom made to accommodate an alternative head to promote fast changes of hardness in mallets.

Sticks: As with mallets, the two ends can be used as striking points and also covered to control the hardness (and consequently the timbre produced)

Hybrids: Shakers such as maracas can produce a struck sound at the same time that they produce a shaking sound.

(2) Friction action

Brushes: Shakers, such as a bamboo branch, can be used to produce a 'windy' friction sound when shaken on top of membranophones to increase the friction and sound level.

Bows: Bowing idiophones with a cello or double bass bow can bring sounds of very high pitch. This pitch is normally stable and easy to sustain.

Idiophone-to-idiophone friction: as in the case of the singing bowls (clave-like single stick rotating around a bronze bowl), and fingertip friction with the idiophone (as in the case of glass harmonica).

Hybrids: Maracas or a similar shaker can be used as a friction instrument on top of a microdiscrete instrument while being shaken up and down within a chromatic row (of a tone range for example) so the pitch of the idiophone produces a vibrato effect on top of the continuous shaking sound of the maracas (or shaker employed). Another idea would be a bow with a water container incorporated so, for example, the water is shaken while playing trills or fast passages requiring continuous bow changes.

(3) Plucking action

Plectra and false nails can be used to pluck idiophones. This action can be done in a sequence to perform microdiscrete-sliding pitch or arpeggios with the appropriate layout, and false nails can also be used to play randomly across the layout.

(4) Shaking action

Tremolo can easily be achieved by shaking sounding bodies if they have a cavity and a clapper is hung inside. On the other hand a mallet or stick can be shaken inside the cavity in order to produce a similar tremolo effect. If instead the holder of a maraca is used (with the desired covering material) then a double shaking sound is produce with one single shaking action.

(5) Scraping action

Any uneven surface on an idiophone can be scraped to produce vibrations. Among the many kinds of scraper surfaces one can consider to affect the sound are undulated, granular and parallel cuts. Other factors to consider are: size of the contact surface and the material employed.

(6) Blowing action

Hollow idiophones invite to blow inside the cavities as an alternative to use their bodies as main vibrating source, since although they might produce a secondary vibration, the resonance of the air inside the cavity is most likely to become the main vibrating source. If blowing with the mouth is not achievable an air compressor gun could be employed.

(7) Pressing action

Pressing actions with idiophones are mainly used to activate mechanisms that can activate the sound producing action rather than to directly produce the sound. Therefore a second kind of action, produced by the mechanism to activate the main vibrating body is involved in the process. Keyboards are the most common pressing surfaces that activate mechanisms, as there are no limits as to how many kinds of actions the mechanisms can execute (hammering as on the piano, plucking as on the harpsichord, etc.).

2.2.3.2 Resonating cavities

Resonators and the performance space (and subsequently the positioning within the performance space) are the main type of resonating cavities considered. There are individual and shared resonators. Their material and hardness affects the sound. One can also consider variable resonators as in the case of the mouth cavity when playing one single vibrating body (e.g. Jew's harp) or several (e.g. *kou xiang* / 梁詠琪). This could also be transposed to a tube or box resonator with sliding mechanism to either match the note played or to amplify different harmonics of the sound being vibrated inside the resonator.

2.2.3.3 Sympathy strings

Strings that vibrate in sympathy with the main vibrating body can create additional complexity to the spectrum of the musical instrument and are worthy considering when they can be placed (and tuned) perpendicular to the main vibrating direction of the idiophone.

2.2.3.4 Buzzing membranes

Buzzing membranes are normally used for Kazoos and other blowing instruments such as several Chinese flutes: *dízi* (笛子), *qudi* (曲笛) and *bangdi* (梆笛). An idiophone can have an internal cavity that is connected to the exterior through a buzzing membrane, for example a spherical ceramic pot, so the hand tapping on the clay pot produces an internal pressure against the membrane adding a buzzing sound to the spectrum of the instrument. This idea is actually borrowed from the Guatemalan *marimba de tecomates*, which incorporates a buzzing membrane on a resonator's hole.[89]

2.2.3.5 MIDI and mechanised-playing systems

Yamaha's Disklavier system improved the already amazing work done before with Player pianos. The work of Nancarrow would probably not have been so praised had the player piano technology been available to other experimental composers of his time. Solenoid systems attached to the keyboard and linked to sequencer with a MIDI to relay interface have taken over this technology. However, the work of Nancarrow remains an inspiration to the composer working at the edge of the technology resources available to play mechanised acoustic instruments.

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[89] In this case dried cow's intestine skin (paper) is placed on top of a bee wax ring, the resonator being traditionally made with gourds and nowadays with cedar wood (combining for trapezoids and four triangles).

The incorporation of MIDI technology to a simulation of musical instrument was already suggested when defining a MAVMI (MIDI audio-visual musical instrument).[90] Although the 3-D modelling is considered part of this thesis, the internal programming linking the models with MIDI is not since it requires cutting edge programming knowledge. However, a programmer was hired to prove that this is possible in order to promote regular development of MAVMIs as an alternative way of conceiving and interacting with new musical instruments with much higher rate of productivity in the overall compositional process.[91] This approach supports an idea put forward by other experts in the area of instrument making, building the MAVMI for its performance once the instrument has proven to be efficient for a wide range of techniques (in its virtual form).

2.2.3.6 Flight Case and maintenance

Although it is most desired to complete the project with a study of ways to build a hard case for musical instruments and a prototype of case, the subject is available and extensive to consider it in depth. Also, extended versions of the instrument devised in the final stages of this research (see prototypes 1-14, pp. 141-160) that were not built, will have to be considered as a substitute for the instrument built as part of this research (the *conic bellophone*) before considering designing a flight case, since the extended version is supposed to replace the version here developed. A future project focussing on building and studying these extended versions is envisaged as a research expansion that would lead to a finalised extended version. This project should be concluded with the flight case design (and construction) and a simple set maintenance instructions, which is why they are not considered part of this research project.

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[90] See page 40

[91] When dealing with instrument development-led composition.

2.3 The development of the *conic bellophone* in relation to the compositions (Stage groups D and E)

A systematic approach for the development of the bellophone has been adopted (Fig. 5, p. 13), after an initial period of experimenting and realising what the most relevant guidelines were. Each bellophone prototype examines the potential of employing a different shape for the layout of a set of bells.[92] Each prototype explores a different technique or theoretical concept through a parallel composing process to the development. An evaluation system is proposed (pp. 364-371) and used to compare the different bellophone prototypes, so as to provide additional support for a gradual progression into the prototype that best suits the compositional demands of microtonality and microdiscrete-sliding pitch, while still keeping a good sounding aesthetics, and visual appeal in harmony with the performer's movements.

In addition to this comparative approach between stages, a creative-comparative strategy is independently utilised for each bellophone prototype incorporating the same evaluation system. The strategy consists of defining (and designing in some cases), evaluating and comparing variant conceptual instruments with the prototype considered following these guidelines:

(1) Each conceptual variant should employ a different type of sounding body according to previously agreed aspect(s),[93] and ideally the number of variant conceptual instruments should be fixed according to what different subcategories of the aspect(s) considered.

(2) The layout of each conceptual variant must follow the same shape as the prototype that is going to be compared with.

(3) The composition written for the prototype should be playable in each of the variant conceptual instruments.

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[92] In all the cases the prototype is labelled with the shape of the layout, followed by the term *conic bellophone*, since the conical shape of the bells was kept throughout all of these designs.

[93] For the Case Study different materials and shapes of sounding bodies are considered, which is decided as part of Stage XVI, although here anticipated for clarification.

After clarifying the concepts and criteria backing up the evaluation system, the eight bellophone prototypes and six additions already introduced, will be described in chronological order.

For referencing purposes, the detailed evaluation charts for each *group* are provided (pp. 461-473), while the description and sketches of the variant conceptual instruments (to the bellophone prototypes) that where developed further than conceptually are explained on pp. 372-460. In this chapter only the average percentage for each of the four main evaluation categories and the total average value for each instrument is provided together with a detailed description of the corresponding bellophone prototype.[94]

2.3.1 Prototype 1: Non-cylindrical helix layouts and the *spiral conic bellophone*

This group represent instruments that somehow have incorporated in their design any kind of helix apart from the one, which is contained inside a cylinder.

2.3.1.1 The development of the *spiral conic bellophone* prototype

The very first way in which the layout of conical bells was conceived focuses on achieving sliding pitch, with strong influence of corporeality (as defined by Harry Partch in *GM*, see Abbreviations). It consisted of a conical helix around the performer (see Fig. 48).

Fig. 48. Initial disposition of the *spiral conic bellophone* (Ia).

[94] In the sections to follow references to the compositional practice are incorporated to the text describing the score (or sketch) number as well as the CD and/or DVD track number. In order to avoid taking too much space in the text for this purpose the reference to the page in which the composition is described in Chapter 3 is not necessarily described since they are very easy to find, so it is assumed that the reader will look for the composition description in Chapter 3 when additional information about the work that is described in this chapter is required to understand the instrument practice.

In order to sustain the spiral and make it easy between different levels of the spiral, the frame shown in Fig. 49, a slight conical helix with four legs, was first sketched, so equal distance between the striking points could be arranged to easily achieve parallel glissandi (Fig. 50).

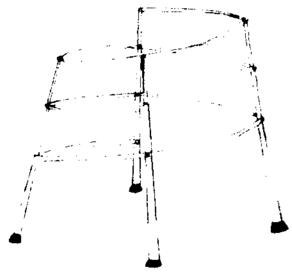

Fig. 49. Non-cylindrical helix frame.

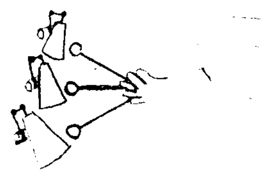

Fig. 50. Ideal striking points inside the spiral.

This frame can be used to position the striking point of the bells in the inside (see Fig. 51 and the outside (Fig. 52). Having extra players increases the potential corporeal expression (see Glossary) of the instruments.

Fig 51. Inner layout of bells in the non-cylindrical helix layout.

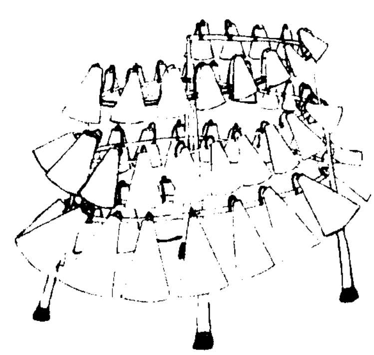

Fig. 52. Outer layout of bells in the non-cylindrical helix layout.

2.3.1.2 Feedback from the compositional practice for the non-cylindrical helix layout

At this early stage of the bellophone development, simple glissando exercises from bottom to top of the range were prepared, either plain or doing zigzag patterns, incorporating parallel glissando too. In the outer layout of the bellophone no problem was encountered and parallel glissando exercises had no limit since as many players as necessary can be incorporated. The speed can be a problem, but in that case is better to use the higher range of the bellophone placed inside the spiral. However, it is difficult to realise the glissandi inside the spiral. Considering the implied cylindrical layout of the striking points inside the conical spiral frame (Fig. 50) it becomes difficult for the player to slide the mallets with parallel glissandi at the lowest level of the bellophone, since it requires the player to bend knees, loosing this way body rotation mobility. Therefore a cylindrical frame would be more practical for that purpose, which would also be equally favouring the inner and the outer curved position of the striking points as explained later on (Fig. 55).

2.3.1.3 Feedback from the variant conceptual instruments with non-cylindrical helix layout

The *spiral conic bellophone* has the highest total average evaluation for the non-cylindrical helix layout group, 79% (Fig. 53, below),[95] while the spiral rotary organ has the highest average percentage for glissando (97%) and also microtonality (100%). Therefore the *spiral rotary organ* apart from challenging the pitch capabilities of the *spiral conic bellophone*, it could have complementary function when combined, since it would provide a sustained tone with clear pitch, unlike the *conic bell* sound, while the corporeal expression is still high thanks to the bellophone player.

Another variant conceptual instrument, and also a struck metallophone, with relevant glissando capabilities is the *cyclic Whitechapel bellophone*, which provides a layout, which allows glissando in either small steps or large steps. This idea can also be applied to the

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[95] From now onwards, the details of the evaluations for the 14 feedback sections (2.3.1.3, 2.3.2.3,..., 2.3.14.3) corresponding to each of the 14 bellophone prototypes can be followed in the full charts available in §A3.3 (pp. 372-460). Also notice that the percentages are subjective values referring to the instrument capability and in other words defining how ideal the characteristic of the instrument considered are towards the achievement of: (1) glissando (sliding pitch), (2) microtonality, (3) a distinctive timbre, and corporeal (visual and spatial sound) expression.

spiral conic bellophone so the glissando is played vertically for larger steps, if placed close to each other.

The *Harrison Luo-Abu Mbira* (p. 430) with its 100% of corporeal expression inspires the *spiral conic bellophone* to explore new sound producing techniques in order to enhance its corporeal expression and its timbre (e.g. blowing compressed air into mouths of the conic bells in a sequence of having people running around while playing glissandi).

Group I

		Glis.	Micr.	Tim.	C.E.	Tot.
I_a	Spiral Conic Bellophone	67	72	81	94	**79**
I_b	Cyclic Whitechapel Bellophone	77	56	76	67	69
I_c	Stand-a-key Spiral Bass Marimba	47	33	39	94	53
I_d	Spiral T'Rungophone	73	39	41	67	55
I_e	Spiral Harp	73	50	52	83	65
I_f	Spiral Splashophone	63	17	43	67	47
I_g	Spiral Rotary Pipe Organ	97	100	52	39	72
I_h	Spiral Tin Oboe (Conic Core)	53	78	69	28	57
I_i	Harrison Luo-Abu Mbira	67	33	44	100	61

Fig. 53. Evaluation for the non-cylindrical helix layout group.

2.3.1.4 An assessment of the *spiral conic bellophone* prototype and its group

Considering the cylindrical layout of the striking points inside the conical spiral frame (above, Fig. 50), it becomes difficult for the player to slide the mallets with parallel glissandi at the lowest level of the bellophone, since it requires the player to bend knees, loosing this way rotational mobility. Therefore a cylindrical frame would be more practical for that purpose, which would also be equally favouring the inner and the outer curved position of the striking points as explained later on (see Fig. 55).

Although the *spiral conic bellophone* can have some movement restrictions when playing from inside of the instrument, it can also be considered an ideal instrument to provide referential microtonal pitches and a precise gliding tone at quite a wide range of speeds, so it can be imitated or used as a clue to indicate pitch.

2.3.2 Prototype 2: Cylindrical helix layouts and the *coil conic bellophone*

This group refers strictly to instruments using a cylindrical helix as part of their design, which means is less flexible than the previous than the previous shaped considered, but at the same time it offers. Whether the shape is used to define a frame, striking points, positioning of sounding bodies, the air-column that vibrates, or any other aspect of the design, it will always offer a cylindrical internal empty space to consider when in the performance of the instrument or simple to incorporate additional sounding or resonating bodies.

2.3.2.1 The development of the *coil conic bellophone* prototype

The name refers to the coil shape that the frame here proposed (Fig. 54). This frame allows the striking points to easily adopt a curve bringing lower ones close to the performer, which makes the performance easier and more effective, whether the bells are positioned inside or outside the coil (see Fig. 55 for an example of the bells positioned inside the coil and allowing a comfortable parallel glissando in this case).

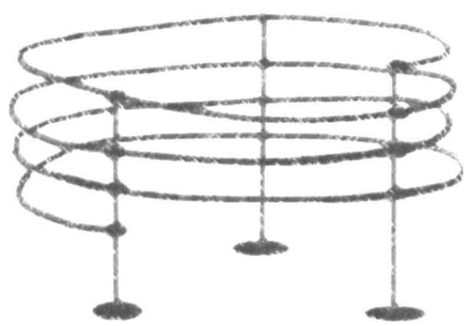

Fig. 54. Sketch of the *coil conic bellophone*'s frame.

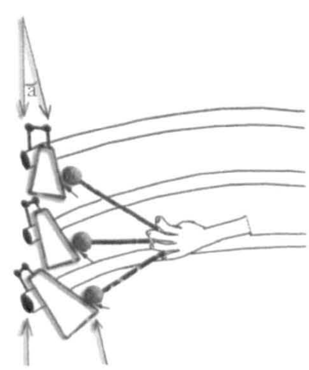

Fig. 55. Example of ideal bell position.

2.3.2.2 Feedback from the compositional practice for the cylindrical helix layout group

No formal composition or study was prepared, but the glissando exercises from bottom to top of the range, and doing zigzag patterns, and the parallel glissando previously considered for the *spiral conic bellophone* were also considered for the cylindrical helix layout group, and there is no doubt that they can be more easily achieved in this new prototype.

A melodic sketch, later on to be used in the central area of *Prelude No 1* (Sc. 11/ CD-tk 11/ DVD1-tk 11) for the *conic bellophone*, was composed keeping in mind this layout and ideally an equal distance between the striking points.

2.3.2.3 Feedback from the variant conceptual instruments with cylindrical helix layout

Most of the mallet instruments from this group are characterised by high corporeal expression including the *coil conic bellophone*. However, the *coil conic bellophone* has better values for most of the pitch capabilities and timbre..

The outer layout of the bellophone also improves the *spiral conic bellophone* prototype since the lower bells do not come out as much in this prototype avoiding the risk of the performer moving around the instrument being hit by the bell. The *rotary harps* (p. 442), with a substantial evaluation and a timbre very different from the one of a steel conical bell, is an ideal candidate to combine with the *coil conic bellophone* within this group.

Group II		Glis.	Micr.	Tim.	C.E	Tot.
II_a	Coil Conic Bellophone	57	50	81	100	**72**
II_b	Coil Sarunay	50	28	87	89	63
II_c	Ring of Roses (Mokugyouphone)	57	22	54	83	54
II_d	Bass Tubaphone	57	33	76	100	66
II_e	Rotary Harps	80	44	65	56	61
II_f	Uchiwa Taikophone (K.Suzu ma.)	40	17	70	94	55
II_g	Sliding French Horn	77	67	67	33	61
II_h	Ceramic Coil Flute	60	33	59	67	55
II_i	Cooperative Ceramic B.Prf.Flute	50	67	63	106	71

Fig. 56. Evaluation for the cylindrical helix layout group.

2.3.2.4 An assessment of the *coil conic bellophone* and its group

The *spiral conic bellophone*'s microtonal and gliding properties can be sacrificed using the *coil conic bellophone* in order to gain corporeal expression, and especially when considering several players. The conceptual variants have provided a wide view of how this shape can highly influence the potential corporeal expression of the instruments.

2.3.3 Prototype 3: Trapezoidal layouts and the *trapezoidal conic bellophone*

Hammered conic bells are here used. They are made of mild steel instead of aeronautic steel, sounding a fifth below a set of *spun bells* of the same size.

After having started with reasonably satisfactory values in a first stage where curves where predominant, a new series of prototypes consisting mainly of straight lines were developed (apart from the concentric layout which is itself part of a frame with a mix of curves and straight lines). Something surprising about these prototypes using straight lines and employing several shapes for the main frame (or layout), is that in most of the cases the total value of the instrument's capabilities is substantially lower than the one of the previous prototypes. The trapezoidal layout is the first shape of this transition period.

2.3.3.1 The development of the *trapezoidal conic bellophone* prototype

The idea is to keep the conical bells sustained in parallel bars placed inside a wooden resonance box keeping the same distance between the edges of the bells, and the same amount of bells per row, so since the bells get smaller as the pitch gets higher the overall layout becomes a trapezium. The frames in Fig. 57 and Fig. 58 have 12 bells per row in sixteenthtones, therefore covering a tone and a half per row, and just one step under the octave interval. In order to reach the octave interval or what is more interesting for the tone quality of steel cone-shaped bells, the stretched octaves, an extra row should be added on top. The *96-et trapezoidal conic bellophone* in Fig. 57 has a balance problem since more weight is on one side and this can easily be resolved by rearranging the lower frame with the legs. The *192-et trapezoidal conic bellophone* in Fig. 58 has no problem with the balance since almost the same weight is kept in both sides and simply the back side keeps an additional 96-et *conic bell* set tuning throughout the bells but thirtysecondtone apart from the front set, in a similar way than two pianos are tuned a quartertone apart from each other to achieve quartertones.

Fig. 57. The *96-et trapezoidal conic bellophone.*

Fig. 58. The *192-et trapezoidal conic bellophone*

2.3.3.2 Feedback from the compositional practice for the trapezoidal layout group

Sixteen notes per row were mostly desirable since it makes it easy to cover a smooth whole tone glissando. For that purpose *Study No 1* (*One row study*/ Sc. 1/ CD-tks 1, 12, 13/ DVD1-tks 1, 12, 13) was written to practice fast passages, so the player can practice and get used to the different distances between striking points for each of the rows. In the end, the 12 bells per row was kept since the glissando sliding mallets cannot be kept smooth with 16 notes per row, at least in the lower rows when moving to the row above. However, the *One row study* could be arranged to 12 bells. Notice that *hammered conic bells* were considered for this layout.

2.3.3.3 Feedback from the variant conceptual instruments with trapezoidal layout

The square handchimes also named handchimes (and metal boncas;[96] other trademark names are also used, such as MelodyChime® by Schulmerich and choirchime by Malmark), and a high quality handbell (such as the one produced at the Whitechapel foundry in London, UK), provide a very simple harmonic content metallic sound, as opposed to the sound of *conic bells*, of rich harmonic components. The metallic tone colour of square metal chimes provides an ideal reference pitch, which is what makes III_b and III_d the perfect microtonal instruments and at the same time places their total value above the *trapezoidal conic bellophone*. However, as reflected in the values of the timbre subcategories (Fig. A3.81, p. 463) there is a higher harmonic content in the *conic bell*, than in the Whitechapel bell (*W. Bellophone*) and than in the square chime used for the

[96] Sawyer, D. 1977. *Vibrations, making unorthodox musical instruments*. pp. 24-25.

trapezoidal boncaphones (p. 454), producing a more distinctive tone and still with a pitch definite enough for up to 32 divisions of the 12-et tone, which makes the *conic bell* ideal when high volume cannot be used to provide cues or references to other instruments.[97]

Group III

		Glis.	Micr.	Tim.	C.E.	Tot.
III_a	Trapezoidal Conic Bellophone	67	100	81	67	**79**
III_b	Trapezoidal W.Bellophones(96&192)	67	106	91	67	82
III_c	Trapezoidal Clavescrapophone	70	89	63	67	72
III_d	Trapezoidal Boncaphones(96&192)	77	106	89	67	84
III_e	Trapezoidal Harp-mbira	50	56	74	56	59
III_f	Water Drumophone	43	56	48	61	52
III_g	Sliding Tecomate Flute (buzz.m.)	60	44	56	44	51
III_h	Sliding Tin Tecomate Oboe	60	44	76	33	53
III_i	Piani-mbira	77	100	85	61	81

Fig. 59. Evaluation for the trapezoidal layout group.

2.3.3.4 An assessment of the *trapezoidal conic bellophone* and its group

The metallic quality of the *conic bell* sound is unique and easy to distinguish among most Western orchestral instruments, unlike the wind-like quality of the handchime sound. However, the loudness of the handchime can support the *conic bell* providing reference pitch to other parts when the overall sound of the composition is loud for as long as the texture is not too thick or rich in wind quality, in which case a good quality handbell such as the Whitechapel, can be used instead. In general the handbell (Whitechapel or similar) can be considered to occupy a mid-range of dynamics between the square chimes and the *conic bells*.

2.3.4 Prototype 4: Square layouts and the *square conic bellophone*

The motivation to explore a square layout was to produce a distribution of the sounding bodies that could ease sight-reading two digits numerical notation. This not only supports Carrillo's 96-et's numerical notation, but also the one proposed by his student Espejo, which uses the 100 pitch values per octave in just intonation (see p. 250 for more details).

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[97] The handchime and the Whitechapel handbell still have a wider amplitude scope than the *conic bell*.

The idea is to distribute the striking points of the sounding bodies in a ten-by-ten layout so the first number from the two digit number notated (0 to 9) corresponds to the row and the second to the column. Although the idea was inspired by Carrillo's persistent striving to improve staff notation with the use of numbers to refer to pitch and less lines to simplify the notation, it also has the potential to be used to associate a number with a position regardless of the pitch, but relating to what is being struck, plucked, tapped, rubbed, shaken, blown, etc. Therefore, this layout also seems to suggest notation for instruments of hybrid nature (see §4.3.6 on p. 214).

2.3.4.1 The development of the *square conic bellophone* prototype

Following the ten-by-ten layout, this prototype was conceived using a frame where the square grid can be rotated at the convenient angle, and the bells can be placed so the striking points are at equal distances (Fig. 60). The bells are positioned in increasing pitch sequence from left to right, so the bottom left bell has the lowest pitch and the top right bell the highest.

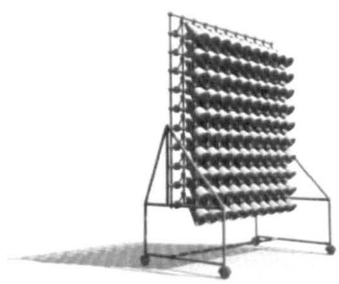


Fig. 60. The *square conic bellophone*.

2.3.4.2 Feedback from the compositional practice for the square layout

Although Espejo's just intonation system was initially considered,[98] the need to maintain the same tuning throughout all the prototypes for the *conic bellophone*,[99] did not leave space for new considerations. And if this had been used, a *conic bell* does not provide a pitch that is clean enough to consider the precision required by just intonation. *Study No 2*

[98] Lowest note has the same relation to the other 99 notes than the 100th harmonic (in the harmonic series) has to the 99 harmonics above.

[99] So as to be able to play all the studies composed for each prototype in the final design for the *conic bellophone*.

(*Chess study* / Sc. 2/ CD-tk 2, DVD1-tk 2) was composed as a work that playing every single bell to serve as a test for the cone positioning before performance.

Having an instrument with highly inharmonic spectra and with four different types of octave (1200 ¢, 1212.5 ¢, 1225 ¢ and 1237.5 ¢) seemed to suggest the usage of the most appropriate octave to match the spectra of the *conic bell* to resolve the study, and although the 1200 ¢ interval (0-97) is notated at the end the performer can play one that sounds more consonant out of the three possible stretched octaves instead. This indication is placed in the published version of the study to provoke awareness of stretched octave and educate and tune the performer's ear to the inharmonic spectra of the *conic bell.*

2.3.4.3 Feedback from the variant conceptual instruments with square layout

The *square Ahualulco chromelodeon* has a keyboard design (p. 409) exploring further the concept of split keys developed by Don Nicola Vicentino's *archicembalo.* It is a contrasting example for the *square conic bellophone*'s approach. The evaluation obtained by this keyboard is much higher than any other instrument of the group (Fig. 61). Using reeds and a mechanised blowing system (rather than a pedal system) makes the instrument ideal for microtonality. The *square Ahualulco keyboard* layout (see Fig. A3.28, p. 408) can be substituted by a ten-by-ten layout if numerical notation was to be considered. In both cases the reeds would provide an interesting sound to combine with the one of the *conic bells,* but a square layout using visible dimensions could influence the visual presentation of the music and consequently its dramatic impact on the audience perceives the music.

The *Chinese opera gongophone* (IV_i) is a variant conceptual instrument derived from the composition *Seasons* (Sc. 12). The part for *Chinese opera gongophone* that has already been written does not require the MIDI interface since it can be played with a bit of practice by a percussionist and probably using two digits with the numbers 0, 1, 2, 3 to notate each coordinate in the four-by-four grid.

Group IV		Glis.	Micr.	Tim.	C.E.	Tot.
IV_a	Square Conic Bellophone	43	78	81	67	**67**
IV_b	Square Rotating Matsumushiphone	50	56	91	56	63
IV_c	Square Buzzing Lithophone	60	67	87	44	65
IV_d	Square stepped Bonangophone	40	56	89	44	57
IV_e	Cubic Mbira	43	67	76	44	58
IV_f	Square Booms (10x10)	50	56	48	44	50
IV_g	Square Panpipe (buzz.memb./zig-z.)	47	44	63	39	48
IV_h	Square Ahualulco Chromelodeon	93	100	67	89	87
IV_i	Chinese Opera Gongophone (MIDI)	73	78	74	44	67

Fig. 61. Evaluation for the square layout group.

2.3.4.4 An assessment of the *square conic bellophone* and its group

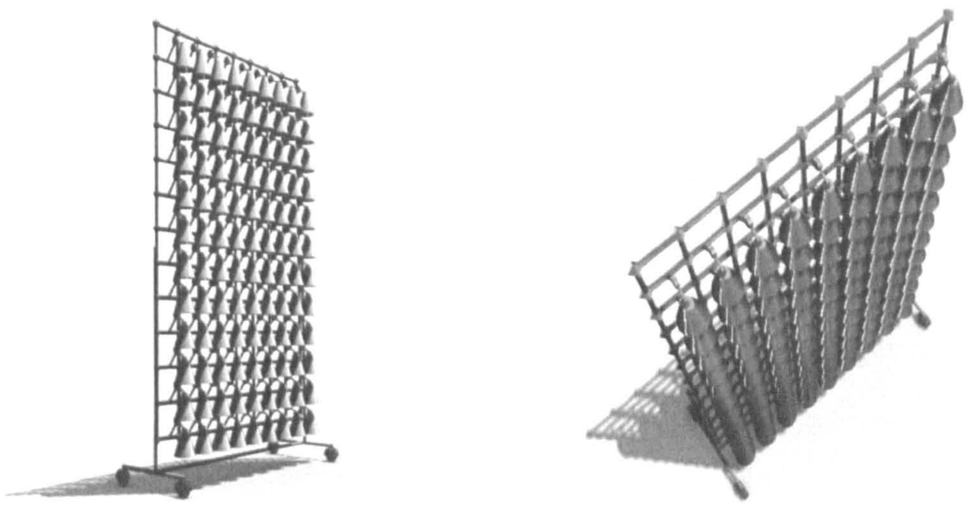
All the struck idiophones designed for this group receive slightly higher evaluation than the others in terms of timbre, while the *square Ahualulco chromelodeon* for microtonality (100% capability value) and sliding pitch (93%), can be easily improved incorporating a mechanised-MIDI player system to the keyboard to make it an ideal instrument to provide microtonal and sliding pitch guidelines to an ensemble together with the *conic bellophone.*

2.3.5 Prototype 5: Rectangular layouts and the *rectangular conic bellophone*

The rectangle and the square are unusual shapes for musical instruments and particularly among mallet instruments, which have trapezoidal shape layout. The interest for equal distances between striking points led us to explore rectangle shapes in six different new mallet instruments and in instruments of totally different nature (plucked string, reed keyboard and sliding brass).

2.3.5.1 The development of the *rectangular conic bellophone* prototype

Hammered conic bells were still used for this bellophone development phase. There was some initial doubt about whether the frame would be twelve-by-eight or the other way around to cover one octave range. If 10 bells straight-line horizontal row were already a tight stretch to perform a smooth glissando in the *square conic bellophone* (from left to right), 12 bells straight horizontal line would have been almost impossible. Consequently the layout employing 8 bells in the horizontal by 12 bells in the vertical layout, was adopted in the end. Finally, and in order to make easy the exact slide of a semitone between two notes contained within the 12-et, an additional bell was placed in each row (a total of 9 bells), repeating the note that comes in the sequence of an 8 bell row and particularly the note of the bells above the one on the very left of the sequence. This repeated note also allows the performer to perform smooth glissandi employing several rows, since there are two options about where to play the note in the sequence that can easily disrupt the smoothness of glissando between 12-et notes. An additional row can be placed on top of the frame so either 9 extra notes in the sequence can be placed above to achieve several types of stretched octaves or simply 9 different tones above the octave required by the composition, regardless of which pitch they have within the indicated high register. The three-dimensional prototype prepared (Figs. 62 and 63) allows frame rotation at the point the square frame joints the stand to allow adjustment with a slight angle, being represented in the diagram in vertical position. The stand is supposed to have adjustable height so it is represented here at its lowest possible height.



Figs. 62 and 63. Eye-level and aerial views of the *rectangular conic bellophone.*

2.3.5.2 Feedback from the compositional practice for the rectangular layout

Having extended the rectangular twelve-by-eight layout to have repeated notes in a ninth column (a twelve-by-nine grid, extendable to thirteen-by-nine) to cover a full semitone step (eight sixteenthtone steps) by means of glissando, *Study No 3* (*Glissando study*/ Sc. 3/ CD-tk 3/ DVD1-tk 3) was composed illustrating a parallel glissandi among two parts 375 ¢ apart, close to the a just major third (ratio 5/4, 386.3 ¢).

The rectangular frame is longer on the vertical axis to cover just above an octave. It seems easy to play a one part gliding tone for the *Glissando study* by sharing half of the instrument with each mallet, but when the parallel parts are initiated it seems better to play the parallel glissandi with two mallets in one hand, also sharing each half of the instrument with the corresponding hand, rather than using one mallet for each of the two parallel parts since the body has to follow the horizontal in parallel to keep it steady. This suggests the curving of the horizontal to ease such kind of movement, and after this prototype a gradual return to the usage of curves in the prototype design made a consistent change in the evaluations.

2.3.5.3 Feedback from the variant conceptual instruments with rectangular layout

The most remarkable value observed is the 100% microtonal capability given to the *Ahualulco portative organ* (Fig. 64). This instrument (V_g) has a similar keyboard design than the *square Ahualulco chromelodeon* (IV_h), although it uses pipes instead of reed. This instrument, also having MIDI capabilities, constitutes an ideal instrument to perform with the *rectangular conic bellophone* (in terms of exploring pitch resources) while keeping rectangular shapes in the stage for corporeal expression purposes.

There is also a remarkable timbre in a *trianglephone* (with square frame), which makes it rather unique. However, its pitch is not as definite as it would be desired, which can be an issue when provided reference pitch to other parts.

Group V

		Glis.	Micr.	Tim.	C.E.	Tot.
V_a	Rectangular Conic Bellophone	43	67	81	67	**65**
V_b	Trianglephone	70	44	94	39	62
V_c	Springophone	53	44	85	50	58
V_d	Tubular Springophone	37	28	81	44	48
V_e	Carrillo Sympathy Harp	67	78	83	56	71
V_f	Finger Rectangular Booms (8x6)	50	39	61	56	51
V_g	Ahualulco Portative Organ (Solar U)	70	100	52	44	67
V_h	Double Sliding Bass Trombone	87	61	72	50	68
V_i	Marimbaflor	63	67	67	56	63

Fig. 64. Evaluation for the rectangular layout group.

2.3.5.4 An assessment of the *rectangular conic bellophone* and its group

The rectangular layout of a hybrid instrument proposed, the *marimbaflor*, suggests the usage of numerical notation using two digits to provide horizontal and vertical position respectively within the rectangular grid. The *marimbaflor*'s layout was defined by the geometry related to the mathematical formula used for a composition originally for *conic bellophone* and guitar duo but envisaged to have at least this additional instrument.[100] From the visual point of view, the *rectangular conic bellophone* matches the rectangular layout of the *marimbaflor*, and the corporeal expression of the performer by using similar movements in the performance. This idea still needs reconsideration and the guitar could also be conceived with rectangular body,[101] while the *Ahualulco portative organ*, or the version using a ten-by-ten keyboard (using two consecutive squares to make a rectangle and reach a wider range) also have the potential to be incorporated into the project.

This group in general (and the previous) has more potential than what the evaluation can offer. In this case documenting the potential is a very important part of the overall instrument development practice, and in this case the ideas have been sketched in Chapter 3 as part of the compositional works in progress they belong to.

The *rectangular conic bellophone* has suggested and informed the composition of an important work for the exploration of clusters with *conic bells*, *Study No 4* (*Timbral study*/ DVD1-tk 4). Its sampled simulation (CD-tk 4) remains as sounding proof for future reference when composing for *conic bellophone* using clusters, regardless of which prototype is used.

The *rectangular conic bellophone* might not be as ideal for performing fast passages with glissandi as it is for microtonality. By having each row containing a semitone it is very easy to locate the seven microtonal values placed between each regular note of the 12-et, and since this is done keeping equal distance between striking points (unlike trapezoidal layouts) it is also easy to perform parallel glissando between notes that are located close to each other.

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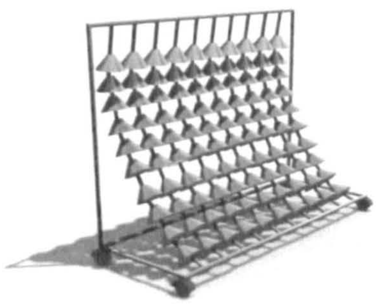
[100] This composition extends the work *Improvisatory patterns II* (*Soleá*) as submitted, but still at an early drafting stage to be considered for this research, which is why is not explained in Ch.3.
[101] In a similar way than the body of the Moroccan *hajhuj*.

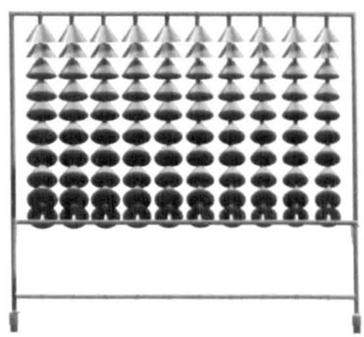
2.3.6 Prototype 6: Concentric layouts and the *concentric conic bellophone*

With the initial idea of having an ergonomic layout in which sounding bodies are mounted into each other or inside each other to save space, the term concentric was adopted involving this way cylindrical or spherical symmetry as it was previously done when conceiving the *conic bells*.

2.3.6.1 The development of the *concentric conic bellophone* prototype

A test was run using regular *conic bells* placing cones slightly inside each other. The result is a substantial reduction of the bell's volume, which is not desired here. Therefore, in order to fit around 10 bells vertical in a slightly curved line (to favour vertical mallet sliding), the shape of the bell has been changed and therefore the bells are not considered *conic bells* anymore, but *wide cone bells*. The angle between the side of the bell's cone and the axis, here considered is 30°. A rectangular frame holds ten vertical bars, each of them containing ten bells (Figs. 65 and 66).





Figs. 65 and 66. The *concentric conic bellophone* starting at ground level and knees level respectively.

The sound of *wide cone bells* and in general conical shape bells with wider angle between side and axis than the *conic bell* proved to be slightly more inharmonic in early experimentation but did not considerably affect pitch clarity, which is what matters.

Fig. 65 and Fig. 66 contain cones of the same size as something that needs to be detailed in this representation, since the gradation of pitch can be used in three different ways according to the needs of the composition:

(1) Ascending pitch from left to right and starting at the bottom left bell.

(2) Ascending pitch from top to bottom and starting with the top left bell going down the vertical and then moving onto the next vertical.

(3) Ascending pitch from bottom to top and starting with the bottom left bell going up and then moving onto the next vertical.

2.3.6.2 Feedback from the compositional practice for the *concentric conic bellophone*

The work composed for the *concentric conic bellophone, Timbral study* (*Study No 4*/ Sc. 4/ CD-tk 4), employs ascending pitch from left to right and starting at the bottom left bell. Therefore the bells get smaller as one goes further up in the verticals, with the smallest at the top-right side of the frame. The composition requires the striking points to be equally distant, so the four-mallet clusters can easily be achieved throughout the grid. This exploration of clusters in three verticals covers four bells per cluster (see p. 170), which produces a harmonically rich sound resembling that of distant church bells. By using the ten-by-ten layout, each horizontal contains three clusters, the middle cluster sharing a note with the one to the left, and another note with the one to the right.

The performer is invited in this work to ornament the clusters doing downwards glissando, suggested by the curves found in the verticals which can also be considered tied cluster notes, and the performer can choose how many tied clusters produces the most pleasant and (or) interesting sound, although this is limited by the tempo at which the work is performed.

2.3.6.3 Feedback from the variant conceptual instruments with concentric layout

The *MIDI multi concentric ceramic drums* (*enchanted forest*), a set of mechanised microtonal tapping drums, is a major contribution to the group, and not only due to its highest total evaluation but also a 97% of glissando capability (Fig. 67), and particularly microdiscrete-sliding pitch that can ideally arrange in sequence around the performance space. This instrument would be ideal to combine the *concentric conic bellophone* and mask the sharp attack produced by wide conic bells when microdiscrete-sliding pitch is played. The curved bars supporting the wide conic bells in a vertical plane would have also match the spherical shape of the ceramic pots of the *enchanted forest*.

To make up for the lack of performer when using instrumentation with the *enchanted forest*, a concentric ceramic drum can be incorporated to have a performer involved in the tapping process too, and interacting with mechanised tapping actions.

This group also has an instrument with a distinctive highly metallic timbre, the *tettouphone*, which could also be considered to cut through the timbre of a large ensemble or orchestra. This instrument, using cylindrical concentric shapes, can produces a wide range of volume keeping its sound quality, unlike the *concentric conic bellophone* which cannot produce a pleasant sound when stroke too hard. Experimenting with different materials would be required to find the ideal one to provide referential microtonal and sliding pitches to other instruments of an ensemble or orchestra.

Group VI

	Group VI	Glis.	Micr.	Tim.	C.E.	Tot.
VI_a	Concentric Conic Bellophone	43	56	48	78	**56**
VI_b	Ekirophones (Thick bronze/alum.bals)	53	39	70	56	55
VI_c	Toroidal Hand Rotating Mbira	60	39	63	44	52
VI_d	Tettouphone	57	56	85	44	60
VI_e	Concentric Fretless Vase Lute (sing)	67	50	56	72	61
VI_f	Conc.Ceram.Drum (Double)	90	17	50	94	63
VI_g	Conc.Ring.Doubl.Ocarina(slid/wat.drone)	80	67	59	39	61
VI_h	Conc.Ceram.Oboe (slid.k./wat.dro)	93	67	61	44	66
VI_i	MIDI Mul.Conc.Cer.Drums (Ench.Forest)	97	78	57	89	80

Fig. 67. Evaluation for the concentric layout group.

2.3.6.4 An assessment of the *concentric conic bellophone* and its group

The *tettouphone* (chromatic version of the Japanese *tettou*), which provides a perspective on how metal cylinders can be placed concentrically, was the most inspiring variant conceptual instruments. The variety of smoothness of timbres makes the group exquisite and unique in sound quality.

2.3.7 Prototype 7: Arched layouts I,[102] and the *3S conic bellophone*

While using straight lines in the designs (trapeziums, squares and rectangles), microtonality was fairly easy to achieve by placing the bells in the appropriate order.

[102] Arched layouts are covered within the periods in which prototypes 7 to 9 were developed, represented with the roman numerals I to III.

However, in order to achieve sliding pitch the movements seemed a bit forced and the fluidity of the performer's movement when covering a full range glissando either in ascending or descending order was not ideal while almost impossible for parallel glissando more than a third apart. For this reason a new series of arched layouts were initiated determining in the end the ideal prototype for *conic bellophone.*

2.3.7.1 The development of the *3S conic bellophone* prototype[103]

This instrument is also named the *arched conic bellophone I* (Fig. 68), to relate to the group name (used in Fig. 69). The frame consists of three poles or stands and six metal bars, each of them divided into two (on fitting and locking inside the other) for portability purposes. Each bar is locked into the side-poles, passing through the middle pole to get support but not being locked to it, so it can easily be adjusted.

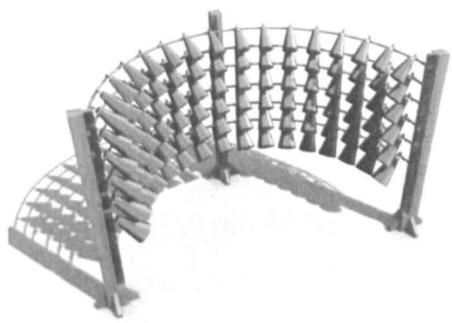


Fig. 68. The *3S conic bellophone.*

This instrument was initially intended to have semi-circular shape but in that case two performers would not be able to play due to the restricted space. For that reason the final shape adopted was arched.

2.3.7.2 Feedback from the compositional practice for the *3S arched conic bellophone*

Study No 5 (*Polyrhythmic study*/ Sc. 5/ CD-tk 5/ DVD1-tk 5) was composed in parallel to the development of this prototype. The difficulties of a study using two parts with crossed

[103] 3S means three stands referring to the three poles holding the whole frame.

rhythms was thought as an ideal way of practicing fast note location on what so far was considered an ideal layout for the *conic bellophone* in terms of microtonality.

Study No 6 (Sc. 6/ CD-tk 6/ DVD1-tk 6), for four hands, was initiated while this instrument was being developed, as a way of illustrating the corporeal limits of this instrument.

The struggle to reach the notes easily in *Study No 5*, while *Study No 6* did require slightly over an octave of range, led to the next prototype in which additional bells are incorporated while the shape can be adjusted between semicircle and arch to match the number of players.

2.3.7.3 Feedback from the variant conceptual instruments with arched layout I (3 or 4 legs support)

Several instruments from this conceptual variant group where thought of as sharing the frame (these being the ones whose name starts with 'waterfall', employing the quarter-section of a cylinder in horizontal position). These instruments have four legs and can be placed facing each other so the overall shape of the two frames together is half-cylinder. Two of them, VII_b and VII_d, have exceptional timbre values within the group and can be considered to accompany an ensemble with this bellophone prototype or in general any of the prototypes to follow since they are also arched (if we consider a semicircle to be an arch), if we look at visual harmony of this shape in the stage.

The *arched conic bellophone I* has low glissando capabilities compared to the last four instruments of the group. Considering that those four instruments are blown instruments and with low corporeal expression capabilities, they can be considered somehow complementary for a balanced overall evaluation of the ensemble.

The *ceramic arched tongued boxes*, having a similar value to the *arched conic bellophone I*, it has a very different timbre which could be explored adding resonators or buzzing membranes to its design in order to expand the range of possible sounding qualities to combine with any of the *arched conic bellophones*, both having high corporeal expression and very similar shape.

Group VII

		Glis.	Micr.	Tim.	C.E.	Tot.
VII$_a$	Arched Conic Bellophone I (3S)	60	78	59	78	**69**
VII$_b$	Waterfall Gender (Slenthem)	60	78	93	72	76
VII$_c$	Waterfall Clavescrapophone	53	67	56	67	61
VII$_d$	Waterfall Copper Tubaphone	60	89	89	72	78
VII$_e$	Ceramic Arched Tongue boxes	50	67	59	67	61
VII$_f$	Sliding Bird Whistle	90	56	61	56	66
VII$_g$	Sliding Cooperative Arched Ocarina	80	78	61	61	70
VII$_h$	Cooperative Brass SlidingArches (coil)	93	100	74	72	85
VII$_i$	Cooperative Kakkou Slide Whistle	80	78	56	67	70

Fig. 69. Evaluation for the arched layout I group.

2.3.7.4 An assessment of the three stand *arched conic bellophone I* and its group

It is probably the high corporeal expression capability of the *arched conic bellophone I* that makes it remarkable among the (partly due to its arched shape invites several players to play in order to reach comfortably both sides of the instrument, while this also makes it difficult to achieve smooth glissando in comparison with other instruments of the group, suggesting flexibility of curvature in future prototypes.

In terms of pitch, the *arched conic bellophone I* has much better microtonal capabilities than glissando, and it has learnt from the *ceramic arched boxes*, that the adjustment of curvature in the arch adopted can make the instrument adjustable to the number of players that need to perform without compromising sliding properties.

2.3.8 Prototype 8: Arched layouts II, and the *16S conic bellophone* (*arched conic bellophone II*)

The *16S conic bellophone*, or *arched conic bellophone II,* constitutes the final prototype of *conic bellophone* and it was fully built as part of this research project. Posterior prototypes were sketched and proposed, and are extended versions of this prototype.

These second group of arched layouts also try to adopt elements that are transformable into curvilinear and free layouts, as in the case of the *arched conic bellophone II,* which employs stands that can be placed in many different ways, although the semicircle disposition proposed here has been envisaged for the compositional practice, as described on pp. 138-139.

2.3.8.1 The development of the *arched conic bellophone II* prototype

Microphone stands where initially used for holding the *conic bells* in the beginning when acoustical tests were being performed. It was convenient to simply use stands to get the desired layout at this stage and search for a convenient distribution according to the needs of the composition.

In the first performance employing the final prototype of *conic bells* (*spun bells*), each of them was placed onto different musical stands to form a large arch that can be reached with two performers (Fig. 70).

Fig. 70. Rehearsal (from left to right: Lee Ferguson, Petar Curic and the author) using a curvilinear simplified layout of the *conic bells* (for the notes being played).

Later on, as an attempt to have one octave range played by one single performer, the semi-circle layout of the *conic bellophone* was conceived employing 96 bells attached to 16 stands (six bells per stand). Figure 71 was a diagram developed (before the instrument was built) by taking a top view picture of a stand with six bells, and rotating it 11.25 degrees,[104] and 15 times to recreate what a wide view of the *conic bellophone* from the performers eyes would look like. In this case the notation indicated in the diagram was based on the assumption that the lowest ideal bell would be an E. This was the pitch distribution designed for the *hammered conic bells,* and later on with the creation and adoption of the *spun bells* the lowest tone was fixed to the G above middle C (and a minor third above the previous lowest note.

[104] 11.25 degrees is 180/16, which is the 180 degrees of a semicircle divided into the number of stands considered.

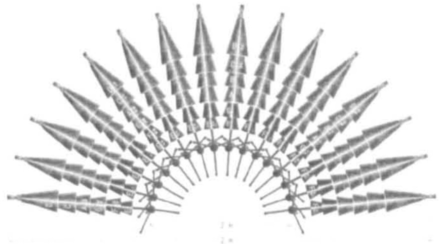


Fig. 71. *Conic bellophone*'s diagram made rotating the picture of one stand 16 times.

The finalised *conic bellophone* in semicircle distribution (Fig. 72) with the *spun conic bells* was considered for compositional practice consolidating this way the usage of the name *conic bellophone* without any further description, strictly for this specific layout, which is was used for performances and seminars as a follow up of the preliminary experimentation with the curvilinear layout.

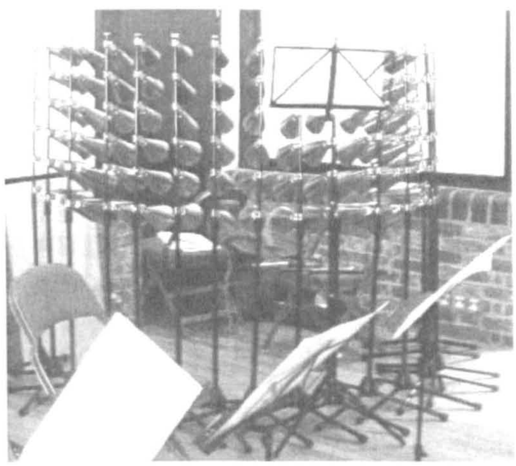


Fig. 72. The completed *conic bellophone* (prototype 8) on the day *Autumn* was premiered.

2.3.8.2 Feedback from the compositional practice for the *16S arched conic bellophone* layout

The work *Improvisatory patterns I* (*Duet*/ Sc. 8/ CD-tk 8/ DVD1-tk 8) was firstly used to experiment with the free arrangement of the stands and in this case using an arched single line with two performers (see above Fig. 70). This experience led to conceiving the stands with several bells from slightly below performer's waist level to slightly above the shoulders, and the semicircle layout using 16 stands covering a tone per horizontal plane considered.

Study No 6 (*Pasacalles*/ Sc. 6/ CD-tk 6/ DVD1-tk 6) was already composed for a similar layout, demanding a range wider than an octave. The *conic bellophone* layout (prototype 8), did not reach the required range by this composition, which was left on stand-by, while

Study No 7 (*Mollienaire*/ Sc. 7/ CD-tk 7/ DVD1-tk 7) was composed for the *conic bellophone* and also ending up with a range larger than an octave and left in stand-by, both expecting future additions to the *conic bellophone*. These two works also suggested having an extended *conic bellophone* prototype to cover a range slightly wider than an octave.

The work *Autumn* (Sc. 10/ CD-tk 10/ DVD1-tk 10) was the first composition completed that while contributing to the design process of this final version of the *conic bellophone* was also able to employ the whole bellophone range without the need to extend it. *Prelude No 1* (Sc. 11/ CD-tk 11/ DVD1-tk 11), was the second and it was written around the same time. It informed the development of the *conic bellophone* and the work *Autumn*. *Prelude No 1*, completed shortly after *Autumn*, explores the limitations of a virtuoso player.

An expansion of the work *Improvisatory patterns II* (*Soleá*),[105] not completed by the time the research was over,[106] has suggested the incorporation of a range extension, and a MIDI-mechanised version with MIDI-pedal controller for the guitarist, so the sixteen stands can be placed around the audience faced by the guitarist.

2.3.8.3 Feedback from the variant conceptual instruments with arched II layout group

The *arched stand-a-matsumushiphone* ($VIII_b$) was the first conceptual instrument employing stands in a semicircle (in this case using with the small high pitched Japanese *matsumushi* gongs, name adopted from a Japanese cricket specie). Tuned in eighthtone steps and originally in arched position to achieve microdiscrete-sliding pitch by means of striking the gongs, it ended up suggesting the semicircle disposition of the stands towards the achievement of microdiscrete-sliding pitch by means of sliding the mallets. This idea was also used to resolve the same problem when playing the *arched conic bellophone I* with one single player. Due to the size of the *conic bells*, fitting 16 stands in a semicircle instead of eight was ideal for the space required, so the performer can easily access both sides of the bellophone. The same problem was resolved with the arched marimba, using semicircle and the five-stand support for the net that holds the *khong wong yaiophone* also

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[105] Duo for *conic bellophone* and Sixteenthtone Guitar (Sc. 9).
[106] Still being drafted.

proposed. The *Carrillo bridge double harp* ($VIII_e$) employs eight double harps units in stands (alternating strings with some angle so the area where the strings meet microdiscrete-sliding pitch in sixteenth tones can be achieved), each of them covering an octave.[107] The resonance of this instrument informs future sympathy string experimentation with the *conic bellophone*, and ways of dealing with strings in the space.

The semicircle layout is also applied to *splashophone* stands ($VIII_f$) and in this case using quartertones, so eight stands are considered covering two tones in a horizontal plane, also providing an idea of how the *conic bellophone* could be laid out in quartertones. The rest of the instruments contribute to provide new instrumentation possibilities, but did not have much influence on the design of the *16S conic bellophone*.

Since a cooling system was thought necessary for maintaining the correct temperature of the *ice drums*, temperature experimentation cooling down *conic bells* was initiated and left open for future possible experimentation.[108] The possibility of making *conic bells* with ice and thicker walls is simply noted for future possible experimentation.

Group VIII

		Glis.	Micr.	Tim.	C.E.	Tot.
$VIII_a$	Arched Conic Bellophone II (16S)	60	78	72	78	**72**
$VIII_b$	Arched Stand-a-matsumushiphone	53	67	94	67	70
$VIII_c$	Arched Marimba (Stand-a-key)	53	44	63	61	55
$VIII_d$	Khong Wong Yaiophone	40	44	78	61	56
$VIII_e$	Carrillo Bridge Double Harp in 8ve stands	90	67	65	72	73
$VIII_f$	Arched Stand-a-splashophone	37	44	46	67	49
$VIII_g$	Arched Coop.Hototogisu Mouth Organ	70	78	59	67	68
$VIII_h$	Double polyphonic sliding oboe (2x2s wtc/key)	80	67	67	50	66
$VIII_i$	Ice Drums	40	33	48	67	47

Fig. 73. Evaluation for the arched layout II group.

2.3.8.4 An assessment of the *arched conic bellophone II* and its group (arched II)

The *arched conic bellophone II* ($VIII_a$) when evaluated stands at the head of the group (Fig. 73), together with $VIII_b$ and $VIII_e$, the arched *stand-a-matsumushiphone* and the

[107] Each stand has a double harp containing two rows crossed, each in eighthtones.

[108] An experiment with the third lowest *conic bell* at cold temperatures (with almost same results between 0°C and -20°C) produced a sound with shorter sustain and brighter quality than at room temperature 25°C. Cold temperatures also lowered the pitch of the hum and prime partials about 5 ¢, while the nominal and tierce raised pitch about the same amount (the interval between the nominal and the tierce raised 12 ¢).

Carrillo bridge double harp respectively. Looking at the main categories, $VIII_e$ has a 90% glissando capability that can compensate the 60% of the *arched conic bellophone II*. Also worth considering the *khong wong yaiophone* for a small ensemble due to its unique soft timbre or the double polyphonic sliding oboe if considering a larger ensemble or orchestra due to its sliding properties and its easily recognised tone quality, which can also be combined with regular oboes.

Apart from suggesting a wide range of possibilities of alternative instrumentation for this final version of the *conic bellophone*, the variant conceptual instruments described as part of group VIII have had a substantial contribution to the design and future considerations of the *conic bellophone*, and also informed group X and particularly the *sopranino conic bellophone*.

2.3.9 Prototype 9: Arched layout III, and the *extended arched conic bellophone*

The pitch range extension of the *conic bellophone* was supported by creating a series of instruments from scratch that were thought of as instruments that covered a wide pitch range so they did not need to be extended. The prospective comparison between the development of *extended arched conic bellophone*, and of these variant conceptual instruments, takes an important role in this group since the concept of MAVMI (MIDI audio-visual musical instrument) was taken into practice. The resulting MAVMI is not included in the thesis due to the involvement of a programmer, but it did provide the evidence required to develop further ideas based on the capabilities of present 3-D MIDI interactive JAVA programming.

2.3.9.1 The development of the *extended arched conic bellophone* prototype

In order to provide an extension option for the *conic bellophone* design, the top part of the microphone stand is adopted (see figs. 74 and 75).

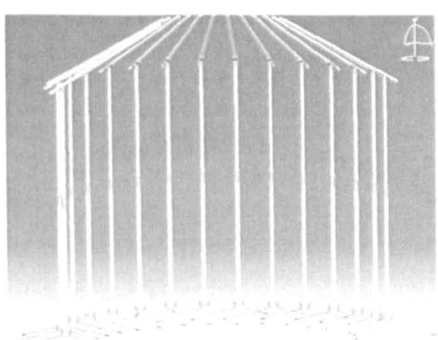


Fig. 74. Front view of the 16 stands.

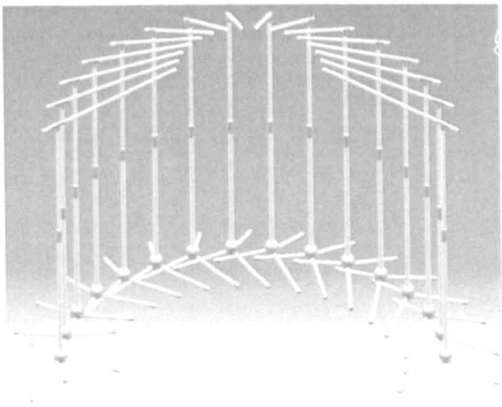


Fig. 75. Another front view of the 16 stands.

This way support is provided for three additional semicircles in a horizontal plane, each of them containing 16 *conic bells* (Fig. 76). An extra tritone is then covered (not including the tritone interval, in a same way than the octave interval was not included in the regular version of the *conic bellophone* with 96 bells). Interlacing the three legs of the stands is possible in most of the microphone stand models when a 2 metres diameter for the semicircle considered ideal (see the semicircle in the top view on Fig. 77). However, if less distance is desired, it is better to have them custom made as indicated in Fig. 76, where a front view of the 3-D model produced and used for the MAVMI version (programmed to be interactive) of the *extended conic bellophone* (Fig. 76), developed outside this research's framework.

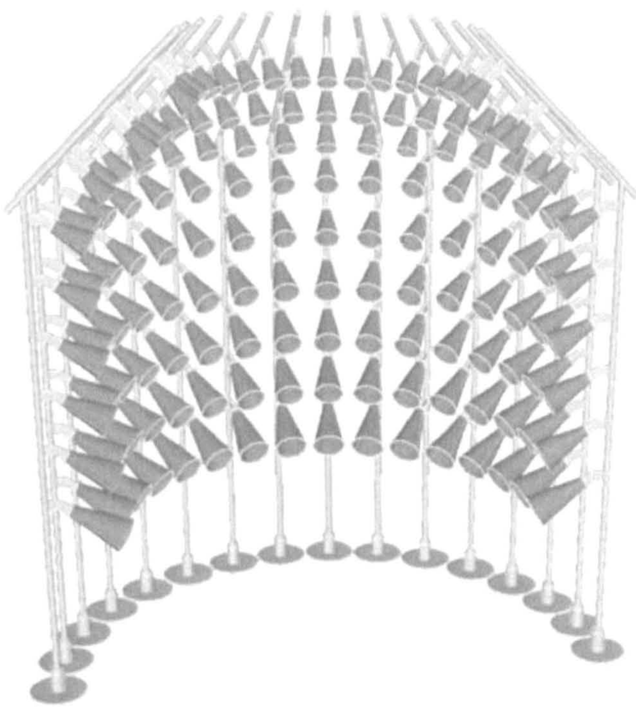


Fig. 76. Player's view of the *extended conic bellophone*

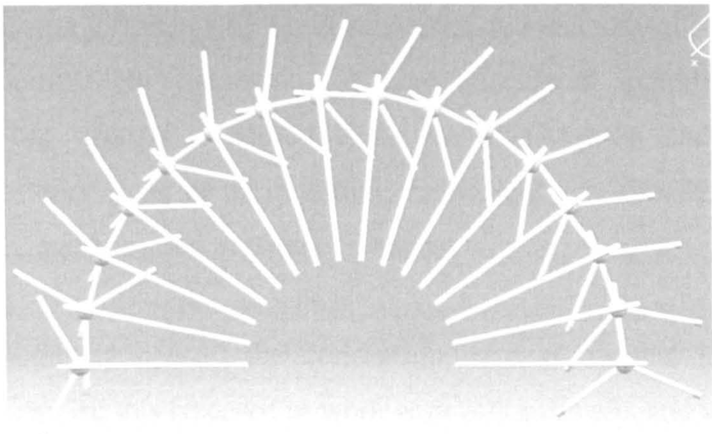


Fig. 77. Top view of the 16 stands interlaced.

2.3.9.2 Feedback from the compositional practice for the *extended arched conic bellophone* and its group

The previously composed works, *Study No* 6 (*Pasacalles* / Sc. 6/ CD-tk 6) and *Study No 7* (*Mollienaire* / Sc. 7/ CD-tk 7), have contributed to the development of the *extended arched conic bellophone*.

The second movement of the composition *Seasons* (Sc. 12) relies fully on this model to explore non-octaval scales requiring more than an octave to prove their nature. This movement also explores the stretched octaves found in the harmonic spectrum of the *spun conic bells*.

2.3.9.3 Feedback from the variant conceptual instruments with *extended arched layout*

Before entering into the details of these group members, it is important to state that at this point in the time-line (2008), the patterns of the methodology proposed in Chapter 1 and the patterns of using creative-comparative designs as part of the instrument development practice (explained earlier in this chapter), started to be recognised, and the empirical approach followed up to this point was to influence the strategies of the research method (Fig. 5, p. 13). At this stage in the research, everything started to get organised into groups, and since the variant conceptual instruments design methodical approach became the guidance, the compositional practice dramatically changed and new instruments were manifested in the creative process of the mind involuntarily when composing. This was partly induced by the conscious process of organising a massive amount of creative design material, and it is a strong reason why being schematic and methodical when involved with instrument development-led composition is here considered important. This whole research process has strongly benefited from this phenomenon and although it was discovered at a posterior stage of the research, the subject was already introduced in the thesis' introduction, and a revised version of Chapter 1.

A need to systematically control the conception of new musical instruments in the compositional process led this research to work with 3-D software, and with a programmer on the devising of a 3-D MIDI virtual model (MAVMI) of the *extended arched conic bellophone* for demonstration purposes. However, this is not considered part of the thesis but indeed proves what the thinking behind stands for.

The *snail jalatarang*, *porcupine marimba*, *arched t'rungophone*, and *sympathy arched sarunayophone* have the potential to be extended several octaves, while the *sympathy bowed octavina*, the *extended portative organ* and the bass 16th-tone Sliding Tuba have a similar range than a piano.

In terms of values (Fig. 78), the *sympathy arched sarunayophone* is the only instrument with higher total value than the *extended arched conic bellophone*, so considering that the corporeal expression is much higher for the *extended arched conic bellophone*, a duo using both instruments could provide a balanced performance and the media to explore a wide range of pitch resources.

Group IX

		Glis.	Micr.	Tim.	C.E.	Tot.
IX_a	Extended Arched Conic Bellophone (16S)	67	78	63	89	74
IX_b	Snail Jalatarang	60	56	81	56	63
IX_c	Porcupine Marimba (ceramic ass.stands)	73	100	67	44	71
IX_d	Arched T'rungophone(ass.stands/cer.res)	50	78	85	61	69
IX_e	Sympathy Bowed Octavina (arched 5s)	80	50	72	50	63
IX_f	Arched Waterslapophone (ass.stands)	50	22	44	72	47
IX_g	Ext.Portative Organ with arch.pipe stands	80	100	74	39	73
IX_h	Bass 16th-tone Sliding Tuba	97	56	72	44	67
IX_i	Sympathy Arched Sarunyaophone (MIDI)	87	100	85	61	83

Fig. 78. Evaluation for the arched layout III group.

2.3.9.4 An assessment of the *arched conic bellophone III* and its group (*arched III*)

This group, being an attempt to extend the design on the *conic bellophone*, has served as a catalyst for the opening of a new conception of the instrument development design by inducing an audio-visual compositional creative process, in which the new instruments are composed with the music in one single creative process rather than separately. leading to the concept of MAVMI as a tool to promote its practice.

MAVMI not only provide a prospective view for the evaluation but also something close to a subjective view since the realism of the simulations can place the instrument development-led composer in a strong and realistic position to judge where one instrument stands among the others.

The *extended arched conic bellophone* has the highest total value if the MIDI instrument is excluded (the *sympathy arched sarunayophone*), which makes it stand as a great tool for the exploration of pitch resources, while still keeping a high corporeal expression, which a MIDI instrument does not have.

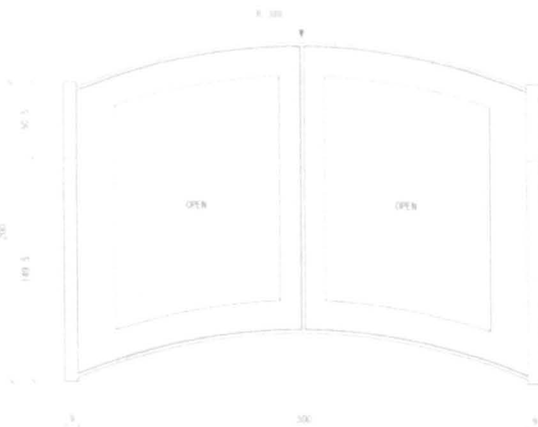
2.3.10 Prototypes 10a and 10b: Other Ranges, the *sopranino conic bellophone* and the *bass conic bellophone*

From this group onwards the work is still in process of experimentation by the completion of this research, which shows the open-ended nature of the method proposed and followed.

By trying to keep the same material, thickness and proportions, the *conic bellophone* could only be extended to almost an octave and a half keeping the integrity of its sound. In order to consider other ranges, material, thickness or proportions, have to be altered, while trying to keep a similar sound.

2.3.10.1 The development of the *sopranino conic bellophone* prototype

In order to reach the higher register of the piano, bronze cones of similar proportions to the *conic bells*, have been considered and placed in a wooden frame (figs. 79 and 80) that holds metal bars going across.



Figs. 79 and 80. Side and top views of the *sopranino conic bellophone*'s frame.

The metal bars hold hammering mechanisms with springs such as those of bicycle bells, so one can pull back the hammer to hit the bell, placed right in front, and soon after recover the position without touching the bell (Fig. 81). The frame was built and the bars placed. The bells could not be cast in time for experimentation but bicycle bells were used to build a preliminary prototype (Fig. 82).

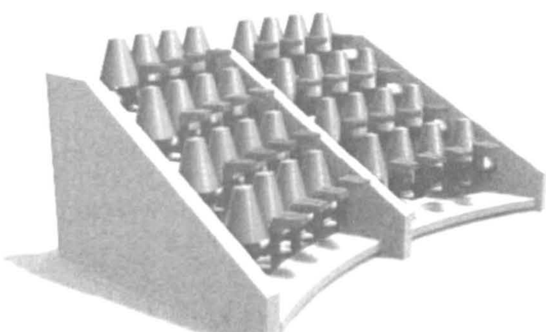


Fig. 81. 3-D representation of the *sop. con. bellophone*.

Fig. 82. Prototype of the *sop. con. bellophone*.

The instrument covers a range of only two tones of range (in sixteenthtones) so there is still a gap between the highest notes of the *extended conic bellophone* and the first notes of the *sopranino conic bellophone*.

2.3.10.2 The development of the *bass conic bellophone* prototype

The only solution to keep so many large *conic bells* in a restricted space was to follow a concentric layout and widening the mouth of the cones, and reducing their height. Using a cylindrical helix as frame is a way to support fast glissando with soft mallets since hard mallets would simply create a very thick sound that would mask at particular point the perception of the glissando itself (Figs. 83 and 84).

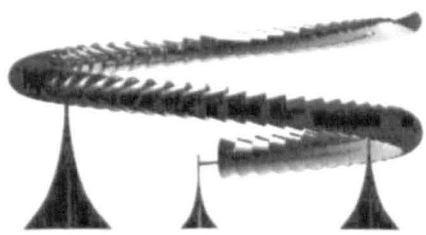


Fig. 83. *Bass conic bellophone*: frontal view.

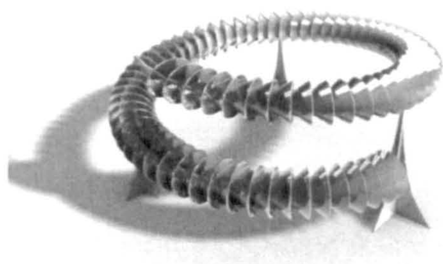


Fig. 84. *Bass conic bellophone*: aerial view.

Since fast microtonal passages also have the danger of masking the sequence, they are not of much use within this range. Slow microtonal passages are achievable in this layout and since fast microtonal passages can barely be appreciated, there is no need to reconsider the layout to favour the microtonal capabilities. This layout also has high corporeal expression, which makes it unique in its group.

2.3.10.3 Feedback from the compositional practice for the *sopranino* and *bass conic bellophones*

The composition *Seasons* (Sc. 12) has a section indicated in the sketch, in which the *sopranino conic bellophone* is meant to have a part (work in progress). Cooling the *conic* *bells* and adding a part for ice drums for this passage is being considered, in both cases to match the staccato and bright sound quality of the *sopranino conic bellophone*.

The *bass conic bellophone* has not still been considered for any composition, but there are still many questions that need to be resolved, such as the ideal thickness of the bells and the ideal angle of the bell (between axis and the bell skirt).

2.3.10.4 Feedback from the variant conceptual instruments in very high or low registers

The *dynamic piano* and *dynamic baton* (X_e), stand with difference in this group from the rest of the instruments in the total value (Fig. 85). Therefore these instruments have been considered for a possible fourth movement of *Seasons* (Sc.12).

The *sopranino* and *bass conic bellophones* (X_a), ought to ideally be combined with instruments that can provide higher glissando capabilities. The *dynamic piano and dynamic baton* (X_e) is an outstanding choice for this purpose, while the *brass sliding organ* (X_h) also provides similar capabilities with a contrasting timbre. The *220-stand bowlophone* can also complement the previously mentioned instruments providing a unique timbre and high corporeal expression. The instruments not mentioned yet from the group have also attractive timbres ideal for specific sound colourings, and should also be considered as possible candidates to combine with instruments of this group.

Group X

		Glis.	Micr.	Tim.	C.E.	Tot.
X_a	Sopranino & Bass Conic Bellophones	57	67	81	61	66
X_b	Rotary Hoyureyophone (high range)	70	50	98	44	66
X_c	Rotary Piccolo block xylophone (kki)	73	28	61	44	52
X_d	220-stand Bowlophone	53	72	87	67	70
X_e	Dynamic piano and dynamic baton	107	100	94	56	89
X_f	Solenoid assisted water streamophone	73	67	54	33	57
X_g	Ahualulco Portative Hototogise Organ	77	100	59	39	69
X_h	Brass Sliding Organ (10-solen.-contr.)	90	94	74	50	77
X_i	Soprano & Bass Marimbaflores	43	44	69	61	54

Fig. 85. Evaluation for the other ranges group.

2.3.10.5 An assessment of the *sopranino* and *bass conic bellophones* and their group

The *sopranino* and *bass conic bellophones* have been evaluated as one single instrument (X_a). Most of the instruments in the group have higher values for glissandi than X_a, and half of them have better microtonal capabilities, considering that the timbre value of X_a is third in the group, and since having the appropriate timbre was the main priority, this group can be considered to provide a positive prospective view of X_a. In order to balance the low values (Fig. 85) X_a can combine with a variety of instruments within the group.

2.3.11 Prototype 11: The *mechanic extended conic bellophone*

Mechanised instruments have more visual impact and consequently more corporeal expression when their mechanisms are shown to the audience and effectively distributed in the space, as if they were choreographed. Having flexibility of distribution in the space once the instrument has been built, potentially provides more corporeal expression. An effective combination of parts for mechanised elements of the instrument and parts played by performers, is also considered to increase the overall corporeal expression.

2.3.11.1 The development of the *mechanic extended conic bellophone* prototype

The *extended conic bellophone's* MAVMI (MIDI audio-visual musical instrument) version simulates with 3-D graphics what the mechanised instrument can do also using a MIDI file with the score data. Therefore making a MAVMI can be considered a way to prepare MIDI files while obtaining audio-visual feedback, and while building the mechanised system to play the instruments, so by the time the construction is finished the MIDI files are ready and have been virtually reviewed.

2.3.11.2 Compositional ideas to explore with the *mechanic extended conic bellophone*

A MIDI-mechanised version of the *extended conic bellophone* has the potential to achieve complex rhythms, simultaneous tempi and dynamic tempo, as well as dynamic pitch, microtonality, dynamic volumes, and dynamic spatial projection. These ideas could be explored in a future expansion of the work *Seasons* (a fourth movement) and in a further development of the work *Improvisatory patterns II* (*Soleá*, Sc. 9), by means of MIDI controller to interact with the tempo of the sequencer, which is attached to the MIDI-mechanised playing system.

Using a MIDI-mechanised instrument on a live performance reduces corporeal expression to the actual movement of the mechanised beaters. By incorporating a MIDI controller (e.g. controlling tempo when playing with other performers) involving additional corporeal expression from the performer's perspective, implements its visual impact on the audience.

2.3.11.3 Feedback from the variant conceptual mechanised instruments

A lot of work and cost seems to be involved in the development of most of the instruments here referred to, and virtual realisations might help raise funds to support such projects while allowing cost free experimentation.

The group for prototype 11 (see Fig. 86), is characterised by a very steady glissando capability, varying from 80-97% and an extremely high value for the microtonal capabilities of four instruments (XI_a, XI_b, XI_c and XI_i), which also have unique timbres of a metallic nature. From those four instruments, the *mechanic 1200ET boncaphone* seems to have the best corporeal expression (see Glossary) potential since it can be played by many performers and by a mechanised system. This instrument is ideal to explore pitch resources at the very limits and can be considered an ideal solo instrument for an orchestra. The *mechanic extended conic bellophone* is the second of this group in terms of corporeal expression, so it still has a great value for each of the main aspects considered. If the *mechanic extended conic bellophone* requires some additional corporeal expression combined with instruments from this group, an ideal choice would be the *mechanic water splashophone* in a full range and distributed along the performance space. This *splashophone* has the potential to add an unlimited number of players and many addition and also unique sounds by incorporating tapping-blowing, buzzing and bubbling, to the splashing sound.

Group XI

		Glis.	Micr.	Tim.	C.E.	Tot.
XI_a	Mechanic Extended Conic Bellophone	93	100	81	78	88
XI_b	Mechanic Pyramid Carillon	87	100	98	56	85
XI_c	Mechanic 1200ET Boncaphone	87	100	87	94	92
XI_d	Mechanic Gongophone & keyboard	73	56	81	56	66
XI_e	Mechanic Spiral Rotary Harp	83	56	63	61	66
XI_f	Mech. Waterslapophone (Full r./additls)	93	78	59	83	78
XI_g	Mechanic Sliding Ocarinophone (10sl/ocs)	93	94	65	56	77
XI_h	Mechanic Sliding Clarinetophone (soled.ped.)	97	89	72	44	76
XI_i	Mechanic 440-Stand Bowlophone (Cont.Keyb.)	80	117	93	67	89

Fig. 86. Evaluation for the mechanised layout group.

2.3.11.4 An assessment the *mechanic extended conic bellophone* and its group

Considered aspects of corporeal expression directly related to the mechanisms used to play computer MIDI files, requires reconceiving corporeal expression. This has been done so the visual aspect of the performance relates also to the movement of the sound activators and their distribution, bringing a new dimension to the way the performance is perceived.

The *mechanic extended bellophone* and its group are all mechanised-MIDI instruments not aiming to substitute the performer but to play additional parts humanly impossible to play. For that purpose, the performer can also be involved in the playing of a tempo controller (or any other MIDI controller for a different parameter). The *mechanic extended conic bellophone* stands as an ideal instrument for ensemble work in 96-et, while the *1200ET boncaphone* as an ideal solo polymicrotonal orchestral instrument. The rest of the instruments from the group provide a wide range of timbral properties, while still keeping a top of the range microtonal and sliding pitch capabilities.

The group in general could be improved by incorporating some interaction between the players and the instruments, or between the conductor and the instruments, when being sound with a mechanised system, which is what leads into a study of MIDI controllers within the next group.

2.3.12 Prototype 12: MIDI controllers for the *mechanic extended conic bellophone*

The mechanised-MIDI instrument's lack of human interaction can be can be avoided by employing a MIDI controller as an interface between the performer's movement and the instrument. This increases the expression potential of the instrument, and allows an exploration of gradual changes in time of the parameters considered.

2.3.12.1 MIDI tempo controllers and *dynamic baton*

The *dynamic baton* (MIDI tempo-controller) together with the *dynamic piano* (8 MIDI pianos a sixteenthtone apart from each other distributed around a space) was already proposed as an instrument of group X, so the conductor could have dynamic control of the tempo at which the MIDI file was playing the 8 pianos with a slider MIDI controller installed in the baton and attached to the sequencer. As an alternative, a performer could be placed among the orchestra (or ensemble) using a turntable MIDI tempo-controller application on a tablet display or a MIDI-pedal controller, linked to the sequencer application that plays the MIDI file and controls the instrument.

If the composition does not require a conductor, a MIDI pedal controller (set to control tempo) can be used by a performer whether the hands are engaged or not in the performance. This idea has been taken as part of the compositional practice.

These ideas can be implemented to devise MIDI controllers of other parameters with dynamic potential (*PADTS* parameters, see Abbreviations).

2.3.12.2 Feedback from the compositional sketching and ideas using MIDI controllers

The *mechanic extended conic bellophone* with *dynamic baton* allows the conductor to control the tempo of the computer application playing the MIDI file to sound the 8 pianos.

As previously mentioned, extending the work *Seasons* (Sc. 12), would be an ideal way to incorporate the *mechanic extended conic bellophone* and future research on *PADTS* parameters other than pitch. At this point, a mechanised version of the Chinese opera gongs could be included with other mechanised instruments from this group all linked to a *dynamic baton*.

Using a MIDI pedal controller for tempo was urged by the need to incorporate dynamic tempo for an expansion of the work *Improvisatory patterns II*, initially sketched for 96-et guitar and *conic bellophone*.[109] This work is still at an early stage and the experimentation between the design and the compositional practice has not started yet. *Improvisatory patterns II* (*Soleá*) will be the introductory part of the composition, and has been performed live since it does not use dynamic tempo (DVD1-tks 9, 14/ CD-tks 9, 14). This has provided some clues about how both instruments can be balanced between each other and about what would be expected from the MIDI pedal controller.

[109] Draft in progress at an early stage, therefore not included here.

2.3.12.3 Feedback from the variant conceptual instruments using MIDI controllers

Considering the MIDI controller together with the sequencer and the MIDI instrument all one instrument (and the space considered when applicable), the two highest values are found in the *MIDI extended conic bellophone* with tempo pedal controller, and the *Snowdome* with MIDI controlled *umbrella-chime system*. The *Snowdome*, being a spherical auditorium, would naturally amplify the sound of the *MIDI extended conic bellophone* being played in the centre of the dome, and the *umbrella chime system* distributed around the ceiling to provide spatial projection of the sound would also offer an interesting timbral contrast with the sound of the chimes and the additional capability to transform the shape of the ceiling and its acoustical properties. One performer could control the tempo of these two instruments with a MIDI pedal while playing a solo instrument. This idea is applied to the expansion of *Improvisatory patterns II* (*Soleá,* Sc. 9) being drafted, and could be used for any similar idea requiring one single performer. So as to raise the level of corporeal expression the tapping of a Flamenco dancer could be incorporated. Another consideration could be the use of *rotary harps* with *matraca MIDI controller*, since this instrument has the highest value for corporeal expression from this group (Fig. 87).

Group XII

		Glis.	Micr.	Tim.	C.E.	Tot.
XII_a	MIDI Ext. C.Bell. Pedal tempo controller	93	100	81	50	81
XII_b	Sld.Kalimba finger blockphn.contr&metal adder	93	67	72	44	69
XII_c	Octopentag. MIDI contr. for 1200ET	77	83	93	50	76
XII_d	MIDI Matraca controller for rotary harps	93	33	89	83	75
XII_e	Linear Kalimba Contr. for Harps.192ET	87	89	85	44	76
XII_f	MIDI hydroacoustic controller	80	56	59	56	63
XII_g	MIDI sliding lastrophone controller	80	33	48	44	51
XII_h	MIDI sliding 96ET Ahual.chromelod.contr.	87	100	67	44	74
XII_i	Snowdome's MIDI Umbrella Chime Controller	103	100	96	56	89

Fig. 87. Evaluation scheme for the MIDI controller group.

2.3.12.4 An assessment of the *conic bellophone*'s MIDI controllers and its group

A MIDI pedal set to control tempo, as well as the *dynamic baton* seem to offer corporeal expression capabilities and have the potential to be used with most of MIDI-mechanised instruments.

Each component of this group consists of a mechanised instrument (or its mechanised version if not specified) with an ideal MIDI controller. In the nine cases presented a full range of capabilities has been considered, so a different combination of instruments within the same group (or combining from different groups) can be considered according to the needs of the instrument development-led composer.

A MIDI-pedal controller and the *MIDI extended conic bellophone* compared with the other instruments of the group shows superiority together with the *Snowdome* with *MIDI chime umbrellas* for all the aspects considered apart from corporeal expression due to the replacement of the performer for the mechanised playing system.

2.3.13 Prototype 13: Portability, ergonomics and the *compact extended conic bellophone*

Making the instrument not only compact but also portable is the main goal of this prototype's design, although additional resonating bodies that are easy to incorporate into the new frame are also introduced.

2.3.13.1 The development of the *compact extended conic bellophone* prototype

The *compact extended conic bellophone* has been envisaged with a cylindrical base for each of the sixteen poles replacing the microphone stands. These are conceived touching each other to contribute to the stability of the frame. The cylindrical shape is ideal for considering placing them forming different shapes than a semicircle (in aerial view), from a circle to a wider arch. This flexibility makes the instrument ideal for exhibitions requiring unique spaces or simply for the achievement of a more stylish form. Changing the semicircle disposition of the poles makes it difficult for performer to locate the notes, but since this prototype incorporates the mechanised system, the composition could incorporate a mechanised-system part and a performer part for this purpose.

Each cylindrical base is conceived as a bag that takes shape when filled with water. So as to keep the poles approximately at the same distance from each that the distance used for the *16S conic bellophone* (that in aerial view makes a semicircle with 2 metres diameter), the diameter of the cylindrical base should be about 20 cm diameter, with a hole where the pole fits, following the axis of the cylinder. The height of the bags would have to be determined by experimentation to keep the stability of the instrument. Extra support would be achieved attaching neighbour poles to each other with bars, but light metal and clamp systems for fast assembly would be mostly desired. An alternative would be finding a way to keep neighbour bags tight close to each other.

These water bags would make the instrument safe for children in exhibitions where the audience is invited to play the instrument. The bags would be emptied when travelling, substantially reducing the weight of the instrument.

This prototype could also incorporate attached metal bottles to the poles slightly above the bags, attached to the stands, so by placing a small amount of water inside of them, the vibration of the bell can be transmitted to the bottles through the poles and produce a vibrating waterphone-like effect when the *conic bells* are bowed, since the poles can easily be bounced when bowing.

Experimentation with sympathy strings could be initiated figuring out where to place both ends of a metal string (with tuning pegs for fine pitch adjustment) for each *conic bell* within the pole where they are attached, so the vibration is transmitted from the bell to the string, through the joint or pole. Each sympathy string would have to be tuned ideally to the same frequency than the corresponding bell.

2.3.13.2 Feedback from the compositional sketching and ideas for the *compact extended conic bellophone*

These ideas of adding water and sympathy strings are considered at this point (and also by the time the research was completed) an experimental possibility for a future additional movement of the work *Seasons* exploring particular elements of the nature (in this case wind and water) in interaction with the *conic bellophone*.

Additional features for the *conic bellophone* are inspired by the theme the work in progress *Seasons*, and it is expected that the sound that these features will inform and inspire the composition.

2.3.13.3 Feedback from the variant conceptual instruments with *compact extended layout*

The variant conceptual instruments of this group are large-scale, stand-alone ideas or environments to accompany a solo instrument, which were strategically planned since there would be more to learn from making compact a large-scale instrument, or from large sets of independent sounding bodies. The only exception is a large ceramic lute without frets and with water in the inner cavities, conceived as a visualisation during a composing exercise. Since the instrument was not compact, a compact version was designed, in this case resembling the South Indian fretless sliding *vina* called *chitara vina* (also named *guttuvadyam*). We are referring here to the *compact ceramic water chitaravina* or $XIII_e$ (see values in Fig. 88).

The instrument $XIII_i$ is a MIDI-mechanised water musical instrument ensemble (named dynamic MIDI water environment but also referred to as *aquacoustic park*) envisaged with an additional MIDI-mechanised carillon. The *aquacoustic park* on its own gets the highest total value followed by the *MIDI weather bell tower*, which is followed by the *compact extended conic bellophone* here evaluated with MIDI mechanism and dynamic MIDI tempo controller, reducing its value for corporeal expression.

Group XIII

		Glis.	Micr.	Tim.	C.E.	Tot.
$XIII_a$	Compact Extended Conic Bellophone	87	100	81	67	**84**
$XIII_b$	MIDI Weather Bell Tower	93	100	94	67	89
$XIII_c$	Compact Square Buzzing Marimba	67	100	63	61	73
$XIII_d$	MIDI Chime Tree Pyramid	87	100	96	67	87
$XIII_e$	Compact Ceramic Water Cithraveena	67	67	69	50	63
$XIII_f$	Comp.MIDI Tap Ceram. 24-edo Caterpillar	87	44	54	89	68
$XIII_g$	Cer.8sld.-Panpipe&10sld.key-96locks960-edo	100	117	54	61	83
$XIII_h$	Reed Cer.Ahualulco Chromel. adj.96-9600-edo	80	106	70	44	75
$XIII_i$	Dyn.MIDI water envir.& chorus/ens .water bell-pagoda	100	100	80	117	99

Fig. 88. Evaluation for the *compact extended conic bellophone*'s group.

2.3.13.4 An assessment of the *compact extended conic bellophone* and its group

The lack of corporeal expression capability of the *MIDI extended conic bellophone* with *dynamic tempo controller* would be substantially enhanced if performing in the *aquacoustic park* proposed ($XIII_i$), which has a corporeal expression capability evaluation of 117%.

This group has exceptional values for glissando and microtonal capabilities suggesting the incorporation of resonating water trays into the *conic bellophone* design, plus other ideas, which are developed within the next group.

The diversity of corporeal expression and timbre found in the group can easily be balanced by choosing the instruments (or sets of instruments) within this group at least.

Outdoor spaces and unusual auditorium spaces are envisaged by the instruments treated in this prototype group, such as a bell tower environment, a park environment, etc., which opens the scope of what mechanised instruments are capable of, inspiring also the future possibilities of the *conic bellophone* concept, and its derived ideas.

2.3.14 Prototype 14: *PADTS* parameters and additional resonating bodies: The *compact extended conic bellophone with resonators*

Additional resonating bodies are envisaged within this group as an additional characteristic that instruments could have incorporated if not conceived like that from the beginning. In some cases, this is done to amplify the sound, and in others and in others to transform the sound envelop or to emphasise a particular timbre or frequency in the spectrum of the sounding body. This is also a good occasion to explore dynamicism and microdiscretism through *PADTS* parameters (see pp. 216-219) and how they fit into this research based on the first of the *PADTS* parameters, pitch, since the additional resonating bodies already deal with three of the parameters: pitch, amplitude and timbre. Dynamic meter and dynamic sound projection have been suggested already, and particularly with the *dynamic piano* with *dynamic baton*. Here, they are again treated considering two additional designs for each parameter, in the same way that is done with amplitude and timbre. Pitch is kept for the new additions to the *conic bellophone* considered, resonators and buzzing membranes.

2.3.14.1 The development of the compact extended conic bellophone with resonators

Harry Partch attached bells to the mouth of gourds to develop his Bell Tree. This idea can be extended, by placing buzzing membranes in the resonators as it is done in the traditional marimbas from Guatemala. This is done by making a small hole and placing a ring of black bee wax where the membrane is placed (in this case a paper made by drying the skin of the pig's intestine with salt, as I was taught by an marimba maker in Guatemala).

Resonators would totally change the visual aesthetics of the instrument and substantially its sounding quality. If the resonators were designed as an optional way of playing the *conic bellophone* then the instrument's integrity would not change since it would be considered an extended sound or option such as the different mutes for a brass instrument. Therefore it is preferred to devise a system of resonators that can amplify the sound of the *conic bells* (without substantially changing it), with the purpose of gaining volume so they can be played in a full size Western orchestra rather than on an ensemble as they were employed and used up to this point.

The work has not been initiated but experiments need to be conducted amplifying the mouth of the bell, which gets the highest vibration, especially inside the mouth rather than outside.

2.3.14.2 Compositional practice ideas to consider for the *compact extended conic bellophone with resonators*

There would be a lot of experimental work to be done before considering starting compositional projects in which the *conic bellophone* is with a full spectrum of *PADTS* parameters, but it is likely that the instrument becomes difficult to play after incorporating resonators and therefore it is likely to be simply a MIDI-mechanised instrument that is played with *dynamic baton*, the Western orchestra being a first consideration, but other large ensembles and orchestras, such as a traditional Chinese could also be considered, if not an orchestra employing a selection of the instruments proposed within this research.

2.3.14.3 Feedback from variant conceptual instruments exploring *PADTS* parameters and additional resonating cavities

The variant conceptual instruments aiming the exploration of gradated timbre employ sympathy string regulators and buzzing membrane regulators, which are also proposed as additional resonating bodies for the *conic bellophone*.

Gradated mouths for resonators of percussion instruments and a gradated prepared MIDI piano are concepts that can be used to explore changes of amplitude and timbre (specially when these are conceived gradually). A MIDI-based mechanised system has already been proposed for the *conic bellophone* although gradated mouths for resonators can be borrowed upon success on a future experimentation with instrument XIV_d.

The use of a pressure-based *dynamic baton* is implied with the two instruments exploring tempo (XIV_e, XIV_f), which also inform the last *conic bellophone* prototype suggesting an additional tapping action on the mouth of the resonators to get extra plosive sound, and the usage of compressed air inside the bells (for effect) or inside the resonators (which could have string inside, probably in diagonal and tuned to the corresponding note).

The exploration of spatial projection has been envisaged by placing the *conic bellophone*'s stands around the performance space.

The values (Fig. 89) place the *arched MIDI sarunayophone* with regulated sympathy strings on the head of the group with 89% but considering that this percentage is followed by one 86% and three 84%s (which includes the XIV_a) and the other four instruments slightly lower, it can be said that the total results are very similar as it also happens with the glissando capability. The other three main categories have a wider range of values, which makes the microtonality be the factor to consider when looking for a balanced instrumentation as part of an the exploration of pitch resources.

Group XIV

			Glis.	Micr.	Tim	C.E.	Tot.
XIV_a	Pitch	Comp. Ext. Conic Bellphone & Resonators	87	100	81	67	**84**
XIV_b	Timbre	Arched MIDI sarunayophone.&regul.symp.	93	100	94	67	89
XIV_c		Bell tecomate tree & grad.buzzing membr.	67	100	63	61	73
XIV_d	Amplitude	Al..MI.Tubaphone with grad.Resonators	87	100	96	67	87
XIV_e		Buzzing-Symp-stop.regul.prepared MIDI piano	67	67	69	50	63
XIV_f	Tempo	Presure-sensor-D.Baton &Tim.Tap.Forest	87	44	54	89	68
XIV_g		Compressed Air Aeolic Harp (with d.baton PATT)	100	111	63	61	84
XIV_h	Spat Proj	MIDI Spatial Oboe with bell clappers C.B.	80	106	85	67	84
XIV_i		Giant Mercury Sympathy Harp	90	56	81	117	86

Fig. 89. Evaluation for the *PADTS* parameters and *resonators* group.

2.3.14.4 An assessment of the compact extended conic bellophone with resonators and its group

The *mechanic extended conic bellophone* with *dynamic baton* and resonators has been considered to have the potential to achieve a full range of dynamic *PADTS* parameters, since it has looked into pitch in depth already; the amplitude and tempo can be regulated with a MIDI-controller linked a sequencer; the timbre can be transformed according to the striker and area where the cone is struck; and the spatial projection can be achieved by distributing the 16 stands throughout the performance area.

In order to have the ideal instruments to explore dynamic and *microdiscrete PADTS* parameters other than pitch (amplitude, duration, timbre and spatial projection), similar parallel research should be conducted in the four *PADTS* parameters mentioned, but for the moment this group has been an introduction to the new four directions left to be pioneered, as an expansion of the work of this research.

Chapter Three: Compositions for the bellophone

This chapter explains how microtonality and sliding pitch were used in my compositional practice, with references to the simultaneous development of the *conic bellophone*. The works in the composition portfolio submitted herewith (Volume II) are based on the research set out in Chapter 1 and are inextricably linked to the prototypes of the *conic bellophone* accounted for in Chapter 2.

3.1 Compositional Aims

The corpus of compositional output of this research aims to scrutinise and materialise the study of microtonality and sliding pitch accomplished in Chapter 1, with the support of a parallel instrument development process (detailed in Ch. 2). For this reason, a tuning system with very small steps was initially desired, in order to allow for the realisation of polymicrotonality and microdiscrete-sliding pitch (see Glossary). The steps of the tuning initially envisaged were ideally to be of equal size, in order to allow for smooth micro discrete-sliding pitch progressions. These ideas were incorporated into the development of a new musical instrument, tuned to the 96-et and designed in parallel with the compositional process: the *conic bellophone.*

Possible techniques for performance using the different prototypes of the new instrument were explored – through composition and in collaboration with players – and assessed in relation to variant conceptual instruments for each prototype. This was achieved mainly by composing a series of studies for the several prototypes of the instrument. Each of the prototypes developed addressed the exploration of a specific performance technique; the trials of each prototype served to inform successive prototypes until the final version was envisaged and developed.

These material and musical developments had a bearing on how the music needed to be notated for each specific case. Hence, several different types of notation were considered, each being tested with performers who collaborated in the choice of the most suitable notation for each piece and form of the instrument. In practice, the proposed extended Stein-Couper notation (pp. 54-58) was adopted for ensemble score writing. This is due to its simplicity and the fact that it respects and expands the standard quartertone notation used in contemporary music (p. 54).

In general, the compositional practice herewith described is part of an instrument-development-led strategy that was implemented in order to produce an effective exploration of microtonality and microdiscrete-sliding pitch and – occasionally – of precise guided sliding-pitch contours.

3.2 Compositional approaches

The pieces in the composition portfolio submitted herewith were composed either exploring a sequence-based structure or a specific performance technique. The studies were composed to achieve the function of exploring techniques in an improvisatory style, while the ensemble works were thoroughly structured. Moreover, the studies were composed simultaneously with the development of the *conic bellophone* (including its prototypes and conceptual variants), and in parallel with the other compositions. The reprocessing of completed works and compositional materials was firstly employed at a small scale by drafting a melodic motive for solo *conic bellophone*, and later on by developing the material into a prelude. This strategy was then utilised at a larger scale in an ensemble composition of over 6 minutes that was thereafter developed into a ensemble composition in three movements of approximately 30 minutes, including the initial ensemble piece (with minor modifications) as its first movement. In both ensemble works, the 96-et has been employed to play non-octaval scales and to simulate sliding pitches, while also fitting into a main structure of the twelve pitch classes of 12-et.

For the ensemble composition *Autumn* (and the extended work-in-progress developed from it, *Seasons*), a sequence following the pattern of the numbers 1-3-4 is used to organise not only the pitch classes but also durations. The multi-movement sketch extending the ensemble composition has a central movement in which the bellophone takes the leading part in a quasi-improvisatory style, and a final movement with a scheme of internal microstructures.

The other portfolio of compositions consists of pieces written in an improvisatory style, since their focus is on the exploration of possible performance techniques with each form of the instrument. This second portfolio was made of seven studies, plus *Prelude No 1*; the prelude combines a wide range of techniques and requires a certain degree of virtuosity.

3.3 Compositions

The compositional techniques and processes used in the works for the *conic bellophone* are explained in this section. The scores referred to are included in Volume II.[110] The attached DVD1 and CD contain audio-visual and audio documentation respectively, related to these scores (performances and simulations) and to the *conic bellophone*,[111] while DVD2 contains *conic bellophone* technique and *conic bells* tuning demonstrations.

3.3.1 Works for the solo bellophone (2003-2009)

These pieces include most of the complete solo works composed for bellophone using one or two players between 2003 and 2009. Although they were originally written for various 96-et bellophone prototypes developed during this research, all of these compositions are also playable on the finalised *conic bellophone* (prototype 8).

3.3.1.1 *Prelude No 1* (2003 and 2009) (Sc. 11/ CD-tk 11/ DVD1-tk 11)

This composition started in 2003 at the initial stage of this research, in which the melodic subject was drafted using *hammered conic bells* for the *spiral conic bellophone* (pp. 116-119). Since these bells have a long sustain, they do not work well for fast microtonal passages. The spiral disposition of the bells also does not favour a fast location and execution of microtones. Consequently, the composition was left aside for a few years. The piece was completed in 2009, at the final stages of this research, when the arched conic bellophone II (prototype 8) was already built (pp. 136-141). This prototype allows fast location and execution of microtones, incorporating *spun conic bells*, which have shorter sustain than the *hammered conic bells*. The draft of the melodic subject was kept aside for over five years until new techniques to play the *conic bells* were developed and the ideal *conic bellophone* layout to support them was concluded, so this material could be developed into the composition.

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110 The scores are represented in the thesis by 'Sc.' followed by a number relating to their order in Volume II.
111 Track numbers of DVD1 and CD (recordings of performances and realisations of the compositions here presented), are referred to as 'DVD1-tk' and 'CD-tk' respectively, followed by the track number.

This melodic sketch was taken from an improvisation with the first *conic bells* using a non-octaval 5-equal-step scale within the 96-et. Since an interval of forty sixteenthtones matches the perfect fourth, the tuning can also be named the 8-equal division of the perfect fourth,[112] and the initial melodic sketch was saved under the title *Tune for the 8-equal division of the tempered fourth,* both in extended Stein-Couper notation (In Fig. 90 transposed a fifth above to match the range of the *spun conic bells)* and in Carrillo's *Sonido 13* notation (in Fig. 91, in its original form for the range of *hammered conic bells*).

Fig. 90. *Tune for the 8-equal division of the tempered fourth* (in extended Stein-Couper notation, transposed).

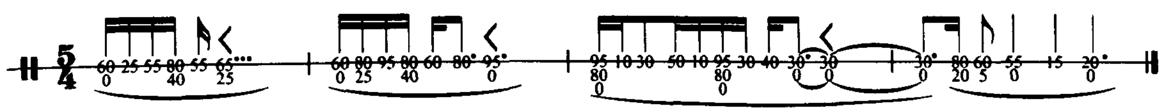

Fig. 91. *Tune for the 8-equal division of the tempered fourth* (in Carrillo's *Sonido 13* notation).

The perfect fourth in 12-et contains 5 equal semitones steps. If the perfect fourth is subdivided into 8-equal steps and steps of that size are extended to form a scale, the octave is never reached. This melodic sketch was the first compositional material produced for cone-shaped bells, and particularly for the second prototype of bellophone considered (p. 120-121). These bells were made by hammering and welding metal sheets to form the cones. The irregularity of this process and the 2 mm thickness of the mild steel brings richness to the spectrum of these bells, while intervals that normally imply dissonance, are not perceived as such, as for example the one-sixteenthtone-flat octave (1187.5 ¢) at the end of bar 2, and the quartertone-sharp second at the end of the sketch (250 ¢) (Figs. 90 and 91). It is striking and noteworthy that the same level of consonance is found between the 15-sixteenthtones-sharp second sustained at the end of bar 3 (387.5 ¢),[113] which is only 1.2 ¢ above a just intonation pure major third (ratio 5/4, 386.3 ¢), and the previously mentioned intervals that were expected to sound dissonant.

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[112] Since eight times five sixteenthtone steps makes an interval of forty sixteenthtones.

[113] Notice that flats are here avoided in the previously proposed extended Stein-Couper notation (and throughout this research) to ease the sight-reading process. Although in this case referring to a sixteenthtone-flat major third would have been more logical, the trend is kept firm to bring homogenity to the text in parallel to the scores.

Having realised that the initial spiral disposition of the bells was far from efficient to explore melodic passages at a speed faster than that of the original melodic subject, the prototypes that followed tried to find a balance between micro-intervallic capabilities and microdiscrete-sliding pitch capabilities, so all notes were equally accessible while still being able to produce sliding pitch by sliding the mallets.

The perception of *Tune for the 8-equal division of the tempered fourth* as part of *Prelude No 1* for the finalised *arched conic bellophone II* (with sixteen stands), is very different than in its original form. *Prelude No 1* was elaborated with an improvisatory style involving virtuoso technique before and after a slow climax passage. This climax is the *Tune for the 8-equal division of the tempered fourth* which brings a slow and thoughtful moment of peace to the work, ideal for the listener to appreciate the microtones sounded with the final model of *conic bells*, the *spun conic bells*. The work resolves moving back to a concluding section, which is a variation of the opening section, back to the opening tempo. Considering that the tone quality of the early melodic material changed appreciably when *hammered bells* were substituted by *spun thick bells* (see Glossary), the opening of *Prelude No 1* was composed inspired by the impression of listening to the early material played with the new bells, and therefore loyal to their sound.

3.3.1.2 *Studies* (1-7) (2004-2006) (Scs 2-8/ CD-tks 2-7)

Each of these studies was written focussing on one technical aspect of the bellophone performance technique. In some cases, the techniques were defined by the prototype developed while writing each study; in other cases, however, the layout of the prototype was designed with the technique envisaged.

The studies were written in parallel with the ensemble work *Autumn*. These studies were either performed or simulated (with sound samples on a sequencer) as they were being composed, and before finishing composing the work *Autumn*. Through feedback from players and auditory experience, these studies interacted with the development of several prototypes of the *conic bellophone*, and with the composing process of *Autumn*. The last one was accomplished by making available a wider range of techniques and sounds for the bellophone part.

(1) *Study No 1. One row study* (2004) (Sc. 1/ CD-tks 1, 12, 13/ DVD1-tks 1, 12, 13)

The purpose of this study is to practice zigzag movements by striking contiguous notes across a single row of *conic bells*, and gradually widening or reducing the span (pitch range) of the zigzag, so as to produce swift transitions between pitch vibrato and sliding effects. For example, the piece starts with a roll over one bell and then moves into a trill between two contiguous notes, producing a fast vibrato, which turns slower by moving to 3 and 4 notes zigzag, so by the time 5 notes or more are used, as the piece progresses, the sound is not perceived as vibrato but as a sliding pitch according to a zigzag movement. From the didactic point of view, this piece serves to reinforce technique and precision of execution through rapid playing of contiguous notes.

The study was originally composed for the third bellophone prototype, the *trapezoidal conic bellophone* (pp. 122-124), which still used *hammered bells*, although it can be played in the same way as any of the earlier prototypes using sixteen-bell rows (all of them designed to accommodate *spun bells*). The distinctive higher overtone, of the lower-pitched *hammered bells* (when played with soft mallets, as intended here), which is perceived distinctly from the fundamental, produces, when playing a rapid sequence of contiguous notes, a high sliding tone which may be compared in its effect to the sound of a flute. This remarkable effect is less noticeable in the higher-pitched rows of bells, but due to its pedagogical value, the study is transposable to other rows for practice purpose, so as to develop this technique in different horizontal planes. The study can be played in each single row to establish familiarity with the position of the bells in space, which has been found to be especially important with the rows that are at the most difficult angles for the player. Playing this study in each row can also be used to check that every bell has been adjusted to the correct angle, and that none of them is loose. *Study No 1 (One row study)* was performed in the March 2007 performances at the UKM2 Festival,[114] and at the MAN symposium.[115]

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[114] Second UK Microfest, 3 March 2007 (program included in Appx 4).

[115] EPSRC Musical Acoustics Network Symposium on Tunings and New Musical Instruments, London Metropolitan University, 5 March 2007.

(2) *Study 2. Chess study* (2004) (Sc. 2/ CD-tk 2/ DVD1-tk 2)

The original purpose of this study was to check the positioning of the bells for the *square conic bellophone* (pp. 124-127) while warming up for performance. This can be achieved by sight-reading the score, since the layout of this prototype is designed for that purpose. It has the compositional aim that all of the bells have to be played one by one, to ensure that they are clearly sounded and that they are correctly fixed, whilst the angles are set to the player's convenience.

The bells are arranged in a ten-by-ten layout. The compositional procedure followed consists of playing all of the bells in a sequence defined by movements similar to those of a Knight on a chessboard. Each tone is only used once, except in a very few cases in which one or two steps backwards in the sequence are taken to rectify the route, to allow for reaching the complete set of bells. The rhythmic patterns are very basic and steady, in order to allow the player to hear any possible anomalies in the setting up of the instrument.

The accompanying audio-visual illustration of this work (DVD1-tk 2) shows the notes in numerical representation (and the 96-et text notation mentioned below in Fig. 107, p. 181) in a ten-by-ten grid, highlighting the notes as they are being sounded, clearly showing the Knight's moves throughout the layout.

(3) *Study No 3. Glissando study* (2005) (Sc. 3/ CD-tk 3/ DVD1-tk 3)

This study explores a wide range of mallet sliding techniques through a range of almost one octave. It alternates the use of single and parallel sliding pitches. Parallel sliding pitch movements are to be played using two mallets in one hand, and a change of hand is required in most cases in the mid-area of the instrument, while sliding through two parallel rows. Parallel sliding pitch employs a 31-step interval in the 96-et scale (a major third of 387.5 ¢), which is 1.2 ¢ greater than the just major third with the ratio 5/4 (386.31 ¢).

The bellophone prototype used for the previous study (*Study No 2*), the *square conic bellophone*, had ten bells per row. This was thought to be an unnecessary long distance when playing smoothly with a continuous mallet sliding movement covering several rows in straight lines; thus, the number ten was reconsidered to recognise the primacy of the tone and semitone and allow compatibility with the 12-et. As a consequence of this reconsideration, 8-bell rows were adopted for this study, with each row separated by a semitone from its neighbour, conveying vertical contiguous steps of semitones, and an auxiliary column of bells is placed to the left of the array, duplicating the highest pitch of each row (to the right of the array) to ease the execution of parallel sliding 31-step major thirds. This results in an array of thirteen rows of nine bells (Fig. 91). An additional row at the top was considered as an option, to allow stretched octaves above *c''*, which is the lowest note normally employed in the prototypes using *hammered bells*. The last note of each row repeats the first of the last row above, in order to allow smooth glissandi between different rows, as well as serving as an alternative location when striking notes.

$\overline{00}$ C 8ve	$\overline{01}$ C' 8ve	$\overline{02}$ C'' 8ve	$\overline{03}$ C''' 8ve	$\overline{04}$ C+ 8ve	$\overline{05}$ C+' 8ve	$\overline{06}$ C+'' 8ve	$\overline{07}$ C+''' 8ve	$\overline{08}$ C# 8ve
88 B	89 B'	90 B''	91 B'''	92 B+	93 B+'	94 B+''	95 B+'''	$\overline{00}$ C 8ve
80 A#	81 A#'	82 A#''	83 A#'''	84 A^	85 A^'	86 A^''	87 A^'''	88 B
72 A	73 A'	74 A''	75 A'''	76 A+	77 A+'	78 A+''	79 A+'''	80 A#
64 G#	65 G#'	66 G#''	67 G#'''	68 G^	69 G^'	70 G^''	71 G^'''	72 A
56 G	57 G'	58 G''	59 G'''	60 G+	61 G+'	62 G+''	63 G+'''	64 G#
48 F#	49 F#'	50 F#''	51 F#'''	52 F^	53 F^'	54 F^''	55 F^'''	56 G
40 F	41 F'	42 F''	43 F'''	44 F+	45 F+'	46 F+''	47 F+'''	48 F#
32 E	33 E'	34 E''	35 E'''	36 E+	37 E+'	38 E+''	39 E+'''	40 F
24 D#	25 D#'	26 D#''	27 D#'''	28 D^	29 D^'	30 D^''	31 D^'''	32 E
16 D	17 D'	18 D''	19 D'''	20 D+	21 D+'	22 D+''	23 D+'''	24 D#
08 C#	09 C#'	10 C#''	11 C#'''	12 C^	13 C^'	14 C^''	15 C^'''	16 D
00 C	01 C'	02 C''	03 C'''	04 C+	05 C+'	06 C+''	07 C+'''	08 C#

Fig. 92. Layout for the *rectangular conic bellophone*.

The potential of the *rectangular conic bellophone* (pp. 127-130) is explored in this study, a progressive exercise for *conic bells* employing horizontal sliding techniques.

Another peculiar aspect of this study is the juxtaposing use of a four-note chord built by adding two additional notes contained within the 31-step major third interval. This originally improvised chord is formed by adding two notes 10 and 21 sixteenthtone steps above the lowest note (both close approximations to ratios 13/12, 7/6 respectively),[116] to the almost pure major third (ratio 5/4) already exploited throughout the piece. Analysing the ratios between contiguous notes in this cord, three contiguous 13-limit intervals can be curiously observed (13/12, 14/13 and again 14/13), setting a precedent when composing future pieces for using similar relations to produce unique contrasting dissonant chords with the bellophone using sixteenthtones while relying on Partch's limit theory.

(4) *Study No 4. Timbral study* (2005) (Sc. 4/ CD-tk 4/ DVD1-tk 4)

This study explores new sonorities with *conic bells* by means of four-note clusters played using four mallets in each hand. These clusters resemble the sound of a church bell. The simple rhythmic sequences allow the player time to perceive and compare the clusters. As it is played keeping the distance between the 4 mallets in each hand constant throughout, the *Timbral study* is helpful in checking that the striking points of the bells are equally spaced. The *Timbral study* was written for the *concentric conic bellophone* (pp. 131-133). This conception divides each horizontal row into three clusters (A, B and C respectively), with one note in common. Since clusters in the vertical blocks A, B or C are only used (Fig. 93) each of them is notated with the row number (0 the lowest; 9 the highest), followed by the letter position.

Fig. 93 illustrates the thirty clusters palette of used in this work. The numbers correspond to Carrillo's numerical notation, except for pitches 96-99, which repeat pitches 0-3 an octave higher. Due to the simplicity of the rhythm used (which in part acknowledges the feasibility of handling eight mallets), the score is a table.

[116] Notice that in this case, the maximum deviation found from these ratios by approximating to intervals from the 96-et (or sixteenthtone steps) is 3.1 ¢. Due to the inharmonic sound of the *conic bell*, this error has not been considered large enough to discard relying on Just Intonation, since the beating frequencies that these errors might produce between higher partials are likely to be masked by other higher harmonics of the bell.

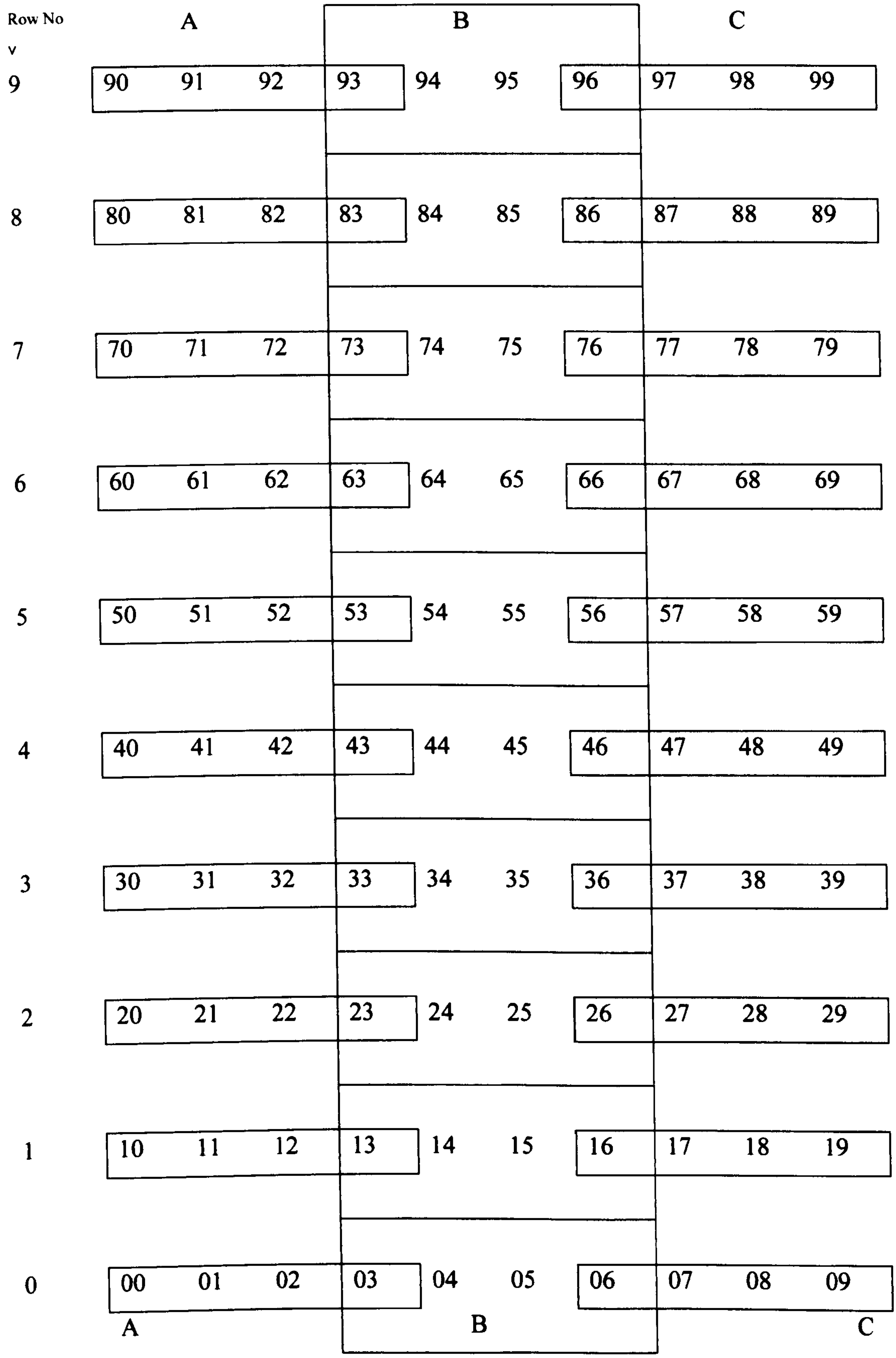

Fig. 93. Diagram explaining the notation used for the ten-by-ten bell layout of the *concentric conic bellophone*.

In the notation employed, each crotchet is represented by a box (Fig. 94), and contains either a cluster (right-hand and left-hand clusters being separated by a forward slash) or a hyphen (for rests). The accents rely on the last strike before each rest and therefore are not indicated.

1st M O V E M E N T

1B/4A	-	0B/7C	1B/4A	2C/9C	-	3C/9A	0B/7C	-	1B/4A	-	1C/6B	-	0B/7C	1B/4A	-

Fig. 94. *Study No 4* (bar 1).

The prototype developed for this – the ten-by-ten layout of the *concentric conic bellophone* – was suggested by the cluster technique explored in this study, since the placing of bells partly inside each other intended to bring the striking points closer together, in order to simplify the handling and timing of two voices, both hands having simultaneous four-mallet strikes. Notice that the interaction between composition and building the instrument is remarkably evident with regard to this study.

(5) *Study No 5. Polyrhythmic study* (2005) (Sc. 5/ CD-tk 5/ DVD1-tk 5)

This study was written to explore the difficulties of locating the notes when playing fast polyrhythmic passages, in this case, five beats in the time of four. This two-part study simultaneously employs rhythms of four semiquavers (U.S.: sixteenth note) for one voice, and semiquaver quintuplets for the other. The pedagogic benefit of this study is that, due to the fast polyrhythmic figures, the player is not able to look at the *conic bells* but must locate the right striking points, developing a greater understanding of the instrument. This study was written for the *3-stand conic bellophone* (p. 133-136), which has a 180-degree semi-circle layout, allowing the performer to reach each half of the layout with each hand without having to move the feet.

(6) *Study No 6. Pasacalles* (Duet) (2006) (Sc. 6/ CD-tk 6/ DVD1-tk 6)

This study was written to explore the tone quality of the *thin spun bells* and the coordination of two players playing either a fast single voice, divided between them, or a voice for each player with cross-rhythms. Rapid cross-rhythms are viable with the *thin spun bells* of the *16S conic bellophone* (pp. 133-136), due to their characteristic short decay. 'Thin' refers herewith to as the thickness of the steel employed in the construction of the bells, which substantially increases the inharmonicity and reduces the pitch clarity of the sound produced.

In this study and in *Study No 7*, the semicircular layout of the *extended conic bellophone* can be varied, reducing or increasing the radius of curvature of the arch until it feels comfortable. By this means, both players can have access to the bells without interfering with each other, while also being able to see each other's movements for coordination. A range extension is suggested by this work, included in the next prototype (Pr. 9).

Pasacalles ('walk the streets' in Spanish) is music written specifically for street parades. The visual impact of having two players working with a high degree of coordination suits the expectations of a street parade; the same standard is maintained in *Study No 7,* making the pieces an ideal set of duo works for a street parade performance.

(7) *Study No 7. Mollienaire* (duet) (2006) (Sc. 7/ CD-tk 7/ DVD1-tk 7)

Mollienaire was written to explore to a very high degree the interaction and alternation of notes between two players. Similarly to *Pasacalles,* this composition originally aimed to be written for a performance by two virtuoso performers, which explains the difficulty in coordination between the players. *Mollienaire* is an integration of the words 'Molien' and 'millionaire'. The first refers to the Molien series, used to calculate the sixteenthtone steps used to devise the scale adopted. The second is a figurative term representing the enrichment achieved in this work by using this microtonal scale.

The guidelines for the scale used in this study was originally sketched for an ensemble work, *Autumn*, and were developed here not only to produce a study but also to inform the composition *Seasons* (expansion of *Autumn*) from the performance of the smaller work. The only requirements already determined for *Seasons* were to select the scale within the 96-et according to the use of the sequence of numbers 1-3-4, and to avoid octaves. Since the Molien series contains the numbers 1, 3, and 4 but not the number 97 (the octave), it was selected for the devising of the scale. For instance, the closest number to 97 in the Molien series is 104, which represents an interval of 1287.5 ¢ (a wide octave of rather unique tone quality when played with the *thin spun bells*). This work also was initiated with prototype 8, but since it implied a wider range than an octave, the design of prototype aimed and expansion the bellophone range. The integral sequence of the Molien series for certain 4-D representation of dihedral group of order 8, determines the sixteenthtone steps for each degree of the scale adopted, as shown below:[117]

1, 1, 3, 4, 8, 10, 16, 20, 29, 35, 47, 56, 72, 84, 104, 120, ...

The gamelan-like sound quality of the *thin-spun bells* was ideal for a composition played in a scale with stretched octaves, as it can be heard in CD-tk 7.

3.3.2 *Improvisatory patterns* (2005 and 2007)

These consist of two works, which were written to provide players with guidelines for improvisation, aiming to suggest new performance techniques: a 4-hand bellophone piece and a duo for bellophone and guitar.

3.3.2.1 *Improvisatory patterns I. Duet* (for *conic bellophone* four-hands) (2005) (Sc. 8/ CD-tk 8/ DVD1-tk 8)

The purpose of this work is to perform easy parallel movements at a wide range of speeds, with the purpose of warming up before a performance. This duo was written for a row of 16 contiguous notes in the sixteenthtone system played by one player and another row of 20 contiguous notes in the eighthtone system for the other. The initial *thick spun bells* were used arranged in one single row of stands, each of which supported a single bell.

This work was performed in September 2006 in London as part of a seminar demonstration showing the progress of the *conic bellophone*. The composition, which was restructured in consultation with the players, represents the closest collaboration with the players in the compositional and development work. Notably, the performers here decided the height and curvature of the 36 bell single row (p. 137), which was a selection of bells from prototype 8 (p. 136-141) using quartertone steps for one player and eighthtone steps for the other.

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[117] G.f.: $(1-x+x^2)/((1-x)^2*(1-x^2)*(1-x^4))$

3.3.2.2 *Improvisatory Patterns II. Soleá* (duo for *conic bellophone* and Sixteenthtone Guitar) (Sc.9 / CD-tks 9, 14/ DVD1-tks 9, 14)

The idea behind the work was to explore the combination of the *conic bellophone* with the sound of a guitar. Despite their similarity in intensity, range and decay, they contrast in tone colour. The guitar tuning adopted here was originally proposed by Pascale Criton to achieve 96-et on a quartertone-fretted guitar. Prototype 9 (pp. 141-145) was originally considered, but the piece was finally performed with prototype 8. An extension using prototype 11 (mechanised, pp. 149-151) or 12 (adding pedal MIDI controller, pp. 151-154), has been structured using the steps of the toothpick sequence built on half toothpick extending one side of an infinite square in the outside corner (1, 2, 3, 3, 4, 7,...). These steps count bars between motives (*falsetas* in Flamenco terminology), the first one being an introductory-style reconsideration of the work *Soleá* here presented.

By using concepts, which pertain to the Flamenco song form (*soleá*), the piece suggests ways in which Flamenco can combine with contemporary music by means of microtonality and micro-discrete sliding pitch. The *soleá* form offers many different styles, normally classified geographically, according to the area of Andalucía in which they originated (Triana, Alcalá de Guadaira, Lebrija, Utrera, Cádiz, Jerez, Córdoba, etc.). The fact that I spent my childhood in the Seville neighbourhood of Triana – where the earliest examples of *soleás* originated – influenced my initiative to examine and compare the *soleá de Triana* style with the other *soleás*. Notice also that the slow tempo and melodious style implied in the *soleá de Triana* when compared other *soleás* (e.g. *soleá de Jerez* and *soleá de Cádiz*) is also ideal for a precise rendering of sliding-pitch contours.

Twentieth-century instrumental *soleás* for solo guitar developed separately from the guitar accompaniment of a sung *soleá*. In both cases the incorporation of dance was always an option, and the use of a twelve-beat rhythm is respected throughout the structure. A twelve-beat rhythm is also employed here, and although this work is instrumental, the *conic bellophone* takes the vocal role, using microdiscrete-sliding pitch contours as an abstraction of the Flamenco song, while the guitar takes the accompanying role.

3.3.3 *Autumn* (for *conic bellophone* and mixed quintet) (2004-2007) (Sc. 10/ CD-tk 10/ DVD1-tk 10)

This composition shows how the *conic bellophone* can combine and interact with several instruments. A recorded live performance is included on the attached CD and DVD.

Autumn was initially conceived as the first movement (*Season I*) of a larger structure including two further movements. However, once finished, it was clear to me that it could stand also as an independent piece.[118]

3.3.3.1 *Autumn* – Instrumentation

Although a trial of the *conic bellophone* playing with an orchestra would have been ideal to complement its development as an orchestral instrument, this was not feasible. In order to provide a full range of techniques and dynamics (with instruments of the orchestra representing the different kinds of sound vibrating bodies) while having regard for economic considerations, the *conic bellophone* was incorporated into a small ensemble of widely varied instruments strategically selected. *Autumn* was written for *conic bellophone* and five instruments, which were selected to represent different sections of the orchestra: bass clarinet, C trumpet, trombone, cello, and timpani (plus other percussion instruments). The microtonal and sliding-pitch capabilities of the instruments were primary considerations in making this selection, ensuring also that a wide range of the pitch spectrum was considered. Instruments affording a wide dynamic range were also a priority, so that a range of balances of amplitude and sonority could be achieved, either blending the sound of the bellophone with the ensemble or having it stand out as a solo instrument with the other instruments accompanying or supporting. With regard to timbre, the instruments were chosen to afford a wide range of sonorities, including those allowed by the use of extended techniques and by the alternative percussion instruments allocated to the timpanist. As there was not an opportunity to record the bellophone with several other instruments before this work was composed, it was important to have a wide palette of timbral possibilities to allow variety of experimentation and comparison with the bellophone, and to characterise the sounds appropriate to each of the seasons represented.

The bass clarinet was chosen among the woodwinds due to its wide range of dynamics and techniques. Originally the trumpet and French horn were chosen among the brass, due to their contrasting timbres and ranges. Since it was impossible to produce sliding passages, initially desired for French horn, it was substituted by trombone in the early stages of composition. Timpani were chosen due to their capability to produce both, microdiscrete-

[118] The entire structure incorporating *Autumn* as the first movement is described below, under the explanation of *Seasons*.

sliding pitch (sliding with the pedal while playing rolls) and sliding pitch (initiated with single attack followed by sliding with the pedal). Other orchestral tuned percussion instruments, such as the slide whistle and the musical saw, can provide sliding pitch, but since the *conic bellophone* was to occupy the higher part of the pitch spectrum, the timpani were favoured as they can effectively be used to extend the low register, not covered by the bellophone. Although the sliding whistle and musical saw were at one stage considered as elements of the timpanist's part, to alternate when a higher register was required, the likelihood of finding a timpanist who could play these instruments fluently was thought to be slight, so instead a basic selection of fixed-pitch instruments was incorporated into the part, bringing varied elements to the spectrum of the full ensemble and serving also to set a wide range of new timbres to be combined with the *conic bellophone* microdiscrete-sliding passages in particular.

The cello was chosen from among the strings mainly due to its ability to cover a wide pitch range, interacting with both the trumpet and the bass clarinet while having a fingerboard of a size that allows accuracy when executing pitch slides at a wide range of speeds.

Details of the use – in regard to microtonality and sliding-pitch – of each of the instruments in *Autumn* are presented separately below.

Bass clarinet: The bass clarinet part in *Autumn* was initially conceived with a continuous sliding effect; but as this is not always possible, it was left to the player to decide whether to lip-bend particular pitch progressions, or alternatively to use very rapid chromatic scales, according to the player's skill and judgement (Fig. 95 and Fig. 96).

Fig. 95. Excerpt from *Autumn*: bass clarinet (bars 11-12).

Fig. 96. Excerpt from *Autumn*: bass clarinet (bars 47-48).

Other effects used are throat tremolo, key slaps, and a variety of multiphonics. The throat tremolo is produced before the airstream reaches the mouthpiece of the clarinet, resulting in a distortion of timbre and a slight undulation of the pitch (see an example in Fig. 97). The key slap is a percussive pitched effect produced by abruptly closing an open-standing key over its tone-hole, thus producing an explosive attack which works best in the lower register of the bass clarinet (Fig. 98). Multiphonics for the bass clarinet, which combine overblown notes with the fundamental, by means of special fingerings and blowing techniques, are often used in *Autumn*. Their complex sound quality is very different from normal tones, flourishing the sound quality by playing simultaneous pitches and providing more variation of timbre (Fig. 99).

Fig. 97. Excerpt from *Autumn*: bass clarinet (bar 2): slap key.

Fig. 98. Excerpt from *Autumn*: bass clarinet (bars 4-5): multiphonic.

Quartertones can be articulated at high speeds on the bass clarinet and some can also be sounded with a multiphonic effect, as in Fig. 99.

Fig. 99. Excerpt from *Autumn*: bass clarinet (bars 15-16): quartertones.

C trumpet and Bb trombone: The trumpet and the trombone parts in the first movement were conceived with one single sliding tone throughout the entire composition, as if using circular breathing. In order to ease the performance of the piece, commas are placed in the score to indicate points at which normal breathing is allowed. Parallel and contrary motion sliding pitches between the trumpet and trombone are used, carefully choosing the progressions in which lip-bend is possible for the trumpet, and taking into consideration transitions between harmonics in relation to the movement of the trombone slide (Fig. 100).

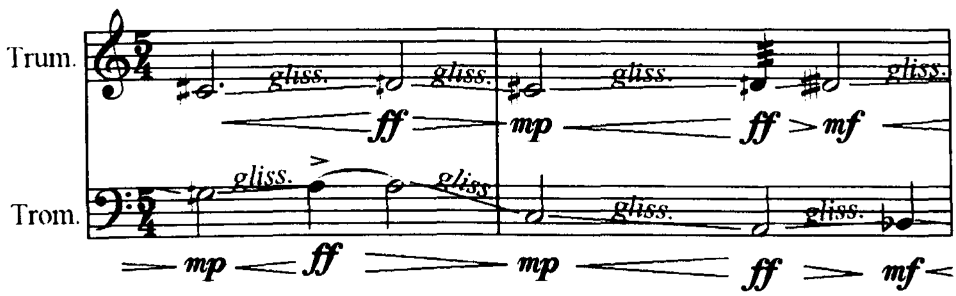

Fig. 100. Excerpt from *Autumn*: trumpet and trombone slides (bars 29-30).

Cello: The cello is an ideal sliding pitch instrument and quartertones can be played at high speeds if the phrases composed consider fingering carefully (Fig. 101).

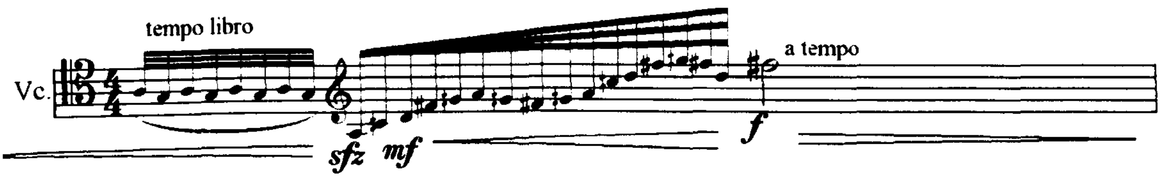

Fig. 101. Excerpt from *Autumn*: violoncello (from bar 45).

The parallel glissando passage in Fig. 102 explores alternative timbres for the cello and bellophone, with progressive timbral change supported by the pitch slide in both parts.

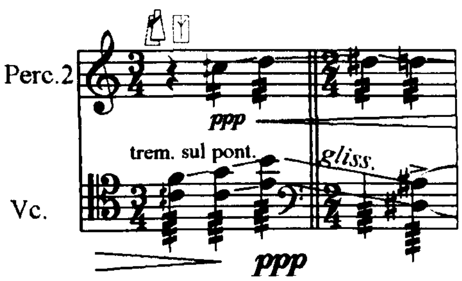

Fig. 102. Excerpt from *Autumn*: *conic bellophone* and cello (bars 20-21).

Percussion: As a counterpart to the first percussion instrument in the quintet, the *conic bellophone*, I decided to include pedal Timpani, which can produce microdiscrete-sliding pitch in a lower register than the *conic bellophone*. The additional percussion instruments are primarily written for the timpanist, as part of a second percussion part. The two parts are named 'Percussion 1' (Timpani and other small percussion instruments) and 'Percussion 2' (*conic bellophone*, with brief use of triangle, boat-bell in F/ bell plate, and handbell in C) in the score, while symbols – some of them specially designed for this piece – indicate the instruments played in each voice.

(a) Percussion 1: Timpani and other small percussion instruments.

Timpani are mainly used for playing rolls while the pitch is gradually changed with the pedal. These passages are indicated without noteheads, apart from the starting and ending notes. This technique produces microdiscrete-sliding pitch in a similar way to the *conic bellophone*, and it is used to produce pitch contours in parallel with or in contrary motion to the bellophone. The same percussionist also plays a range of percussion instruments, including bamboo tree branch (as a shaker), plaque, wind chimes, kazoo, cymbal, and four Japanese temple instruments: *mokugyo* (temple block), *mokusho*, *hojurey* and *rin* (Japanese temple bowl). These additional instruments are largely decorative and several of them produce a range of arbitrary shaking, blowing and friction sounds, which a mild wind might cause in an outdoor space. The Japanese temple instruments help to recreate a meditative atmosphere in the slow passages of *Autumn*.

(b) Percussion 2: *Conic bellophone* with brief use of triangle, boat-bell in F (or bell plate), and handbell in C.

The *conic bellophone* proved to be distinctive when heard alongside the trumpet, trombone, timpani and bass clarinet when playing fortissimo. An example is shown in Fig. 103 (bar 31), where the *conic bellophone* (Percussion 2) can be clearly distinguished in the recording (CD-tk 10).

Fig. 103. Excerpt from *Autumn*: general score (bars 29-32).

The *conic bellophone* in *Autumn* is played considering a wide range of sonorities, as it can be observed in Fig. 104, were soft and medium mallets are used, as well as brush and bow. The brush brings a distinctive wind-like frictional timbre when slid over the bells (as in Fig. 105). In Fig. 104 bar 6, a black mark is placed diagonally across the top of the icon for the *conic bells*, to indicate the specific striking area of the bell, which brings a complex harmonic spectrum to the sound of the instrument. The bells are also bowed (see Fig. 104, bar 7), using a cello bow, while the player's other hand supports the stand corresponding to the bell being bowed. Although the original idea here was to bow a Japanese temple bowl, the *conic bellophone* was later on substituted (since the quality of the sound is remarkably similar), in order to illustrate this specific characteristic of the new instrument, while also reducing the number of instrument changes for the percussionist.

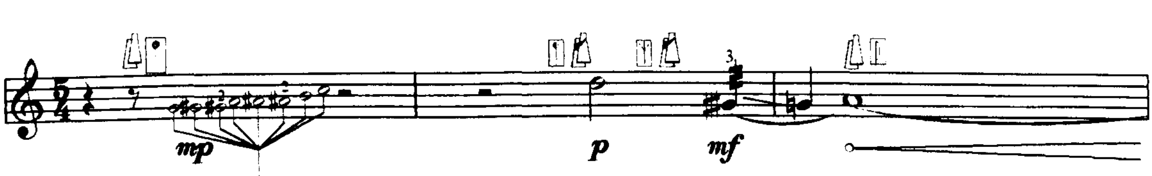

Fig. 104. Excerpt from *Autumn*: *conic bellophone* (bars 5-7).

Fig. 105. Excerpt from *Autumn*: *conic bellophone* (bars 19-21).

A rapid ascending sliding effect, starting with the note indicated and followed by another three consecutive ascending notes, the speed always indicated in the rhythm, is represented by an upward-pointing notehead, which saves writing many additional noteheads, as shown in Fig. 106.

Fig. 106. Excerpt from *Autumn*: *conic bellophone* (bar 14).

As an alternative to the accidentals for the proposed extended Stein-Couper notation (pp. 54-58), a system based on a normal computer font was used in order to better identify notes when using text in messages to communicate with the percussionist. This 96-et text notation is illustrated in Fig. 107. In order to simplify reading, flats are not included in this system. It must be noted, that this is not a major notation development system, thus useful for the purposes mentioned above.

'	Sixteenthtone sharp
"	Eighthtone sharp (two-sixteenthtones sharp)
'''	Three-sixteenthtones sharp
+	Quartertone sharp (four-sixteenthtones sharp)
+'	Five-sixteenthtones sharp
+"	Three-eighthtone sharp (six-sixteenthtones sharp)
+'''	Seven-sixteenthtones sharp
#	Semitone sharp (eight-sixteenthtones sharp)
#'	Nine-sixteenthtones sharp
#"	Five-eighthtones sharp (ten sixteenthtones sharp)
#'''	Eleven-sixteenthtones sharp
^	Three-quartertones sharp (twelve-sixteenthtones sharp)
^'	Thirteen-sixteenthtones sharp
^"	Seven-eighthtones sharp (fourteen-sixteenthtones sharp)
^'''	Fifteen-sixteenthtones sharp

Fig. 107. The 96-et text notation used to communicate with the percussionist.

The patterns for the non-octaval scales employed in the *conic bellophone* part in *Autumn* were represented in the form of a diagram and provided to the performer prior to rehearsals using the *96*-et text notation (Figs. 108, 111 and 123, show three of them). The first pattern used in *Autumn* is the already mentioned 5-equal-step scale (which may be expressed as the 62.5-cet (cents equal temperament)[119], devised by taking 5 note steps in the 96-et (Fig. 108). The term 'cet' was first used by Gary Morrison to denominate a non-octaval tuning he devised and named 88-*cent-equal-temperament* (88-cet). Among the equal-step tunings, non-octaval tunings are best described using the 'cet' denomination. In further movements sketched for this work (under the title *Seasons*), the term 'cet' is applied for all the non-octaval equal-step scales contained in the 96-et.

80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
F	F'	F"	F'''	F+	F+'	F+"	F+'''	F#	F#'	F#"	F#'''	F^	F^'	F^"	F^'''
64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
D#	D#'	D#"	D#'''	D^	D^'	D^"	D^'''	E	E'	E"	E'''	E+	E+'	E+"	E+'''
48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
C#	C#'	C#"	C#'''	C^	C^'	C^"	C^'''	D	D'	D"	D'''	D+	D+'	D+"	D+'''
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
B	B'	B"	B'''	B+	B+'	B+"	B+'''	C	C'	C"	C'''	C+	C+'	C+"	C+'''
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
A	A'	A"	A'''	A+	A+'	A+"	A+'''	A#	A#'	A#"	A#'''	A^	A^'	A^"	A^'''
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
G	G'	G"	G'''	G+	G+'	G+"	G+'''	G#	G#'	G#"	G#'''	G^	G^'	G^"	G^'''

Fig. 108. The 5-step scale starting with G in a sixteen-by-six layout (96-et).

The use of the 5-step scale is indicated at the beginning of the passage concerned, to help the player to relate to the previously studied diagrams, and to convey to the conductor that the particular sound of this scale is to be expected. This notation, which consists of the starting note name for the pattern (G in the case of *Autumn*), a hyphen, the number of intervals followed per step in the scale, and the word 'STEP', is placed between brackets at the beginning of the passage, and applies until a change of instrument or scale is indicated.

The *conic bellophone* part in *Autumn* did not use the extended Stein-Couper notation proposed (pp. 54-58) by request of the percussionist, who found difficulties learning the new symbols in a short time. Instead he preferred a notation, which places the numbers 1, 2, or 3 above the corresponding notehead to indicate sixteenthtone deviations above the

[119] Sethares, W. 2005. *Tuning, Timbre, Spectrum, Scale*. 2nd edition. Springer-Verlag London Ltd. p. 113.

corresponding quartertone (Fig. 109). This notation is also used for the conductor's score, since the sound of the scale is already described and the concentration of numbers above the noteheads can help to convey the difficulty of the passage.

Fig. 109. Excerpt from *Autumn: conic bellophone* (bars 33-34), in *Ferguson* notation.

The 10-step scale (Fig. 110), also called 125-cet (125 cents equal temperament), is included in the 5-step scale, providing a sub-pattern with which to improvise when composing for the 5-step scale, by using larger equal steps.

80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
F	F'	F"	F"'	F+	F+'	F+"	F+"'	F#	F#'	F#"	F#"'	F^	F^'	F^"	F^"'
64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
D#	D#'	D#"	D#"'	D^	D^'	D^"	D^"'	E	E'	E"	E"'	E+	E+'	E+"	E+"'
48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
C#	C#'	C#"	C#"'	C^	C^'	C^"	C^"'	D	D'	D"	D"'	D+	D+'	D+"	D+"'
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
B	B'	B"	B"'	B+	B+'	B+"	B+"'	C	C'	C"	C"'	C+	C+'	C+"	C+"'
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
A	A'	A"	A"'	A+	A+'	A+"	A+"'	A#	A#'	A#"	A#"'	A^	A^'	A^"	A^"'
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
G	G'	G"	G"'	G+	G+'	G+"	G+"'	G#	G#'	G#"	G#"'	G^	G^'	G^"	G^"'

Fig. 110. 10-step scale starting with G (dark grey), contained in the 5-step scale.

The 20-step scale (Fig. 111), also named 250-cet (250 cents equal temperament), was also employed, and although it only uses quartertone accidentals (Fig. 112), the 20-step indication is easier to follow, once the pattern has been learnt by the percussionist.

80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
F	F'	F"	F"'	F+	F+'	F+"	F+"'	F#	F#'	F#"	F#"'	F^	F^'	F^"	F^"'
64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
D#	D#'	D#"	D#"'	D^	D^'	D^"	D^"'	E	E'	E"	E"'	E+	E+'	E+"	E+"'
48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
C#	C#'	C#"	C#"'	C^	C^'	C^"	C^"'	D	D'	D"	D"'	D+	D+'	D+"	D+"'
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
B	B'	B"	B"'	B+	B+'	B+"	B+"'	C	C'	C"	C"'	C+	C+'	C+"	C+"'
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
A	A'	A"	A"'	A+	A+'	A+"	A+"'	A#	A#'	A#"	A#"'	A^	A^'	A^"	A^"'
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
G	G'	G"	G"'	G+	G+'	G+"	G+"'	G#	G#'	G#"	G#"'	G^	G^'	G^"	G^"'

Fig. 111. 20-step scale (darker grey) starting with G, contained in the 5-step scale.

Fig. 112. Excerpt from *Autumn*: *conic bellophone* (bar 36).

The diagonal gliding technique on the *conic bellophone* is performed by sliding the mallets or brushes in diagonal patterns across the layout (Fig. 113). With regard to the mallets to be used, semi-soft mallets have proven ideal for this purpose, as the distance between striking points is too wide to achieve a smooth progression of sound with hard mallets at the required speed (Fig. 114).

80 F	81 F'	82 F"	83 F"'	84 F+	85 F+'	86 F+"	87 F+"'	88 F#	89 F#'	90 F#"	91 F#"'	92 F^	93 F^'	94 F^"	95 F^"'
64 D#	65 D#'	66 D#"	67 D#"'	68 D^	69 D^'	70 D^"	71 D^"'	72 E	73 E'	74 E"	75 E"'	76 E+	77 E+'	78 E+"	79 E+"'
48 C#	49 C#'	50 C#"	51 C#"'	52 C^	53 C^'	54 C^"	55 C^"'	56 D	57 D'	58 D"	59 D"'	60 D+	61 D+'	62 D+"	63 D+"'
32 B	33 B'	34 B"	35 B"'	36 B+	37 B+'	38 B+"	39 B+"'	40 C	41 C'	42 C"	43 C"'	44 C+	45 C+'	46 C+"	47 C+"'
16 A	17 A'	18 A"	19 A"'	20 A+	21 A+'	22 A+"	23 A+"'	24 A#	25 A#'	26 A#"	27 A#"'	28 A^	29 A^'	30 A^"	31 A^"'
0 G	1 G'	2 G"	3 G"'	4 G+	5 G+'	6 G+"	7 G+"'	8 G#	9 G#'	10 G#"	11 G#"'	12 G^	13 G^'	14 G^"	15 G^"'

GLIDING GLIDING

Fig. 113. 5-step scale. Parallel gliding with two mallets (downwards).

Fig. 114. Excerpt from *Autumn*: *conic bellophone* (bar 45).

3.3.3.2 The inner and outer structure of *Autumn*: the use of the numeric row-pattern 1-3-4

The numeric row pattern 1-3-4 is used to govern the entire organisation of pitches, durations and overall structure (form) of the piece. Using a numerical relation seemed the most appropriate way to deal with a structure adopting ideas familiar to serialism, and using a simple structure with three different numbers that added together made number eight was thought of as a way to extend these ideas to micro-intervallic structures using the octuple division of the semitone. Repeating a number in a simple sequence can produce audibly repetitive patterns in a structure. Since the addition of four whole numbers (without repeating any of them) equal 10 or more, a three-number sequence was considered to obtain a one-digit number. There was only one solution left for this purpose, to use the numbers 1, 3 and 4, and although this group of numbers is referred to in ascending sequence, all possible permutations were considered when structuring the piece.

With regard to the organisation of pitch, twelve pitch classes were divided into two hexatonic modes, to be sounded simultaneously. An atonal four-part structure was built, based on the pattern C-D-E-G-A-B. This scale was transposed by an augmented fourth in order to obtain its complementary hexachord.[120] Expressed in tone and semitone intervals, the chosen pattern is *T-T-T1/2-T-T-s*.[121] The scale is C-D-E-G-A-B, starting in C, is shared by parts two (led by the trumpet) and four (led by the cello), while the pattern F#-G#-A#-C#-D#-F, starting at F#, is shared by parts one (led by the bass clarinet) and three (led by the trombone). Three pitches are assigned per part in the first diagonal block of 12 notes (Fig. 115) and instruments are allowed to exchange parts. Where there is no other choice, a part can take a note from the scale that does not belong to it, in order to keep the 12-note diagonal block without repeating notes at different points within the block. These diagonal blocks are represented in Fig. 116, using contrasting grey tones.

Parts (starting Instr.)	Pitch		
Part 1 (Bass Clarinet)	D#	F	G#
Part 2 (C Trumpet)	C	B	D
Part 3 (Trombone)	C#	F#	A#
Part 4 (Cello)	G	A	E

Fig. 115. The first 12-note block at the beginning of pattern 'A' in *Autumn*'s four-part structure.

By keeping the 12-note verticality rule, it is impossible to apply the 1-4-3 sequence (variation of 1-3-4) to the starting point of each part (as it can be observed in Fig. 116) without having to insert rests in the four instrumental parts. As it is of fundamental importance here to maintain the structural continuity of the sliding tones in the movement,

[120] Reinhardt, L. 2009. *Josef Matthias Hauer's Melischer Entwurf.* Moldenhauer Archives.
[121] Here '*T*' refers to 'tone' and '*s*' for 'semitone'.

the rule is used for diagonal 12-note areas (Fig. 116) instead of using rests (always trying to avoid octaves, which can be otherwise perceived as a break of texture).

Fig. 116. *Autumn*'s 4-voice structure for pattern 'A_1' (first half of pattern 'A').

Fig. 116 shows an example of how the pitch for the second voice (trumpet in this case) moves following the sequence 1-3-4 and 3-1-4,[122] in this case using 2 instead of 4 as an exception (see the two semitone step between the third and fourth notes, D and C,

[122] Regardless of pitch direction. Notice that in Fig. 117 pitch decreasing is indicated with a minus sign.

represented in Fig. 117), since as the structure develops it becomes more difficult to adhere strictly to the 1/3/4 rule, while keeping the 12-tone diagonal blocks as a priority.

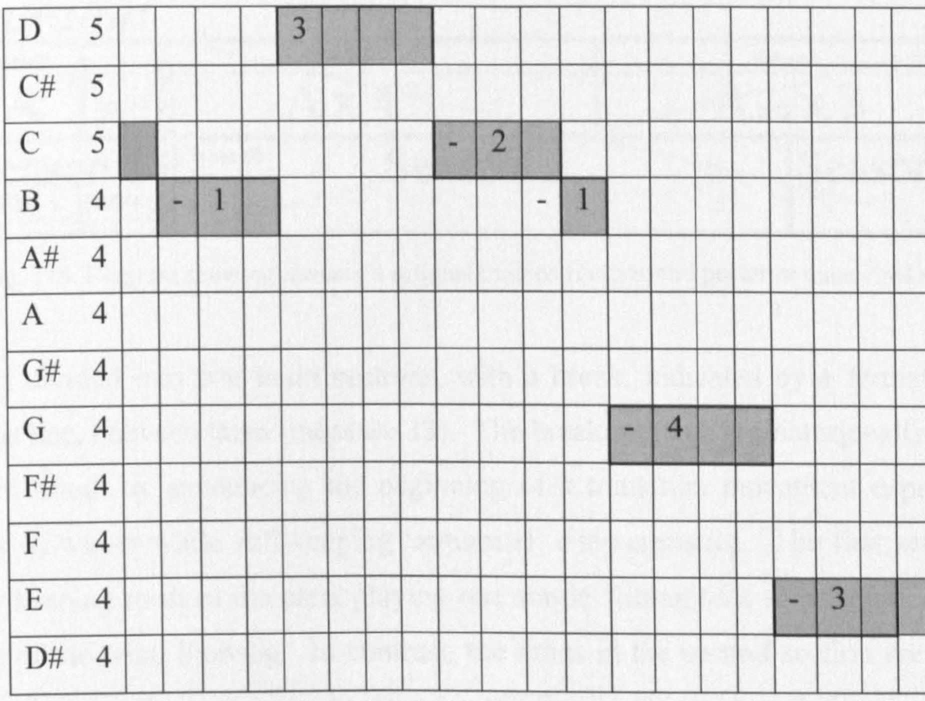

Fig. 117. Pitch sequences in *Autumn* (1-3-2/1-4-3) for trumpet in pattern 'A$_1$' (from left to right in time).

With regard to its outer structure, *Autumn* was initially conceived as part of a macrostructure based on a pre-composed pattern, called pattern 'A'. This major structure is built upon the sequence 1-4-3 (variation of 1-3-4), where '1' represents pattern 'A'; followed by pattern 'A' in quadruple augmentation (four times the original overall durations), but maintaining the original durations of the notes and achieving the augmentation by adding long rests between the notes; and finally, the macrostructure ends with pattern 'A' in retrograde triple augmentation, or in other words, augmenting the durations of 'A' three times, in reverse sequence (Fig. 118 and Fig. 123).

Autumn was developed as a separate project from the large, multi-movement structure drafted for three main reasons: (a) to be performed and recorded in order to test an advanced *conic bellophone* prototype in a live situation; (b) to have a clear idea of how it sounded in an ensemble, in order to inform the development of the full macrostructure;[123] (c) to be able to evaluate in practice the combination of microtonality, sliding-pitch and

[123] Which is employed for the posterior work *Seasons*.

microdiscrete pitch in a composition of moderate size which included an instrument derived from the study of pitch resources of this thesis.

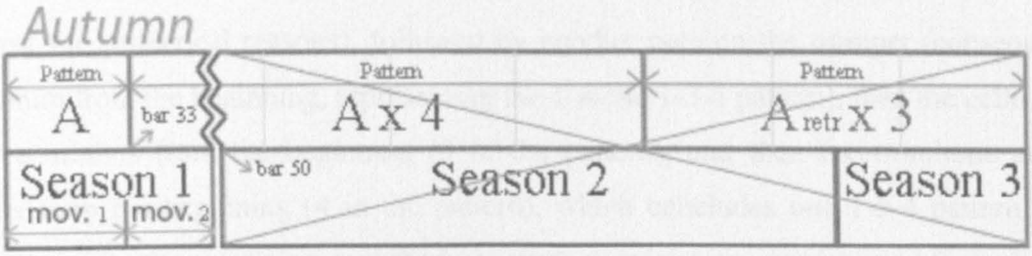

Fig. 118. Diagram showing *Autumn*'s original macrostructure, and posterior emancipation.

Autumn is divided into two main sections, with a break, indicated by a fermata above a double bar line, between them (measure 33). The break marks a dramaturgically important change of mood, by announcing the beginning of a transition movement expressing the proximity of winter while still keeping 'autumnal' characteristics. The first section (bars 1-32), by keeping most of the parts playing one single sliding tone throughout, evokes the sensation of the wind blowing. In contrast, the notes in the second section are separated, instead of showing the continuity displayed in the first section, although the same pattern is used with the rhythms augmented while keeping the same note values (which is described above when detailing the macrostructure). The second section (bars 33-end), also allows the brass and woodwind players to recover their breath, since the first movement consists of continuous blowing using circular breathing where possible. A marked change in the texture of the second section, which helps to evoke the sensation of a seasonal turn, the weather getting colder, is achieved by breaking the previous continuity of notes and by introducing a dialogue between the instruments. The aim of these changes is to incite in the audience a feeling of anxiety, which is necessary before the dramatic resolution of the movement is reached, by a return to the music of the first two bars and finally a dissipation of the season in a combination of non-pitched wind-like effects from all of the instruments.

The inner structure of *Autumn* defines how microstructures for the piece were designed for four of the parts: bass clarinet, trumpet, trombone and cello (parts 1 to 4 respectively). The parts are occasionally exchanged between the instruments, and the two percussionists complement the four parts by ornamenting, or by drawing parallel or contrary motion patterns suitable to the four-part structure. As with the compositional process of the outer structure (form), durations and pitches are organised following the pattern 1-3-4. The chosen unit of duration, which represents the '1' of this three-number row, is the minim.

Thus the pattern 1-3-4 is used to determine the positioning in time of the starting note of each of the four parts constituting the main structure. The piece starts with a minim on the trumpet (considered neutral since its attack starts the work and it was simply filling the gap of a rest for aesthetical reasons), followed by another note on the trumpet (consequently one minim from the beginning, representing the 1 in the 1-3-4 pattern), then the cello starts at three minims from the beginning (3 in the pattern), and then the trombone at four minims from the beginning (4 in the pattern), which concludes one 1-3-4 pattern. The staring point for the remaining part, the bass clarinet, is kept one minim apart from the start of the previous note (the start of the trombone), and represents the 1 of the next 1-3-4 cycle), completing the positioning of the starting notes for each of the four parts (Fig. 119).

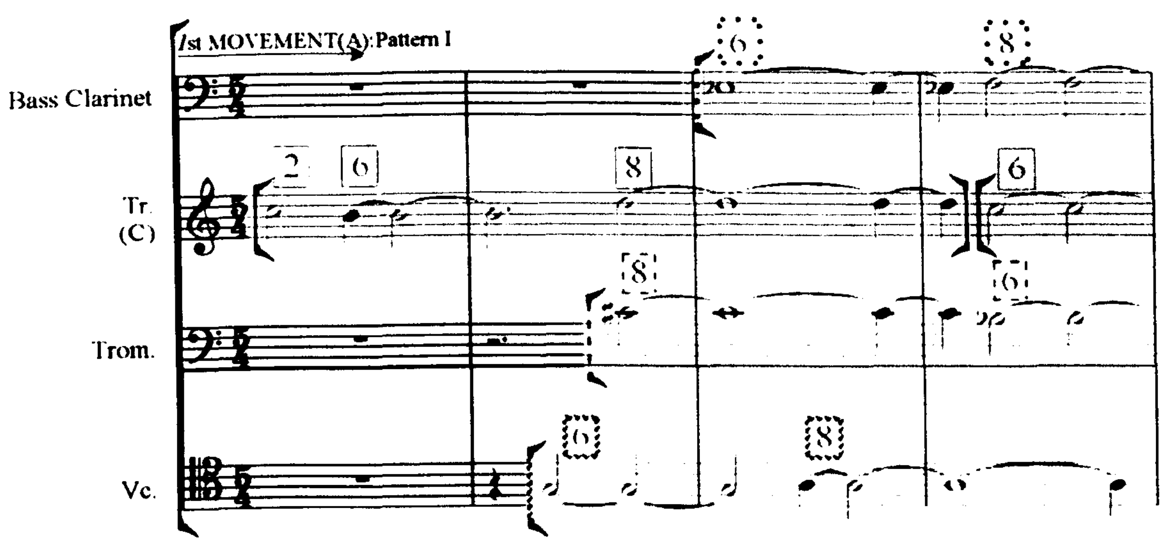

Fig. 119. Beginning of *Autumn*'s four-part structure.

Each voice repeats a permutation of the minim rhythmic pattern, 1-3-4, chosen every eight minim beats. For example, in pattern 'A1' (see above in Fig. 116), the second voice (led by the trumpet) follows the pattern 1-3-4/3-1-4/3-1-4/3-1-4/3-4-1/3, which, expressed in beats, corresponds to 2-6-8/6-2-8/6-2-8/6-2-8/6-8-2/6.

The rhythmic augmentation process followed in the second section (Ax4) is shown in Fig. 120, where square blocks represent the duration of a minim, and the grey areas are the duration of the notes, first representing the pattern 1-3-4 in the first section, and below it representing the pattern 1-3-4 in the second section.

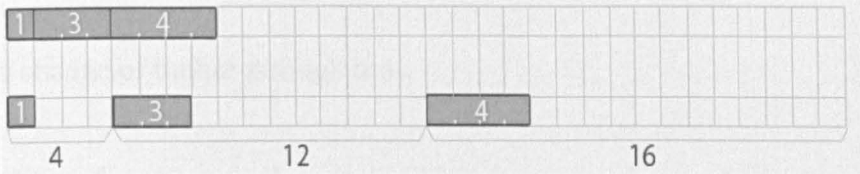

Fig. 120. Diagram clarifying the augmentation in the second section (Ax4).

3.3.3.3 Usage of sliding and microdiscrete-sliding pitch in *Autumn*

Dynamic (sliding) pitch, notated as portamenti or glissandi, embraces a wide range of instrumental techniques in *Autumn*. Whether using pure sliding or microdiscrete-sliding pitch, sliding effects and sliding tones are employed throughout the first movement of *Autumn* to produce smooth transitions between the fixed-pitch values of the structure. This is achieved in most cases by starting sliding towards the new pitch half way through the previous sustained pitch, in order to reach the new pitch smoothly.

Although voices three and four in the structure, led by the trombone and cello respectively, start their rhythmic pattern in different positions, they nonetheless share many structurally important note attacks on the same beat. If those attacks were to be avoided in order to keep an even distribution of texture, the consistency of serial-related techniques employed would have been affected. Since both parts are played by sliding-pitch instruments (trombone and cello), it is difficult for the listener to notice the coinciding note attacks, since both instruments are normally sliding simultaneously before the structurally significant attacks, and their timbres blend well. This retains the texture of the composition, while giving the impression of a sliding complex tone, which becomes gradually simpler in harmonic context until the two pitches depart for their next target.

3.3.3.4 Other dynamic compositional parameters related to pitch in *Autumn*

Other compositional elements, apart from pitch, are timbre and amplitude, which were treated with gradual changes through time and are directly related to the dynamic changes of pitch.

(1) Dynamic change of timbre through time

The first section of *Autumn* is characterised by four continuous glissando parts, with the two percussionists also executing glissandi in the timpani and *conic bellophone* at times, and sound effects with alternative instruments occasionally. Having six different sliding pitches at the same time contributes strongly to the production of a dynamically changing timbre as an overall effect in this movement. For this purpose, the *conic bellophone* provides precise sliding-pitch passages, which at times are doubled by the timpani, sounding two octaves lower. Although these two percussion instruments are not originally part of the numerically regulated structure, they are responsible for modulating the structure, smoothly or dramatically, creating contrasting sections.

(2) Dynamic treatment of amplitudes (crescendo/diminuendo)

Dynamic treatment of amplitude in *Autumn*, simultaneously with the gradual pitch changes, was achieved intuitively to obtain a balance of the overall sound in the first section. Crescendo and diminuendo signs alternate in the first part of pattern 'A'. In the second part of pattern 'A', this is achieved at two different levels: the first consists of a slow, gradual crescendo (pianissimo to fortissimo) throughout the part, up to the very last note (which is held with fermata using a '*sffzpp* (súbito)' in all voices). The second level consists of small changes arising inside the structure, alternating crescendi and diminuendi to control the balance and consequently the overall timbre.

3.3.3.5 Usage and notation of microtones in *Autumn*

Both sections of this work use quartertones in the bass clarinet, trumpet, trombone and cello parts, while the *conic bellophone* and timpani use sixteenthtones in the micro discrete-sliding pitch passages and for microtonal scales in the case of the bellophone. The scales used are respectively the 5-chromatic-step scale, the 10-chromatic-step scale and the 20-chromatic-step scale, all of them starting from G. These scales correspond to the 87.5-cet (cents equal temperament), the 150-cet and the 250-cet respectively. Although these scales were originally notated using the proposed extended Stein-Couper notation (pp. 54-58), for the general score, the percussionist suggested a variation using the quartertone and three-quartertone symbols in conjunction with numerals (from 1 to 3) above the noteheads to refer to sixteenthtone steps deviations. This obviated the use of flat symbols. This variation is referred to here as *Ferguson notation*, in recognition of the percussionist, Lee Ferguson, who proposed it during the preparation period for the premiere of *Autumn*.

3.3.3.6 The bellophone's referential function in *Autumn*

That the timbre of the bellophone, when sounding with other instruments, is easily distinguishable by its metallic quality helps it to serve as a pitch reference for the timpanist. Fig. 121 shows the timpani part and the *conic bellophone* part executing parallel glissandi two octaves apart. For this passage, the timpanist can refer to the *conic bellophone* in order to keep the interval pure throughout.

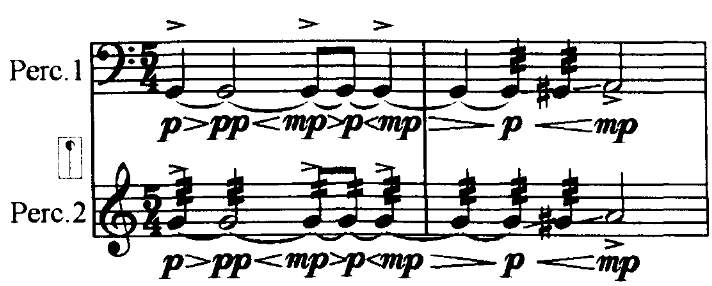

Fig. 121. *Autumn*: Timpani (upper stave) and *conic bellophone* (lower stave) (bars 24-25).

3.3.4 *Seasons* for *extended conic bellophone* and mixed quintet (work in progress)

The *extended conic bellophone* is simply a *conic bellophone* with three additional horizontal rows of 16 notes on top covering an extra range of an augmented fourth above the regular octave range of the *conic bellophone*.[124]

Of all the works in the composition portfolio submitted herewith, *Seasons* is the only one that not only has yet to be performed, but also, despite being drafted, and, for most of its long structure, almost composed, remains unfinished so far. Hence it must be considered

[124] See more details on pp. 141-145.

at this stage a work in progress.[125] Its repercussions go beyond the mere fact of composing: the piece proposes new developments for the *bellophone,* which exist currently only as proposed prototypes, and new combinations of timbre, due to its refined instrumentation.

The first movement adopted for this composition proved to have a good balance, blending timbres and volumes to accommodate the *conic bellophone* as part of the whole ensemble. The success of passages in which it is intended to stand out suggested the exploration of the *conic bellophone* as a leading part, exploiting both its microtonal and sliding pitch potential in the following movements.

3.3.4.1 Additional elements of instrumentation in *Seasons*

Seasons shares with *Autumn* the same main instruments and number of performers, but the prevailing register is amplified by adding higher-pitched instruments to the ones already described for *Autumn.*

(a) Bass clarinet / Bb clarinet

The bass clarinet was chosen for the first movement (see structure in Fig. 116, p. 186), but to encompass high notes required in the second movement, a brief change to Bb clarinet is required. Sixteenthtones for the bass clarinet and Bb clarinet are frequently used in the second movement (see an example using Bb clarinet in Fig. 122). A form of notehead, adapted from that used when the *conic bellophone* slides in pitch with brushes (see bar 14 in *Autumn*), is used to indicate minute downward-pitch slides (imitating the sliding pitch effect produced by the Chinese opera gongs soon after the attack) for the Bb clarinet (Fig.122).

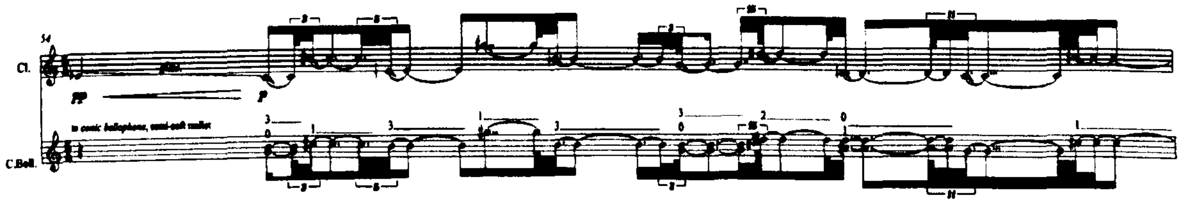

Fig. 122. Seasons: bass clarinet and *conic bellophone* (2nd mov. / b. 54).

[125] The score has been fully drafted, indicating the areas that require incorporating additional materials to be placed, and the word 'SKETCH' is placed in most of the pages to indicate that is still work in progress, the stage reached upon research submission.

(b) C trumpet / C trumpet with additional valves

It was possible to achieve quartertones with the C trumpet in *Autumn*, but for the second and third movement the trumpet considered has three additional valves (quartertone, eighthtone, and sixteenthtone valves). Not much evidence has been found on Carrillo using such a trumpet rather than the implications of his writings when referring to all brasses. The development of a fully new sixteenthtone valve system for a trumpet is challenging, since the standard semitone tubing should be replaced. An alternative though, would be using a regular C trumpet with lip and embouchure adjustments while playing a close convenient note.

(c) Trombone / Bass trombone

Although the bass trombone part has not been drafted, the areas where the bass trombone is desired have been indicated in the draft of the second movement (Sc. 12).

(d) Cello / Cello with sixteenthtones undulating fret-board

In the second movement, in order to perform with precision the sixteenthtones with a cello, the use of an undulating fingerboard, to indicate finger positions, has been considered, similar to that devised and proposed by Lewis Jones,[126] and documented by Patrick Ozzard-Low, who also suggested that 'players do not want to look at the fingerboard when performing'.[127]

(e) Percussion (Framed set of Chinese opera gongs / Timpani / others)

Compared to *Autumn,* Percussionist 1 employs a larger number of instruments in the second movement, including a framed set of Chinese opera gongs. As rhythms keeping the relations of three irrational numbers are used for this part, and considering the difficulty of playing fast passages on an instrument of such dimensions, the preparation of an audio-visual musical instrument (AVMI as explained on p. 40) simulating its performance could reduce substantially rehearsal time in this case. This set of Chinese opera gongs is derived from the alternative instrument design process that took place in parallel with the development of and composition for the *conic bellophone*, supporting the positive effect that this parallel design process has in the overall output. The sliding pitch element of the

[126] Ozzard-Low, P. *21st Century Orchestral Instruments.* p. 86.
[127] Ozzard-Low, P. *21st Century Orchestral Instruments.* p. 85.

Chinese opera gongs' sound relates to and magnifies the gliding tones previously used by the *conic bellophone*. This new instrument is used to introduce the opening of the *conic bellophone*'s leading role at the start of the second movement.

The rest of the percussionist's instrumentation has been left open in the draft score, by indicating aspects of the instrument to be used through a set of basic symbols that indicate the nature of sound required.

(f) *Extended conic bellophone / sopranino conic bellophone/ bass conic bellophone*

The additional augmented fourth range above the octave range already encompassed by the *conic bellophone*, is required for the second movement of *Seasons,* so as to allow the composition process to make relevant the non-octaval nature of the scales drafted for the second movement.

Considering that *Autumn* has been initially adopted as the first movement of the draft of *Seasons* included in this thesis, the bellophone part in the two additional movements has a solo functionality not explored before: (1) although the *conic bellophone* part uses very complex rhythms in the first part of the second movement,[128] it suggests an improvisatory style of writing, based on the indicated non-octaval scales and chords, alternating them with notated sustained notes and patterns from the other instruments in the first section of the second movement, (2) a merely sliding part in the second part of the second movement combined with the continuous sliding part of the timpani and a third instrument providing a sliding part, produces a unique or chord that has the quality of a whole solo sound with gradual changes of texture accompanied by the rhythms of the other parts, and (3) a final movement where a solo bellophone part using chords and clusters as notes is accompanied by an already minimalistic structure has been suggested (to be elaborated).[129]

The *sopranino conic bellophone* is played with the *extended conic bellophone* (bars. 73-92) to colour the texture with its peculiar sharp sound quality: both attack and decay are extremely sharp, lacking resonance. The *bass conic bellophone* was designed to extend the bellophone sound into a lower range in the second and third movements, but due to the

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[128] Notice that the melodic and rhythmiucal structure has been notated but still has to be shaped.

[129] For the moment *conic bellophone* chords following a sequence of n-tuplet rythms increasing and decreasing the n value while also building up the sequence have been simply been placed in a form of study and only using the 12-et, although this has to be composed from the musical point of view still keeping the a wide range of elements so its pedagogical value is kept at the same standard or extended.

complexity of experimenting with bronze, a prototype was not built in time to consider, and the idea has been discarded.

3.3.4.2 *Seasons* – Structure

The structure of this work is based on pattern 'A' (Fig. 123), which is followed by its quadruple augmentation (4xA) in duration and then its triple augmentation in retrograde (3xA(R) or $3xA^{-1}$), following the pattern 1-4-3.

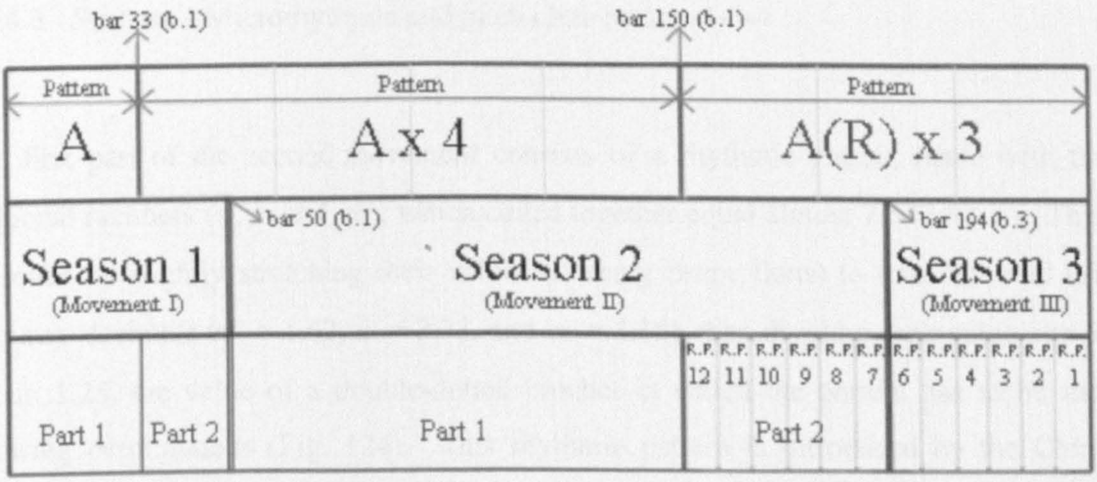

Fig. 123. *Seasons*: structure.

The first movement, named *Season 1*, keeps the piece Autumn intact in this draft submitted for the thesis, apart from the ending sound produced in the last bar which adds a wind machine serving as a transition for the second movement (*Season 2*). In the first part of the second movement all the non-octaval tunings that can be generated with the 96-et by choosing uneven steps are applied systematically from 5-step scale onwards, and although in the draft (Sc. 12), only the details for the first seven scales (indicated as 'NO' for non-octaval and followed by the number) are specified and alternated with timbral experimentations (indicated as 'T' and followed by the number of the corresponding non-octaval scale) which consist of chords played using the notes of the indicated scale.

The internal structure embracing the second part of the second movement and the whole third movement (together being the third pattern of the macrostructure 'A(R) x 3'), consists of twelve pairs of rhythmic patterns (see RPs 12 to 1 in Fig. 123). Each pattern is repeated several times to create a four-voice texture, allowing the bellophone (accompanied by the timpani in most passages) to take a solo role. The four-voice texture is based on bass clarinet, C trumpet, trombone and cello. This macrostructure 'A(R) x 3' first uses fast versions of the rhythmic patterns implied (RPs Nos. 12, 11, and 10), then moves into stretched versions of the patterns with glissandi (RPs Nos. 9, 8 and 7), to finalising with a progression of rhythms gradually employing shorter durations without altering the main structure, which consequently leaves rests across the texture and leads to an overall slower pace toward the end of the work (RPs Nos. 6 to 1).

3.3.4.3 *Seasons* – Microrhythmia and pitch class pattern 1-3-4

The first part of the second movement consists of a rhythmic pattern made with three irrational numbers (φ, e, and π), which added together equal almost 7.5 (7.47...). This is achieved by slightly stretching their values (keeping proportions) to total 7.5, and using only two decimals (φ' = 1.62, e' = 2.73, and π = 3.15), then dividing their value into 6 to obtain 1.25, the value of a double-dotted crochet in which the pattern has to be fitted, allowing permutations (Fig. 124). This rhythmic pattern is introduced by the Chinese opera gongs (Fig. 124) and used mainly by the *conic bellophone*, although the other instruments either fit into the pattern or use it starting at different points to produce counterpoint in most cases.

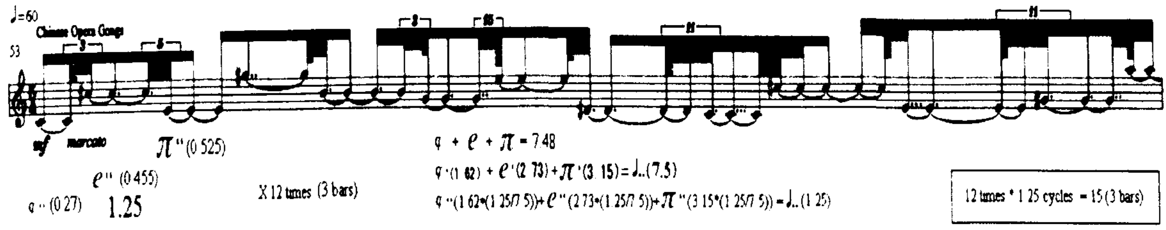

Fig. 124. *Seasons*: approximation to irrational rhythm (Chinese opera gongs).

Fig. 125 illustrates how the pitch class pattern 1-3-4 and its variations are combined with the rhythmic pattern. Twelve pitch classes are indicated in the top right area of the diagram, indicated from left to right: 1 to 9; then followed by 0, 1, 2 (and the three which is not used as it refers to the octave of the 1 on the left of this area), referring to 10, 11 and 12. On the left of the diagram, the note number in the timeline, which moves downwards in the diagram, is indicated. The next cell contains the number of the bar it belongs to. The following cell contains the number of the beat before the note starts, the number of semiquaver durations between that beat and the start of the note, and the number of ticks between the previous semiquaver and the start of the note.[130] In this way, going downwards on the left side of the diagram, the position of the beginning of each note is precisely indicated, while the pitch value of the note is indicated in the right area of the graph with a dark grey square. In order to understand when each irrational number has been used, a square matching vertically the corresponding irrational number and with a number inside indicating how many times each rational number has been used in the pattern is indicated in the middle area of the graph, since the pattern has to close exactly on the first beat of the fourth bar (not indicated in the diagram, but reached using the *pi* related duration). Therefore, although the three durations related to each irrational number have two decimals in time positioning and are not strictly used until the other have been used, at least the pattern can find an ending position on the beat.

The 1-3-4 steps pattern is not strictly followed either, nor the 12-note sequence rule, although the employment of all the pitch classes and the steps 1, 3 and 4 semitones is kept as equal as possible while trying to draw a melodic contour with the pitch classes.

[130] In MIDI standards there are 240 ticks per semiquaver.

Note	Bar	beat-sem.quav-tick	phi	e	pi	1	2	3	4	5	6	7	8	9	0	1	2	3
1	1	1 - 1 - 1	1	3	4	■												
2	1	1 - 2 - 21	1				■											
3	1	1 - 3 - 217		1						■								
4	1	2 - 2 - 1			1									■				
5	1	2 - 3 - 197		2													■	
6	1	3 - 1 - 221			2								■					
7	1	3 - 3 - 178		3						■								
8	1	3 - 4 - 197	2						■									
9	1	4 - 2 - 153		4		■												
10	1	4 - 3 - 173	3				■											
11	1	5 - 1 - 129		5						■								
12	1	5 - 3 - 153			3									■				
13	1	5 - 4 - 173	4												■			
14	2	1 - 2 - 197			4						■							
15	2	1 - 3 - 217	5							■								
16	2	2 - 2 - 1			5	■												
17	2	2 - 3 - 197		6					■									
18	2	2 - 4 - 217	6							■								
19	2	3 - 3 - 1			6									■				
20	2	3 - 4 - 21	7												■			
21	2	4 - 1 - 217		7								■						
22	2	4 - 4 - 1			7			■										
23	2	5 - 1 - 21	8				■											
24	2	5 - 3 - 45			8						■							
25	2	5 - 4 - 64	9									■						
26	3	1 - 2 - 89			9											■		
27	3	1 - 4 - 45		8									■					
28	3	2 - 1 - 64	0									■						
29	3	2 - 3 - 21		9					■									
30	3	2 - 4 - 40	1					■										
31	3	3 - 1 - 237		0							■							
32	3	3 - 4 - 21			0										■			
33	3	4 - 1 - 217		1								■						
34	3	4 - 4 - 1			1			■										
35	3	5 - 1 - 197		2							■							
36	3	5 - 2 - 217	2									■						

Fig. 125. *Seasons*: Rhythmic pattern (with *phi, e* and *pi*) and pitch pattern (using 1, 3 and 4).

The pattern of rhythm and pitch is repeated using adjustments for the closest note in the non-octaval scale indicated for each section in the first half of the second movement (see how this is drafted in Sc. 12). These microtonal variations of the pattern provide the sensation of the melody being slightly out of tune in different ways each time, as if a pattern was being followed, changing the speed of the turntable on a record player, while the rhythmic pattern based on irrational numbers emphasises this effect by providing a sensation of the durations being slightly shifted. These aesthetics, creating the sensation of minute shifts of durations and tempo, make the repetition of the pattern not sound repetitive.

Pitch and duration have proven to have parallel behaviour when considering micro-values, and in this case the use of micro-rhythms has the effect that microtonality intended to produce throughout this first half of the second movement.

Chapter Four: Contribution to the field

This chapter draws together and explains the output of this research and the contribution made to the field. This is achieved in three stages and a concluding section:

(1) A selection of relevant research applications.

(2) Future projects envisaged arising from this work, both those initiated during the concluding period of this research but not included here, and those that are planned for the future.

(3) The potential of this research, including an explanation of ideas and concepts derived from this work, which ideally should be implemented and corroborated through subsequent musical practice.

(4) A general conclusion to the research project.

4.1 Applications of the Research

This research provides new perspectives and strategies for the composer interested in microtonality and sliding pitch, by presenting a method conjointly incorporating both instrument making and composition. It arises from a detailed review of relevant work by Julián Carrillo and Harry Partch (studying their use of microtonality and sliding pitch, classifying their instruments and reflecting upon statistical data which illuminates the microtonal and sliding capabilities of the instruments used in their music), who are identified as instrument-development-led microtonal composers. This research method proposed is so designed as also to accommodate compositional parameters other than pitch. The work of Carrillo and Partch thus influenced my development of a new musical instrument, the *conic bellophone*, which incorporates characteristics stemming from its prototypes and conceptual variants (here presented). To exemplify the instrument-development-led research strategy, a portfolio of original compositions is developed and presented (scores and recordings), with explanations providing a reflective view of how this multidisciplinary method was applied. This systematic, practice-led exploration of pitch resources can be further applied in several other fields of work, and can help to open up new multidisciplinary and collaborative creative endeavours, as described below in fourteen sections.

4.1.1 Music history approach to the study of instrument-development-led composers

This research has assessed the significance of the work of Carrillo and Partch in the field of pitch, and has compared their development of new and adapted instruments, work that they incorporated into their own compositional process. The results of this comparison demonstrate the value of bringing to prominence, through close scrutiny, the contributions of other composers who have worked in the microtonal sphere, with sliding pitch and in instrument-development-led composition. The strategies used here to study Carrillo and Partch could also be applied or adapted for the study of aspects of pitch organisation other than sliding and microdiscrete, or to consider a musical parameter other than pitch.

4.1.2 Instrument-development-led composition as a discipline

Patterns observed in Carrillo's and Partch's multidisciplinary approach to composition, and the research method derived from them (see Fig. 5, p. 13), which integrate instrument development and composition, indicate that instrument-development-led composition can be recognised as a compound discipline in its own right, rather than being viewed merely as an interdisciplinary approach to composition. One of the major contributions of this research, which propounds the potential of this discipline, is the method proposed. This method is intended to be flexible enough to incorporate musical parameters other than pitch (or combinations of parameters), strictly within the boundaries of instrument-development-led composition, thus signalling its importance for future research.

4.1.3 Pedagogy and the discipline of instrument-development-led composition,

Inspired by Carrillo's efforts to reform the musical institutions of Mexico, pedagogical matters brought to light by this research have been examined and reflected upon. In this research, the pedagogical value of compositions, the devised method, and the study and evaluation of compositional parameters related to instrument development are exemplars of a potential new discipline, here referred to as instrument-development-led composition. This discipline is envisaged as an integration of several new and some familiar subjects, such as: non-Western instruments, Western folk instruments, early Western instruments, experimental instruments, method development, 3-D design integrated with MIDI (and with sound samples), tunings, theory of sound projection, architectural acoustics, electronic music theory, music composition, creative and comparative instrument design, conceptual organology, [131] materials science, geometry, conceptual instrumentation, mechanics for mechanised musical instruments, instrument making (theory and practice), database design and dynamicism (explaining the compositional parameters with dynamic and static potential, or *PADTS* – see Abbreviations). The ergonomics of instrument design could also be given strong emphasis. Of most importance, however, would be to work with software developers on a platform allowing the importation of 3-D design to automatically create a MAVMI.[132] Such software would also need to visualise surfaces assigned to musical notes and their linking to samples, which would produce 3-D simulations of the instruments, summarising what a programmer might produce to generate a simulation of, for example, the *conic bellophone*. Adding MIDI facilities would allow the production of demonstrations of any composition (in MIDI format) to be virtually played or using mechanised instruments. Using this software could be another facet of instrument-development-led research, and it would also usefully provide visual training for performers, before they come into contact with the instrument. Details about most of these potential subjects of study are provided in throughout the rest of the chapter.

4.1.4 Instrument development theory (the virtual instrument and the creative-comparative instrument design approach)

Reconceiving the concept of the musical instrument as an idea rather than just a physical artefact can be supported by audio and visual 3-D simulation of instruments. For this reason, the trial and error approach initially employed here allows design processes to be employed to compare alternative versions of the instrument being developed. The variant conceptual designs not only provide feedback to the composer but also enlarge the

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[131] Here referring to the classification of instruments that do not exist (conceptual instruments) together with the one that do exist.
[132] Previously defined as a MIDI audio-visual musical instrument (see p. 40).

instrumentation possibilities afforded in composition. Instrumentation according to instrument characteristics (referring either to existing and non-existent instruments) is here denominated conceptual instrumentation.

A creative-comparative method of developing various prototypes of an instrument design has been proposed (Fig. 5, p. 13) as part of the instrument development-led composition method. This method can be applied in other contexts, to inspire the comparative process when comparing existing instruments from different cultures or historical periods (the creative mind can suggest conclusions before they have been proved) or vice versa.

4.1.5 A conceptual approach to instrument-development-led composition

The instrument-development-led approach to composition proposed and applied in this research does not rely upon selecting instruments prior to composing (instrumentation); rather, it defines instrument characteristics which, through several prototypes, interact with the composition process. This interactive approach differs from the concrete approach of Carrillo and Partch, who mostly developed their instruments prior to composing. The interactive approach taken a step further: the composer could experiment, still treating the instrument as a concept but avoiding direct instrument development, so that the instrument is built afterwards to match the needs of the composition. For this reason, a pictographic notation for the conceptual instrument(s) could be used to represent the characteristics of the instrument(s) used. This would allow the composer quickly to notate what instrument or modified instrument a specific musician is expected to play at any point, by changing the pictogram in the score, as required, while the music is being notated. This approach allows the instrument-development-led composer (or instrument developer experimenting with composition) to conceive of one or more instruments, based on the desired properties notated for each instrumentalist, once the score has been completed.

The development of a standard conceptual pictographic notation system would require a classification system for conceptual musical instruments. This suggests a new area of musicological research, which is treated separately in the following section.

4.1.6 Conceptual organology

The term conceptual organology is here introduced to refer to the classification and scientific study conceptual musical instruments. Such study is necessary as a foundation of conceptual instrument-development-led composition, and both subjects should co-exist with each other. The pitch-based classification system proposed in this research, and applied here in an organological study of Carrillo's and Partch's instruments, has the potential to be extended to achieve a classification of conceptual instruments in general, encompassing both form and sound.

Three organological classification schemes have informed the development of the scheme proposed (pp. 338-344) and the subsequent study of pitch-related aspects of the instruments of Carrillo and Partch: the long-established Hornbostel-Sachs system, and the more recent systems of Kakinuma, and Lysloff and Matson. Kakinuma extends the work of Hornbostel and Sachs to accommodate the instruments of Partch (p. 338); and Lysloff and Matson classify instruments into two main groups: sound (see p. 370-371) and form. This research combines and extends ideas from these three classification systems in order to describe and classify the instruments of both Partch and Carrillo, using two codes linked by a hyphen (e.g. 111.232.225-4-P_{32}-(△)-P for The Boo I):

(1) The first, an addition to the Kakinuma classification code to accommodate Carrillo's instruments.

(2) The second, a description of the pitch capabilities of the instrument, represented by a letter 'P' (for pitch) plus two numerical subindexes representing defined criteria for glissando and microtonal capabilities respectively (e.g. '-P_{14}', representing instruments with microdiscrete-sliding-pitch capabilities and a smallest contiguous interval between 0.12 ¢ and 1.2 ¢), a symbol describing the origin of the instrument (e.g. '-(■)' representing adapted non-orchestral Western instruments), and an initial representing the developer (e.g. '-C' for Carrillo).

The coding system applied in this research can be extended to describe conceptual instruments in detail in two parts:

Part 1. Reviewing the first part of the code to accommodate conceptual instruments emerging from exploration of new possibilities (e.g. instruments with spatial sound projection or those capable producing gradual changes of timbre), avoiding changes in the existing code.

Part 2. Incorporating initials for additional parameters, and subindexes to refer to appropriate criteria. If the capabilities of the instrument are defined in relation to all *PADTS* parameters, the initials of this acronym could be used with as many subindexes as necessary. If two subindexes for each parameter are used it would be represented as: '-$P_{xx}A_{xx}D_{xx}T_{xx}S_{xx}$'.

This further elaboration of the classification coding initially proposed in Chapter 1, can be used for conceptual organology – as an expansion of the discipline of organology.

4.1.7 The multiform *conic bellophone*

The development of the *conic bellophone* has involved fourteen prototypes, six of which employ sixteen independent stands, which are normally arranged in a semicircle for a single player, but which alternatively can be disposed in an infinite number of configurations within the performance space. A composer desiring to use the *conic bellophone* can choose from among the several prototypes and, when adopting one of the 16-stand prototypes (prototypes 8 and 10-14), the possible distributions of the stands. The prototype might be selected to respond to the visual aesthetics of the other instruments to be combined with. The 16-stand prototypes can also be used to achieve spatial projection of sound when strategically placed around the performance space.

4.1.8 3-D prototype simulation

3-D simulation of the *conic bellophone* has provided a never-ending store of ideas, many of them directly related to instrumentation and to how this pitch research could be taken a step further if the same method was used for the study of and experimentation with parameters other than pitch, or of combinations of parameters. For example, if spatial sound projection was being studied simultaneously with pitch, the spatial distribution of the sounding bodies (or several instruments) could be considered, particularly when a pitch-sliding effect is conceived moving around the space. In that case, surround sound technology combined with virtual instrument(s) could be employed to produce accurate simulations.

Taking this a step further, 3-D representation of instruments and the performance space could expand what Partch, for example, achieved with his cardboard models of stages and instruments, which were used mainly for planning concerts and for orchestrating his works.[133] 3-D simulation of musical instruments allows for more experimentation, and is faster, more flexible and portable than physical models. Thus, computer technology, and particularly sound generation software combined with 3-D graphics and surround sound, which are potential feedback instrumentation tools for the instrument-development-led composer, could replace the time-consuming development of prototypes, for example when developing MIDI-mechanised instruments, as explained in § 4.1.9.

4.1.9 MIDI-mechanised instrument-development-led composition with *PADTS* parameters with 3-D prototypes

The method proposed and applied in this research in regard to pitch has been elaborated so it can equally be utilised with the *PADTS* parameters other than pitch, and ultimately extended to combine simultaneous treatments of these parameters from the microdiscrete and dynamic perspectives. Instruments with such capabilities would be highly complex to play, but an interactive development, simultaneous with the cat of composition, of MIDI-mechanised instruments would allow the complexity to be reduced to human capabilities. Although the development of multiple physical prototypes would entail a great amount of work, 3-D instrument-simulation MIDI software attached to MIDI controllers (e.g. turntable, pedals, and interactive applications in tablets) could be used to avoid the physical development of prototypes, while also – by using the desired MIDI controller – allowing interaction between the composer and the instrument.

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133 Blackburn, P. 1997. *Enclosure 3: Harry Partch*. pp. 268-269.

4.1.10 Compositional theory – microdiscretism and dynamicism of the parameter

This research has focused on pitch. Its dynamic and micro-discrete elements have been treated separately and in combination with instrument development practice. Thus, the same could be done for other *PADTS* parameters different to pitch, for implementing an instrument-development-led compositional theory aiming the microdiscretism and dynamicism of the musical parameter. Apart from being a research application, this is also a significant research potential, and is expanded in §4.3 (pp. 216-218).

4.1.11 Polymicrotonal Notation

Sixteenthtones have been used in this research to explore non-octaval scales as well as to approximate to just intonation intervals using the *conic bellophone*. Divisions of the sixteenthtone were not considered necessary, since achieving beatless partials could not be appreciated with the fast decay sound of a *conic bell* (which also has partials beating within its spectrum). However, using sustained sine waves, the centesimal division of the sixteenthtone is here regarded as the maximum multiple-of-ten division required to approximate most of the intervals that might be needed in a polymicrotonal composition. Such polymicrotonal music could be notated by combining a two-digit number above the notehead with the sharp accidentals of extended Stein-Couper notation (proposed on p. 58), to specify the percentage of a sixteenthtone by which the note is sharpened. A recent incorporation to *Sagittal* notation affords an alternative approach to notating such divisions is:[134] additional commas are added to the regular *Sagittal* accidentals to represent the notes of 9600-et.[135]

4.1.12 Ethnomusicological study of tunings and dynamic musical parameters

The proposed 96-et notation system (extended Stein-Couper, p. 58) could be used to notate microtonal passages in ethnomusicology studies and percentages on top of notes placed on top of the notes for greater approximations (9600-et).

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[134] Secor, G. D. and Keenan D. *Sagittal.* 2001-. *A Microtonal Notation System.* <http://sagittal.org>

[135] This system was developed by the creators of *Sagittal* notation in collaboration with the author between July and December 2008.

In the same way that microdiscrete-sliding pitch has been used here to recreate sliding pitch contours (see scores 1 and 3) it could be used to map changes of pitch in time, such as pitch glides, ornaments, Indian raga, etc. Notating a specific rendering of a raga with accuracy would also involve notating the gradual changes of amplitude in time.

4.1.13 Bells with alternative conical geometry

This research defines different alternative kinds of essentially bells with conical geometry, which can be used as a starting point for further research into forms, materials and methods of manufacture. These are plates, cymbals-like shapes and tubes.

4.1.14 Layered instrument-development-led composition

In this research, three layers of simultaneous composition projects have interacted with each other through sharing techniques and bellophone prototypes (Fig. 29, p. 73). Overlapping bellophone prototypes in the timeline, which have shared compositional ideas, have informed the progress of instrument development. By interacting with each other through sharing common compositional projects, prototype and conceptual instrument development have informed the instrument development process, and have informed compositional technique and practice. In general, simultaneous composing and instrument development have provided mutual flourishing through comparison, and consequently have improved the outcomes of the interactive instrument-development-led composition process here employed. The basics behind this layered strategy to instrument development-led composition could also be employed to explore other approaches that are not interactive such as the conceptual (treating instruments as a concept throughout the composition process) and the concrete (with specific pre-existent instrument) approaches, or combining them.

4.2 Future projects following the research

4.2.1 Sliding and microdiscrete-sliding-pitch notation

The pitch continuum can be accurately notated on graph paper, using the horizontal axis as time and the vertical axis as pitch. In this way precise pitch contours can be traced, as can fractions of the pitch continuum. They are notated as discrete fixed pitches rather than as a continuum. In the process of sketching some of my works, fixed pitches were marked with straight horizontal lines, and dynamic pitches with curves (pitch-time graph). An accurate pitch-versus-time graph, requires the use of a lot of space on the page. Having the score for the parts (or solo work) with a video (or software) enlarging the section to be played with a pitch-time graph on a grid gradually moving from left to right, would resolve problem of constantly turning pages. Each performer would then require a tablet, moving the section of the score being played at a previously decided tempo, or having speed of the movie-score (or notation monitoring software) to interact with the tempo that is being played, or controlled by a musician (if a MIDI-controlled capability is incorporated).

4.2.2 The *dynamic piano* and the *dynamic baton*

The *dynamic piano* and the MIDI controller, previously mentioned as variant conceptual instrument set (p. 148), are explained here in detail. The *dynamic piano* consists of eight Disklavier pianos, tuned a sixteenthtone apart from each other, arranged in a circle around a room. By linking a MIDI tempo controller (e.g. pedal or turntable) to a sequencer containing the composition data (pitches, durations and amplitudes, etc.), a performer can match the desired tempo while sounding microdiscrete-sliding parts, panned so they move strategically around the space (e.g. a descending sixteenthtone chromatic scale moving around the room in a circle). When combing the *dynamic piano* setup with an ensemble, the conductor can use a MIDI tempo controller (slide potentiometer with MIDI decoder system) attached to the baton (here termed the *dynamic baton*), to match the desired tempo of the sequencer playing the *dynamic pianos* the ensemble conducted. Although a performance of a work for *dynamic piano* and ensemble using the *dynamic baton* would require eight Disklavier pianos tuned twice the day before, in rehearsal the eight pianos can be substituted for by an 8-channel sound system attached to the sequencer, using piano samples. The conductor can also practice using the *dynamic baton* with such a setup.

4.2.3 The space as a musical instrument: the *Snowdome*

The auditorium here proposed augurs well for future exploration of spatial projection. The *Snowdome* was devised as the ideal concert hall for accommodating a ring-shape (or spiral-shape) orchestra and a ring-shape stage. The auditorium is supposed to incorporate sound manipulation umbrellas (by means of changing the shape of the ceiling) on the top half and to have a roman amphitheatre-like stage with seats arranged in rings that gradually get smaller as you go further down. This concert hall design is still in its infancy and would probably require the ring-shape stage to be placed at a lower position so that there are rings with seats above and below the stage, to improve visibility (rather than relying on mirrors). By placing a solo performer in the middle of the sphere, natural amplification would be very powerful though it could always be reduced and modified with the shape-changing umbrellas. In the same way that the *dynamic baton* controls the mechanised instruments it could also control gradual changes in the acoustics of the hall by having a MIDI interface attached to the morphing umbrellas on the roof in a similar way to current MIDI lighting practice. The upper and lower removable arenas are supposed to accommodate additional performers according to the needs of the composition (see fig. 126).

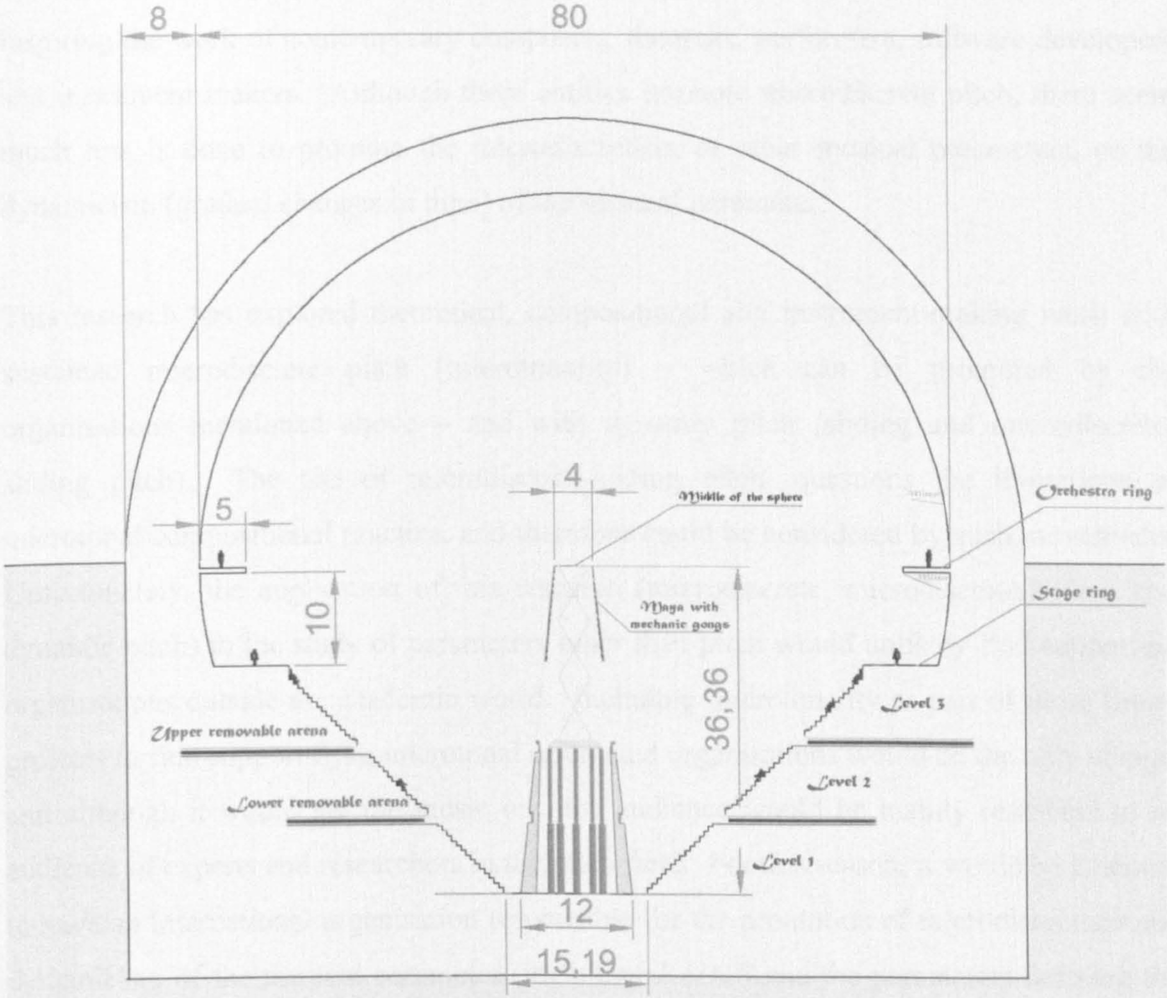

Fig. 126. *Snowdome* (measures in metres)

4.2.4 Institutions and events promoting and coordinating microdiscretism and dynamicism of musical parameters

There are several institutions, organisations and festivals around the world responsible for promoting microtonal music: the Boston Microtonal Society, the American Festival of Microtonal Music (New York), and Microfest (Southern California), all based in the USA; Microtonal Projects, and UK Microfest, both based in the UK; Euro Microfest, based in Germany; The Huygens Stitching Foundation, based in The Netherlands; and the Ekmelic Music Society in Salzburg (Austria). These have played important roles in the recent decades in rescuing the work of little known microtonal composers of the past, and in inspiring the work of contemporary composers, theorists, performers, software developers and instrument makers. Although there entities promote microdiscrete pitch, there seem much less is done to promote the microdiscretism of other musical parameters, or the dynamicism (gradual changes in time) of the musical parameter.

This research has explored theoretical, compositional and instrument-making work with sustained microdiscrete pitch (microtonality) – which can be promoted by the organisations mentioned above – and with dynamic pitch (sliding and microdiscrete-sliding pitch). The use of microdiscrete-sliding pitch, questions the limitations of microtonal compositional practice, and therefore could be considered by such movements. Unfortunately, the application of this research (microdiscrete, microdiscrete-sliding and dynamic pitch) to the study of parameters other than pitch would unlikely find supporting organisations outside the academic world. Including microtonality as part of these future projects to find support from microtonal orientated organisations would be the only choice, and although it would get the music out, the audience would be mainly restricted to an audience of experts and researchers in the pitch field. For this reason, it would be essential to have an international organisation responsible for the promotion of microdiscretism and dynamicism of the musical parameter (including *PADTS* and the parameters defining the conceptual musical instrument). This organisation would ideally promote research, composers, instrument developers, and instruments (including mechanised and electronic), through lectures, workshops, and concerts.

4.2.5 A descriptive instrument database

A project to produce a database holding data for physical characteristics and sounding capabilities of musical instruments, has been envisaged for the support of instrumentation and instrument development in future composition projects. The database intends to be flexible to incorporate as much detail as new data is being added. Once the database is completed it will be extended to incorporate conceptual instruments gradually incorporating new elements of sound and form emerging from a parallel experimentation with *PADTS* parameters different than pitch in instrument-development-led composition. This idea will also target to gradually shape the structure of a conceptual organology coding system.

4.2.6 A square hybrid multi-percussion instrument and ten-by-ten numerical notation

On §2.3.4 (pp. 125-127) the square layout is introduced: a ten-by-ten frame where sounding bodies of any pitch or with any sound activation process can be accommodated is proposed. This does not necessarily have to be related to pitch or action, but could involve materials (especially for struck instruments), for example; the performer would use the same notation, no matter what bodies are to be sounded. Thus a wide range of sounds could be available for a single instrumental part, consequently expanding the instrumentation possibilities for an ensemble work. Only the sounding bodies to be sounded would have to be placed. It is important to remark that what seemed to be the less promising and productive group within this research (square layouts), has inspired a new conception of adaptable musical instrument supported by one single notation system. An alternative to this would be a MIDI instrument as a controller for the mechanised systems required. Also notice here that the Carrillo numerical notation with two digits could cover the 100 notes.

4.2.7 Drafting and sketching compositions

A total of three sketched compositions, as proposed in the research method and documented in the composition portfolio, have been included in the thesis. They demonstrate the continuity of the work and the layers of overlapping output. One of the sketched works consists of improvisatory patterns for two players and requires a linear layout of the *conic bellophone*. This was also recorded. It needs to be compared with the original notation so that these new elements can be introduced into a new piece with 4 hands on the *conic bellophone*. New layouts, using stands placed around a room need to be devised as a way to explore micro-discrete pitch in future spatial projections.

Another sketched work involves a piece for *conic bellophone* and Sixteenthtone Guitar which attempts to incorporate the one and a half version of the *conic bellophone* with a MIDI-mechanised device and a pedal that controls the tempo of the MIDI file. This will allow a guitarist with a sequencer containing the bellophone part on a MIDI file to play the work controlling the tempo with the pedal while playing. This work will attempt to employ dynamic elements of all the *PADTS* parameters.

The last of the sketched works is an expansion of one of the completed works, intended to link and integrate all the work from the very beginning of this research. In this piece, each section of the orchestra, is represented by one or two players to reduce the cost. This also increases the practicability of performing and receiving feedback. Since this work includes the *dynamic piano* and *dynamic baton*, only 5 players apart from the conductor are required. In the future, works extending the range of players and timbres from different sections of the Western orchestra are envisaged.

4.2.8 Sketched instrument and MAVMI developments

As a way to explore further the potential of the three-dimensional design of the *extended conic bellophone*, simulating a virtual performance while manipulating the instrument's position in the space, was considered and suggested to the programmer. At that stage, the consulted programmer Daniel Garland, produced an interactive 3-D *conic bellophone*. Including a link to external MIDI files was requested, with the pedagogical potential of this in mind, but was not developed due to the limitation of the JAVA platform and the software used (3-DXD).

Other sketches presented in this thesis have the potential to be developed in MAVMI format in order to serve as:

1. A portable pedagogical tool for the performer
2. An interactive instrumentation tool for the composer
3. A portable demonstration version of the instrument
4. A testing instrument, allowing sound changes when experimenting with other materials, resonators, buzzing membranes, and sympathy bodies, etc.

4.3 Research potential: dynamicism and microdiscretism

Dynamicism in music is used here with reference to the concept proposed by Tim van Gelder from the cognitive science discipline, which argues that differential equations are more suited to modelling cognition than traditional computer models.[136] According to van Gelder, natural cognition is a dynamical phenomenon and best understood in dynamic terms.[137] This concept shows pitch perception is a dynamic phenomenon, which is best understood in dynamic terms. A mellograph is a pitch-versus-time graph. By looking at a mellograph of Western music it is easy to realise that pitches are usually sustained, and that Western music thus ignores the full scope of the pitch possibilities, which our ears are able to perceive. The term pitch dynamicism is defined as a characteristic applying to any music that makes use of long sustained tones capable of continuous changes in pitch. Karnatic (South Indian Classical) music's use of embellishments (gamaka),[138] and Percy Grainger's works for his Free Music Machines,[139] can both be said to have pitch dynamicism. Consequently dynamic pitch is defined here as the pitch value of a note which changes its value gradually in time, in contradistinction to a pitch that remains static for the duration of the note. It is very difficult to introduce the concept of pitch dynamicism to a musical tradition that is not familiar with using it. For this reason, Grainger started with his sixthtone butterfly pianos, and later on moved on to an eighthtone giant harmonica (with a system equivalent to piano rolls). These instruments divided the pitch continuum into discrete pitches to allow simulations of sliding pitch.[140] Grainger did not consolidate a compositional technique for these instruments, and continued to produce Free Music Machines for the rest of his life, so as to have dynamic pitch constantly played with the best resolution possible. He always used several parts played by oscillators, which were regulated by pitch contour graphs placed on rolls. Grainger's inventions were far in advance of his dynamic pitch compositional technique; he used them as compositional tools. That it was difficult for Grainger to get a satisfactory result composing with feedback obtained from hearing the machines, shows how much more difficult would it have been for live performers to deal with the music.

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136 Port, R. and T. J. Van Gelder. 1995. *Mind as Motion: Explorations in the Dynamics of Cognition.*
137 Van Gelder, T. J. 1999. *Dynamic Approaches to Cognition.* pp. 244-6.
138 Pesch, L. 1999. *The Illustrated Companion to South Indian Music.* pp. 73-78.
139 Linz, R. 1997. The Free Music Machines of Percy Grainger. *Experimental Musical Instruments.* pp. 10-12.
140 Linz, R. 1997. The Free Music Machines of Percy Grainger. *Experimental Musical Instruments.* pp. 10-12.

Non-linear pitch slides can be found in many twentieth century music scores,[141] but they have never been standardised. Partch, for example, in his early works for voice and Adapted Viola, left the interpretation open to the performer, although he worked very closely with them and also performed himself on several occasions. However, though his notation might suggest considerable freedom of interpretation, his recordings give more guidance for passages containing sliding pitch, as they present an interpretation in which the pitch slides follow curves rather than straight lines. In the case of Carrillo, non-linear pitch slides can be found in cello parts or parts for other sliding pitch instruments, and while they are represented with straight portamento lines, the pitch contour has to be rounded by the performer, which suggests some freedom of interpretation. Both composers used non-linear microdiscrete-pitch slides, clearly notated note-by-note (or starting and ending notes), thereby defining precise pitch contours with less room for free interpretation. In Carrillo's case, this was done with his sixteenthtone instruments (especially the *sixteenthtone piano* and *sixteenthtone harp*) where he used the sixteenthtone as a uniform step for microdiscrete-sliding pitch. In the case of Partch, the unequal steps of a self-devised 43-tone-per-octave just intonation tuning still provided small enough steps for the microdiscrete-pitch slides to be perceived smoothly.

Although the aim of this research was not to study dynamicism comprehensively, the work developed here anticipates what only future practice and study of such practice can provide. Other compositional parameters not mentioned are considered secondary, since they can be defined combining several *PADTS* parameters. This is only a speculation and leaves the area open for future research.

Unlike most Western music, Indian Classical *raga* music mostly treats pitch and amplitude dynamically. These dynamic pitch and amplitude features, applied systematically, are responsible for rendering a *raga* which departs from a scale. However, in *raga* music, tempo, timbre and spatial sound projection are primarily static. Non-Western and new

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[141] As opposed to linear representations (notated as portamento or slide with a straight line from starting note to ending note).

experimental musics afford perspectives on how these parameters can be articulated. In combining dynamic pitch with dynamic and static treatments of the other *PADTS* parameters, there are sixteen possible combinations (Fig. 127), and a further sixteen possible approaches to static pitch. This makes a total 32 different ways of combining *PADTS* parameters that the composer can consider in a composition.

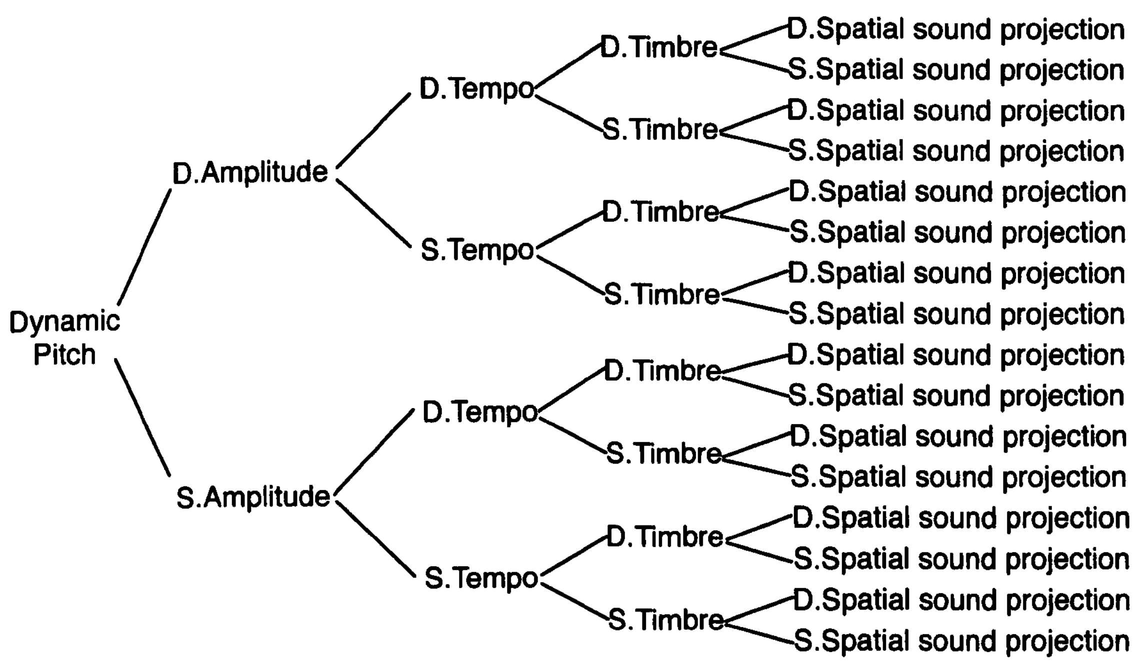

Fig. 127. Subcategories of dynamic pitch considering *PADTS* parameters (D=dynamic/S=static).

It is beyond the scope of this research to explore all these subcategories, but the open-ended instrument-development-led composition method devised (p. 13, Fig. 5) and applied within this research project, has the potential to support such research.

4.4 Conclusion

Following a review of the work of Carrillo and Partch, an instrument-development-led composition method has been developed to explore pitch resources. A case study, defined and enacted in the areas of microtonality and sliding pitch, has provided a comprehensive body of instrument-development-led practice and compositional output. The other major result of this research has been the design and construction of an instrument with microtonal and microdiscrete-sliding-pitch properties: the *conic bellophone.* This instrument, the resulting portfolio of compositions for it (demonstrating wide-ranging use of microtonality and sliding pitch), and the recording of some of the works that contributed to the design of the instrument, have illustrated the wider applicability of the research method proposed.

Glossary

Tuning theory

-et	Equal temperament. For example, 12-et stands for twelve-note equal temperament.
-cet	Cents equal temperament.
sixteenthtone	Sixteenth equal division of the 12-et tone.
macrotonal	Microtonal, excluding intervals smaller than the 12-et tone.
microdiscrete-sliding pitch	A simulation of sliding pitch by means of playing microtonal, discrete pitch divisions.
ultrachromatic	Term used by Julián Carrillo meaning extensive divisions of the tone, unlike 12-et which divides the tone into only two steps (semitones), and in particular when referring to sixteenthtones.
-edo	Equal division of the octave. A new trend among theorist which replaces '-et'.

Bells with conical shape

conic bell	Bell of conical shape made of metal sheet; here referring in particular to a bell formed of thick metal sheet and having an angle of 11.59° between cone side and axis. This angle is considered ideal for sounding purposes when using 1.6 mm steel sheet, which produces a melancholic tone due the second loudest harmonic being the tierce (sounding approximately a minor third above the prime harmonic).
hammered conic bell	*Conic bell* formed by hammering the metal sheet (p. 98).
spun conic bell	*Conic bell* formed by spinning metal sheet on a lathe (p. 100).
thin spun conic bell	*Conic bell* formed by spinning metal sheet on a lathe in one single stage, consequently having the skirt of the bell thinner towards the rim. Its tone has an exotic inharmonic character, with loss of pitch clarity in comparison with the *thick spun conic bell.*

thick spun conic bell	*Conic bell* formed by spinning metal sheet on a lathe in four successive stages, to maintain even wall thickness. Its tone is less inharmonic in character than that of the *thin spun conic bell.*
wide cone bell	Bell of conical shape formed of thick metal sheet conic and having an angle larger than 11.59° between cone side and axis.

Conic bellophone prototypes

conic bellophone	This is the instrument that was designed, built and used for performances and recordings. Is prototype No 8 in the instrument development process, and therefore also named the *16S conic bellophone* and *arched conic bellophone II*). The physical instrument was submitted with the thesis.
extended conic bellophone	Prototype No 9. Extended version of the *conic bellophone* with an additional augmented fourth of range.

Compositional theory and strategies

corporeal expression	Term use to evaluate the aesthetical value of an instrument's sounding and physical (visual) form, the later including the instrument being played and the performer's position playing it.
layered composing	Implies composing for different compositions at the same time (or at least with overlapping periods).

Musical instrument formats or stages

MIC	Musical instrument characteristic(s).
EMIC	Evaluated MIC.
SEMIC	Sketched EMIC.
prototype	A SEMIC for which basic measurements of a sounding body and structure have been specified.
VMI	A visual musical instrument, which is a virtual simulation of the instrument, generated by means of computer software.
AVMI	An audio-visual musical instrument simulation, highlighting the sounding bodies as they are sounded by means of manipulating sound samples through sequencing technology.
MAVMI	A MIDI interface-instrument with AVMI.
BMI	A built musical instrument.
BMPI	A built and successfully performed musical instrument.
BMPI with EMC	A BMPI with Extended Mechanical MIDI Capabilities.

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List of figures

Appendix One

Appendix One: An annotated chronological overview of the output of Julián Carrillo

The following annotated chronological overview of Carrillo's output is combined with biographical data that has been considered relevant for the thinking process of the main text. It is divided into his pre-microtonal period and the microtonal period.

Carrillo rarely used glissando or gliding tones within his non-microtonal compositions. However, during his microtonal period, there is a predominant use of microdiscrete gliding tones mainly based on sixteenthtone chromatic steps. Notice that equal temperaments are indicated with a number defining the equal division of the octave, followed by '-et' (equal temperament), which is a simplification of the classical definition. However, the reader must be aware of a recent trend among tuning theorists to use the simplification of equal division of the octave, '-edo'. [1]

A1.1 Carrillo's pre-microtonal period (1888-1921)

This section starts with a brief introduction to Carrillo's early musical formation and carries on describing the years he was active as a composer but did not compose microtonal works.[2]

From the age of seven, Carrillo attended a choir in Ahualulco (his birth place). The director of this choir, Flavio F. Carlos, was also his music tutor. Aged ten, Carrillo stopped attending school and moved to S. Luis de Potosí with his music tutor, in order to play percussion for his new orchestra. At the same time, Carrillo taught himself the violin, which he eventually played in the orchestra until the age of twenty, when he entered the Mexico National Conservatory. Carrillo followed a top of the range career as a violinist, composer and music director at the Mexico National Conservatory, which was extended with a sponsorship to study in Europe (in Leipzig, Germany and in Ghent, Belgium).

[1] See Glossary.
[2] Although he was already formulating microtonal theory during this period.

His first experimentation with tunings started in 1895, at twenty years of age, when he was a first year student at the Mexico National Conservatory. Carrillo tried subdividing an open string into equal divisions to explore ratios. Carrillo realised that his fingers were too thick to step with accuracy between the eighth and ninth divisions of the E string, when playing close to the nut (around 0.8 cm), so he gave up this idea. He soon returned to his experimentation, however, intending to use the blunt edge of a razor to achieve precision. This time his approach was more intuitive, and he asked a friend to bow his violin as he placed the razor on top of the open G (fourth string), gradually moving it from the nut towards the A, in sixteen different positions that he could perceive as producing different pitches, before arriving at A (including the G, open string).[3] Carrillo did not leave more specific details about how this experiment was achieved, nor the speed at which the notes were played in sequence. He did not mention playing against a continuous G produced by another violin player, so it is assumed here that it was a sequential hearing exercise rather than a harmonic appreciation.

Assuming that the notes were played in sequence, two hypotheses of how this could have been done are here proposed. The first is to play a legato G, followed by a note played raising the pitch by moving the razor as little as can be appreciated by sight (for example using millimetre steps), then the open string, then twice the previous distance, the open string again, then thrice the initial step, then the open string again, and so on (against a ruler), until a different pitch is perceived, and a scale using that interval is played with equal steps within a tone range.[4] This is represented in Fig. A1.1, where sixteen lines stand for each of the sixteenthtones, and the spaces the thirtysecondtones that would not have been appreciated by Carrillo in his experiment, as different notes. This hearing limit test procedure is later on referred to as the *interval-sequence-augmentation hearing test*, since it starts from the smallest interval and gets gradually larger.

Fig. A1.1. Hypothetical explanation of Carrillo's experiment with sixteenthtones in 1985.

[3] Carrillo, J and Carrillo, D. 1965. *Julián Carrillo. Testimonio de una vida*. San Luis Potosí state: The government of San Luis Potosí (2nd ed. by San Luis 400, 1992), p. 194.
[4] This approach is more likely to succeed on a string instrument with larger strings though.

The other possible method would have been to play the open G string followed by the A (a major tone, the smallest interval in the 12-et that Carrillo wanted to subdivide), then play the A, followed by G again, then G#, and keep halving the interval until the two note sequence is perceived as the same note. This procedure is later on referred to as the *interval-sequence-diminution hearing test.* This hypothetical test is represented in Fig. A1.2. The results could easily vary from person to person according to their training, experience, age, etc., but the fact that Carrillo's experiment was performed without any electronic support, distinguishing as far as the sixteenthtone (12.5 ¢), without such an interval having been experienced before, is a memorable achievement. It is more likely; therefore, that Carrillo used the *interval-sequence-diminution hearing test*, which explains why he ended up with sixteen instead of fifteen or seventeen notes in a tone.

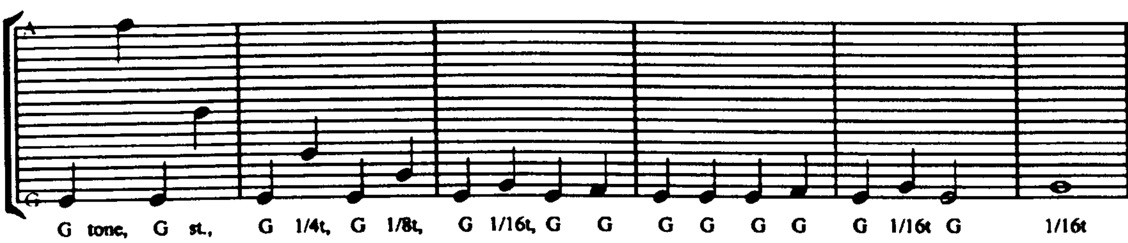

Fig. A1.2. Another hypothetic explanation of Carrillo's experiment with sixteenthtones in 1985.

During the pre-microtonal period of his music career, Carrillo became Director of the National Conservatory twice (in the years 1913-14 and 1920-24). Between those periods Carrillo directed the Symphony Orchestra of America in New York (1915-1918).

In 1917, Carrillo published for the first time a description of his 1895 experiment dividing the tone into sixteen equal divisions (see above), together with his hypothesis that the western theoretical system would gradually extend the pitch palette towards the limit of human perception, which he described as the sixteenthtone.[5] In this publication Carrillo first introduced his theories as *The Thirteenth Sound.* He explains that the number thirteen symbolises the breaking of the twelve note system, exploring the limit of human perception, and clarifies that this has nothing to do with the 13th harmonic, which he

[5] Carrillo, J. 1917. Sonido 13. *Pláticas musicales.* vol. 1. Mexico.

sarcastically calls "a harmless major sixth",[6] most likely aware that this interval was 40.5 ¢ sharp, compared to the major sixth of the tempered scale.

Between 1918 and 1920, Carrillo directed the National Symphony Orchestra and toured Mexico. In 1921, with the independence of Mexico, he became again director of the National Conservatory, a position that he left a year later, after realising that it was time to start to put his theoretical ideas into practice while conducting the National Symphony Orchestra.

A1.2 Carrillo's microtonal period (1922-1965)

Julián Carrillo composed sixty-five microtonal works, out of which fewer than 20% have been recorded, most of them within his lifetime.[7] Recording technology was available when Carrillo first started performing his microtonal works in 1925, and the lack of funds for recordings was most probably not the reason so few were made, but rather the matter of what was the priority for Carrillo. Considering that Carrillo invested plenty of capital developing his instruments, and particularly the fifteen *metamorphosing pianos* (see below), his priority to reform the musical system and the consequent need to have the instruments and writings required for that purpose, rather than achieving recognition through his recordings, becomes evident. This intellectual motivation radically changed the course of his career from 1925 onwards, although the foundation for this change had, of course, been laid gradually since his first experiment with microtonality in 1895 (see above).

In 1922, when Carrillo had already written forty-five works in twelve-equal temperament, including a suite for orchestra and two symphonies, he started to write his first microtonal works, which he would complete and perform in 1925, at the age of fifty. Such a late start with microtonal music production might give a wrong impression about what was to follow, but Carrillo was not even half way through his eighty-three years of involvement with music. On the contrary, Partch wrote his first microtonal composition (see Appx 2) around the same time (1925), at the age of twenty-four. Although there was twenty-six

[6] Carrillo, J and Carrillo, D. 1965. *Julián Carrillo. Testimonio de una vida.* San Luis Potosí state: The government of San Luis Potosí (2nd ed. by San Luis 400, 1992). p. 194.
[7] All Carrillo's compositions, which were commercially recorded after his death (1965) to date (July 2009), were previously recorded under Carrillo's direction.

years difference between them, they were coincidentally writing microtonal compositions between 1925 and 1965, although Partch continued for ten additional years after Carrillo's death.

Carrillo's incorporation of a microtonal vocabulary in his work, thirty-three years after completing his first composition, did have a significant impact on his succeeding output. Although he still produced another forty-two non-microtonal works from this point onwards, the microtonal output became superior in this period, with a total of sixty-five works. This means that slightly over sixty per cent of Carrillo's output was microtonal from the age of fifty until his death (at the age of ninety). Partch's output was one hundred per cent microtonal once he had become initiated into microtonality in his mid twenties, but considering that his instruments and theory did not include the twelve-equal temperament, there was no place left for considering this tuning. Did Carrillo ignore the existence of microtones in forty per cent of his oeuvre simply for the purpose of making a living? Was there an aesthetic reason for avoiding microtones? Carrillo's microtonal theory and instruments included the twelve-equal temperament, and the forty per cent of non-microtonal works, produced alongside the microtonal works, might have paid for the development of microtonal instruments and sponsored some of the microtonal concerts. Carrillo continued, however, to experiment with his numerical notation whilst having twelve-equal temperament works performed; his pioneering spirit led him to expand his theory resources getting involved with microtonality, rather than creating totally new theory from scratch, as in the case of Partch. A similar concept was maintained in the development of instruments for both composers, with Carrillo adapting as many existent instruments as possible, and Partch creating them from scratch in most cases.

The remainder of this section takes the form of an annotated chronological review of those of Carrillo's instruments and compositions concerned in his involvement with microtonality and sliding pitches. Unless indicated, the source of information used is Carrillo's autobiography.[8] The composition dates are all taken from the catalogue of the Carrillo archive[9] in Mexico.

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[8] Carrillo, J and Carrillo, D. 1965. *Julián Carrillo. Testimonio de una vida.* San Luis Potosí state: The government of San Luis Potosí (2nd ed. by San Luis 400, 1992).
[9] Hernández-Hidalgo, Omar. 2000. *Catálogo integral del archivo Julián Carrillo.* Instituto de Cultura de San Luis Potosí. Editorial Ponciano Arriaga. México.

1922: Quartertone guitar ("Carrillo" guitar). This instrument was built by Baudelio García (Fig. A1.3).[10] The only picture of a guitar found (Fig. A1.4), was not detailed enough to distinguish the frets, but shows that it has a tail piece to provide support for the strings (probably substituting the bridge, which remains on the guitar simply positioning the strings). The picture is a section from a larger picture of the group who performed Carrillo's *Sonata 'quasi fanstasia'* on the 13th of March 1926 at New York's Town Hall (concert organised by the Composer's League). The manuscript of this composition clearly says that the guitar is in quartertones, and considering that Carrillo notated the quartertone guitar parts for his scores referring to the standard tuning of a classical guitar, it is likely that this guitar had the quartertone frets placed on the fretboards. The additional tuning pegs, which are still difficult to count on this picture, indicate that this guitar might have had double strings to reinforce the volume of the instrument. This also explains why a tailpiece was used.

Fig. A1.3. Baudelio García, quartertone guitar maker (C.A.).[11]

Fig. A1.4. Quartertone guitar (C.A.).

[10] Carrillo, J and Carrillo, D. 1965. *Julián Carrillo. Testimonio de una vida*. San Luis Potosí state: The government of San Luis Potosí (2nd ed. by San Luis 400, 1992). p. 230.
[11] These initials stand for Carrillo Archive, indicating that the photograph is their courtesy.

In general it can be said that using quartertone frets on a classical guitar leaves small space to place the fingertips comfortably any higher the 24th fret. Taking into account that this uncomfortable area is not regularly used, using somewhere around 24 frets per octave for a regular classical guitar fingerboard can be considered the approximate comfortable limit among equal divisions of the octave. In order to recycle existing strings, the fretboard cannot be any longer without risking the strings breaking, nor can it be any shorter without the strings losing sonority and clarity. Fig. A1.5 shows three guitar fingerboards found in the Carrillo Archive in Mexico City. Both the regular fretboard in semitones and the one in thirdtones seem to have enough space between the frets in the higher register to place and move the fingers comfortably, unlike that in quartertones. However, it may still be possible to play the quartertones fretboard in the higher frets with enough skill.

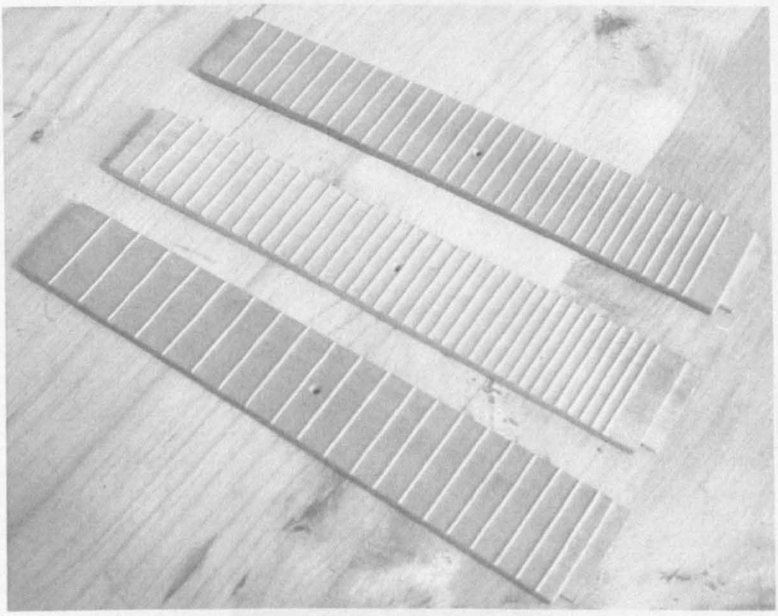


Fig. A1.5. Fretboards used by Carrillo in semitones, thirdtones and quartertones (Photo: D. Langarica).

1922: *Octavina*. Designed by Julián Carrillo and José María Torres.[12] Builder unknown.

The shape of this original lute-type instrument resembles a tromba marina (which is played in harmonics and therefore produces microtonal intervals in just intonation). However, no use of harmonics has been observed in the available scores. Carrillo, in this fretted instrument, looked not just for a low register to cover the lower register of the guitar, but

[12] Carrillo, J and Carrillo, D. 1965. *Julián Carrillo. Testimonio de una vida*. San Luis Potosí state: The government of San Luis Potosí (2nd ed. by San Luis 400, 1992). p. 230.

also for an instrument that could accommodate a fretboard that is long enough to leave sufficient space to place the fingers comfortably between the frets when using a further division than the quartertone guitar, in this case eighthtones. With the string length of almost 2 metres that this instrument seems to accommodate (according to the picture in Fig. A1.6), sixteenthtone frets could also have been included, with an average of 1 cm. between them, and could in general have a similar distance between frets to that found in the quartertone guitar. Here, however, Carrillo used eighthtones – sixteenthtone frets would have been too close to each other. The trapezoidal shape of its resonance box and the two sound-holes resemble the characteristics of the Veracruz harp from south Mexico (Fig. A1.7).

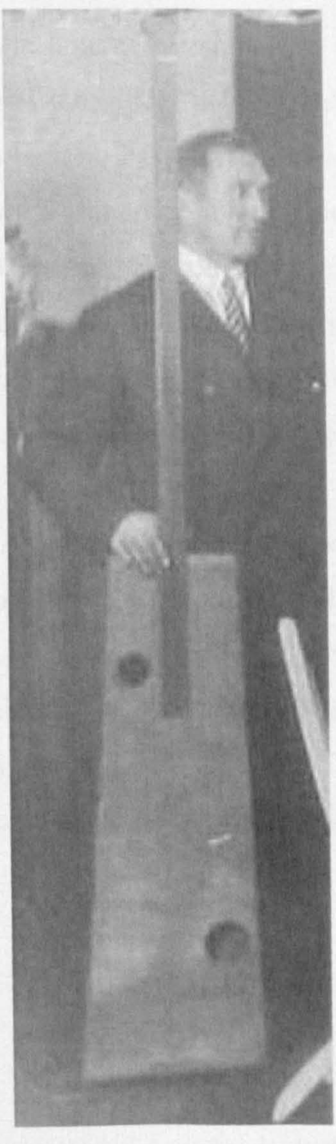


Fig. A1.6. *Octavina* (C.A.).

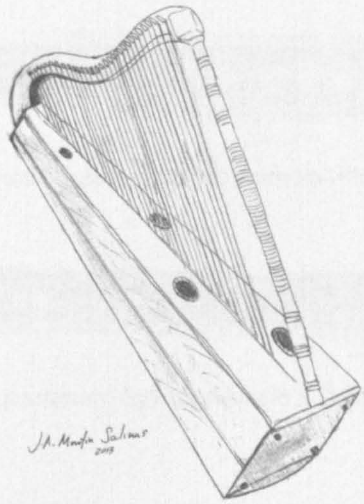


Fig. A1.7. Veracruz harp (sketch by author).

Julián Carrillo includes *octavina* in nine of his sixty-five microtonal works. Only one of these using quartertones (C22), and the others using eighthtones. These nine works also happen to use *sixteenthtone harp* (and no bass part), and were all written by 1934. Notice that the only two microtonal works for ensemble including bass (in quartertones) and *sixteenthtone harp* (C38 and C43) do not happen to use *octavina* and to be written after 1934 (1942 and 1951 respectively). Since Carrillo did not use *octavina* during the late period of his career, and instead used bass (in quartertones), maybe he preferred to compromise the eighthtones for quartertones to get a louder sound.

1922: Quartertone Flute (Fig. A1.9). This instrument was designed, built and played by one of Carrillo's composition students, Manuel Asencio (Fig. A1.8), using a special device for playing quartertones.[13] Fig. A1.9 and Fig. A1.10 show a transverse flute with Boehm system and, apparently, one added key, which opens a tone-hole on the mouthpiece, presumably raising the pitch by about a quartertone. These pictures were taken at the Carrillo Archive (C.A.) in Mexico City, while it still was functional.

Fig. A1.8. Manuel Asencio, quartertone flute maker (C.A.).

[13] Carrillo, J. and Asencio, M. 1924. "El Sonido 13" y las Flautas. *El Sonido 13*. vol. 1. no 8. Mexico. pp. 24-5.

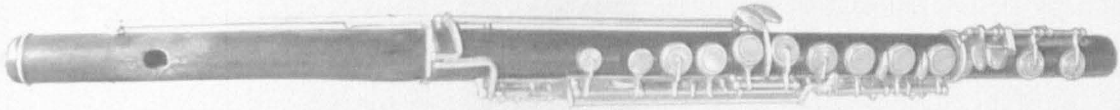


Fig. A1.9. Quartertone flute by Manuel Asencio (Photo: D. Langarica).

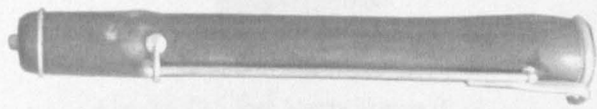


Fig. A1.10. Detail of quartertone key on Asencio's flute (Photo: D. Langarica).

Although microtonal digitations for woodwinds were known, the quartertone key must surely have made the performance a lot simpler.

1922: *Sixteenthtone harp* was invented by Julián Carrillo.

This instrument was also named *arpa-cítara* (zither-harp) in the beginning and *Carrillo harp* or *sixteenthtone harp* in succeeding developments. It had several stages of development, which have not been well documented. The *arpa-cítara* in Fig. A1.11 was one of the earliest zithers used by Carrillo, and it was owned and played by José María Torres (Fig. A1.12).

Fig. A1.11. *Arpa-cítara* (C.A.).[14]

[14] The writing underneath this picture translates as: 'Zither-harp, in which the sixteenthtones were tuned for the first time, and it is owned by José M. Torres'

Fig. A1.12. José María Torres (C. A.).

The *arpa-cítara* might have simply been an existent zither belonging to Carrillo's pupil, used for demonstrations of the microtones to Carrillo's composition students.

Carrillo designed zithers with 97 string rows covering one octave per row. For most of his zithers, stringed in both sides and placed on a rotating stand, he covered more than one octave. Fig. A1.13 shows the side covering two octaves since the 97-strings row has a bridge at $2/3^{rds}$ of the string that divides each string into two playable lengths ($2/3^{rds}$ and $1/3^{rd}$) an octave apart. The rear side of the zither has a full-length sounded row of also ninety-seven strings, an octave below the lowest octave sounded at the front. Therefore this instrument can sound 289 frequencies, produced by two rows of 97 strings (three of these frequencies can be sounded in two different string sections), and covering a range of 3 octaves. The strings are metallic, resembling the sound of piano strings being plucked.

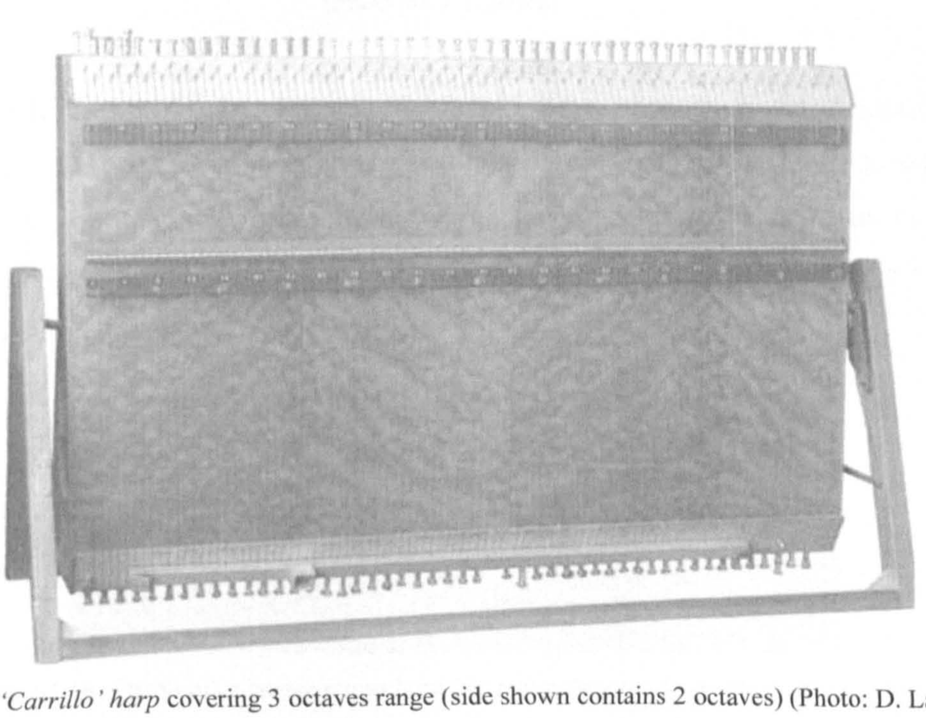


Fig. A1.13 *'Carrillo' harp* covering 3 octaves range (side shown contains 2 octaves) (Photo: D. Langarica).

Fig. A1.14 and Fig. A1.15 show the bolts used as tuning pins and the monochord that he incorporated into the zither, with marks for tuning each single not by unison.

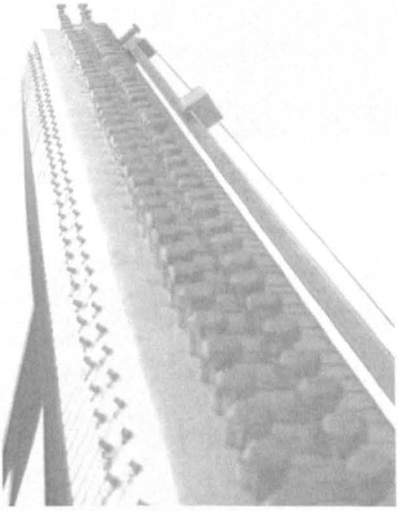


Fig. A1.14. Detail of tuning bolts and reference monochord in the *'Carrillo' harp* in upward position (Photo: D. Langarica).

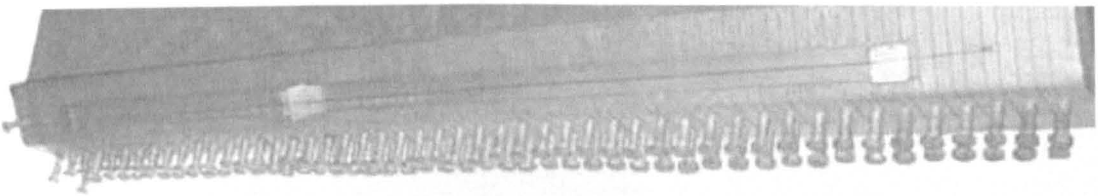


Fig. A1.15. Detail of tuning bolts and reference monochord in the *'Carrillo' harp* in downwards position (Photo: D. Langarica).

In this case (Fig. A1.16), the note number marks have been engraved in metal for the monochord, while the labels have been glued near the bridges to locate the actual strings (Fig. A1.17), and in some cases additional hand marks with chalk can be noticed specifying the note name (Fig. A1.18). Fig. A.19 shows a detail of a hitch pin similar to the ones found on the piano.

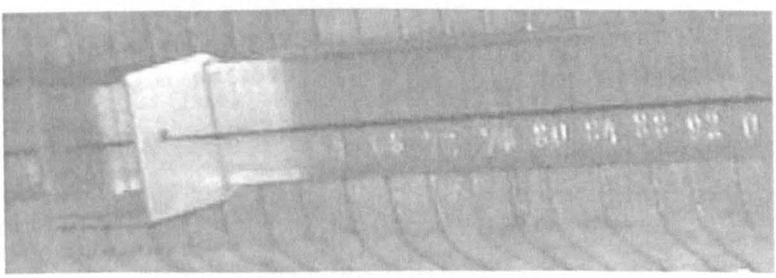


Fig. A1.16. Detail of reference monochord and numbering marks on the *'Carrillo' harp* (Photo: D. Langarica).

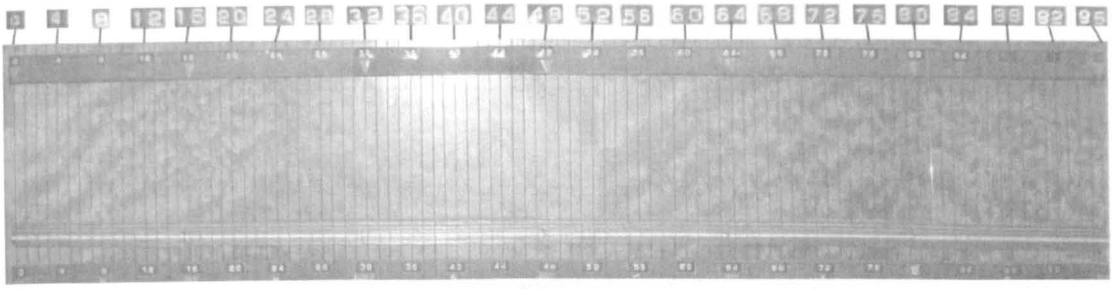


Fig. A1.17. Detail of note numbering labels zoomed in, on the *Carrillo harp* (Photo: D. Langarica).

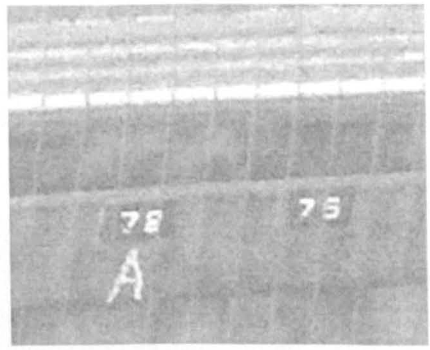


Fig. A1.18. Number and note-name marks (*'Carrillo' harp*) (Photo: D. Langarica).

Fig. A1.19. Hitch pin detail (*'Carrillo' harp*) (Photo: D. Langarica).

Carrillo's obsession with the harp, a commonly used instrument in Mexican folk ensembles, reflects his interest in the Mexican folklore. Fig. A1.20 shows one of the sound holes for the 3 octaves *'Carrillo' harp*. The hole is a circle without ornamentation as found in most Mexican folk harps, although the zither design in square tablet shape has nothing to do with Mexican folk harps.

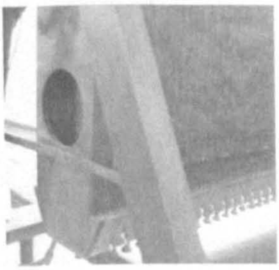


Fig. A1.20. A detail of a sound hole (*'Carrillo' harp*) (Photo: D. Langarica).

Julián Carrillo designed several zithers in sixteenthtones with the same principle, placing 97 strings in one or both sides of the resonance box to cover an octave, and in some cases using one single string to achieve the same pitch in 2 or more octaves by means of bridges. Several models covering three octaves have been found in the Carrillo Archive, plus other more adventurous models covering four octaves (with 385 frequencies) and six octaves (with 577 frequencies), all of them using both sides of the resonance box to lay the strings and a rectangular shape for the resonance box.

The curve used in the model in Fig. A1.21 seems to be an improvement attempting to spread the tension among the strings by relating string size with the pitch targeted.

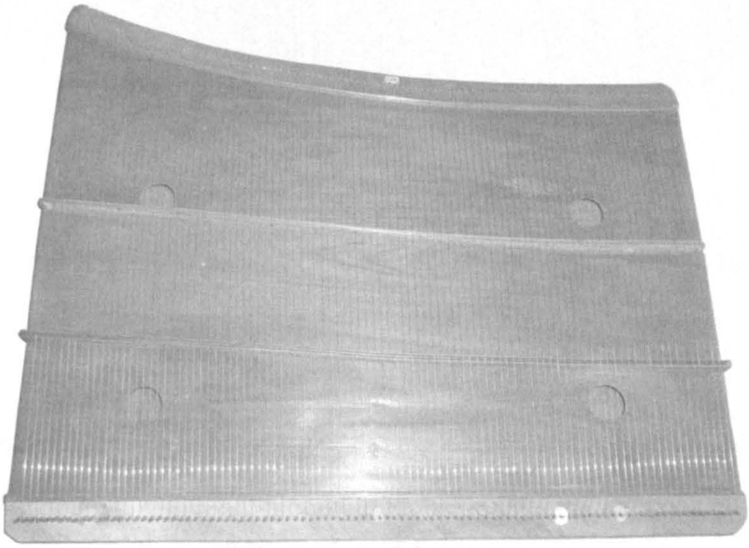


Fig. A1.21. One-sided *'Carrillo'* covering 2 octaves with 97 strings (in 96-et)
(Photo by Peter Kraut. Courtesy of Roman Brotbeck, Bern University of the Arts).

Fig. A1.22. Early model of the one-sided *'Carrillo' harp* (in 96-et) at a New York concert in 1925 (C.A.).[15]

[15] This detail of a picture is all that has been found about this zither at the New York premiere of Carrillo's music. It is slightly unclear, but enough to see that at this point Carrillo was only using a single-sided zither

The early model covering two octaves seems to be the most portable and also the most popular, and, probably due to the fact that most of the works written by Carrillo employing zither in sixteenthtones, do not cover more than an octave. During the first decade of the 21st century, Marc Lucas built a modern version following this early one-sided *'Carrillo' harp* in sixteenthtones covering two octaves (Fig. A1.23). It resembles the *'Carrillo' harp* in Fig. A1.21. This version of the one-sided *'Carrillo' harp* (Fig. A1.23), was built for Ernestine Stoop, harpist of *New Ensemble* in Amsterdam.[16]

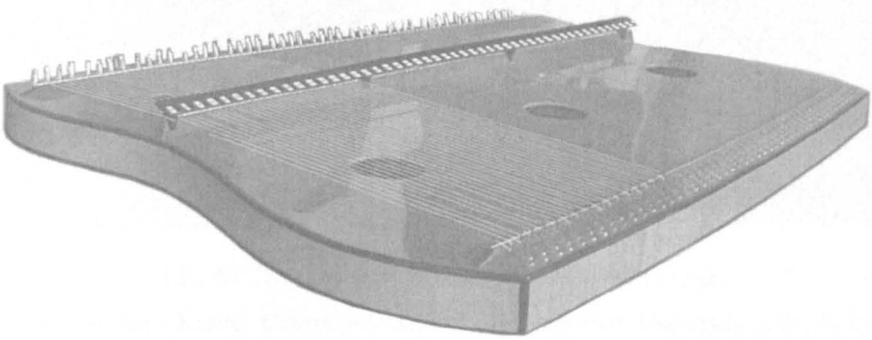


Fig. A1.23 A 1990s zither by Marc Lucas, inspired on the early one-sided *'Carrillo' harp* model (Courtesy of Wim Hoogewerf).

Other zithers that Carrillo might have used to train choirs and singers to pitch quartertones, but that he did not write for, have been found at the Carrillo Archive (Fig. A1.24 and Fig. A1.25), and at Bern Music Conservatory (Fig. A1.26).

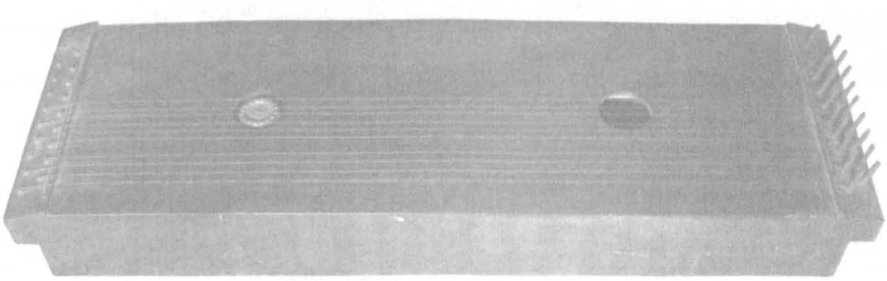


Fig. A1.24. *Quartertone 'Carrillo' harp* with 19 strings (Photo: D. Langarica).

box on a stand, although the term *'Carrillo' harp* would still be kept for the different double-sided zithers he developed.

[16] The charge for this instrument was 3700 euros.

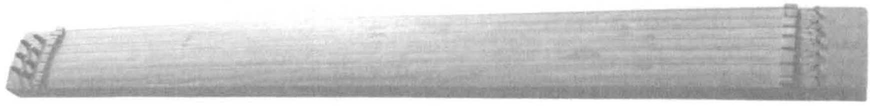


Fig. A1.25. *Quartertone 'Carrillo' zither* with 7 strings (Photo: D. Langarica).

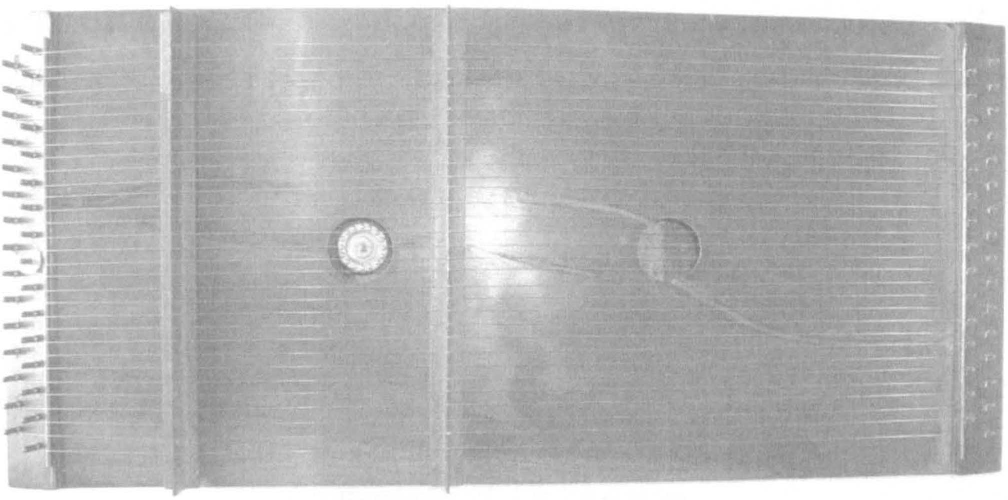


Fig. A1.26. *Quartertone 'Carrillo'* with 31 strings
(Photo by Peter Kraut. Courtesy of Roman Brotbeck, Bern University of the Arts).

Oscar Vargas, a student of Carrillo who helped him to design and build zithers, carried the work of Carrillo after his death with another student, David Espejo, who was responsible for tuning and helping with the devising of tuning theory. Espejo, as an attempt to take Carrillo's work with the 96-et step forward, and in order to achieve the intervals from the harmonic series while still keeping his numerical notation, devised a tuning system where the intervals of an octave are determined by the intervals found in the harmonic series from the 100th harmonic to the 200th harmonic, with the 100th harmonic as starting point or root of the system (which in the language ratios would be described as 100/100, 101/100, 102/100, ... 200/100). This tuning starts with a frequency of 55 Hz, exactly three octaves below concert pitch (440 Hz). It includes a very close approximation of the 12-et values, at the same time that all the intervals are in the harmonic series, and only two digits are required to represent the 100 pitches per octave (from 00 to 99). The work of David Espejo was brought to life by Oscar Vargas, who designed and built zithers similar to the *'Carrillo' harp* but using 101 strings per row to employ the 100 pitches per octave and the octave, in a row. Vargas called these instruments *microintervallic harps* and designed several models containing 4 octaves and 9 octaves (Fig. A1.27). These instruments also have stands, and like the *'Carrillo' harps* are large and heavy, unlike the one-sided early

'Carrillo' harp model. They cannot play works by Carrillo, but they can be considered the Sound thirteen post-revolution since they are the work of Carrillo's close students. David Espejo and Oscar Vargas are both dead, but the work of Carrillo and his students remains documented awaiting to be studied, published and developed further within the guidelines that Carrillo left with us for simplification (of the notation), expansion (of sound quality palette and intervals) and purification (referring to reduction of beating partial frequencies, see Appx 5).

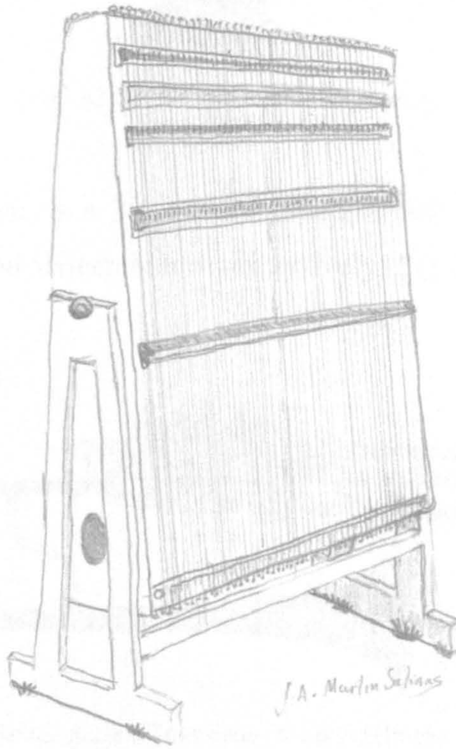


Fig. A1.27. A double-sided 9-octave range *microintervallic harp* by Oscar Vargas (sketch by author)

1922-25: New fingerings were worked out for quartertone violin and cello parts, in the hands of Luis González and Luis Galindo respectively.[17] Mainly with the help of his composition students, Carrillo started rehearsing his works as he was composing for the first concert in 1925. Carrillo's students were also composing, and their works were occasionally included as part of Carrillo's concert programme. This was an ideal working environment for Carrillo in which he was teaching his students as much as he was learning from them, since they were as much involved as Carrillo in the instrument development-led method shared by the whole group (each composer contributing with personal skills).

[17] Carrillo, J. and Carrillo, D. 1965. *Julián Carrillo. Testimonio de una vida.* San Luis Potosí state: The government of San Luis Potosí (2nd ed. by San Luis 400, 1992). p. 230.

1925: Sixteenthtone brasses. These brasses were created by Refugio Centeno (Fig. A1.28), under Carrillo's advice and supervision. Trombones, horns and tubas were developed to have an additional set of 3 valves for quartertones, eighthtones and sixteenthtones.[18]

Fig. A1.28. Refugio Centeno (C.A.).

The Sixteenthtone Trombone is a 3-valve trombone, which has three valves added for quartertones, eighthtones and sixteenthtones respectively (Fig. A1.29 and Fig. A1.30).

Fig. A1.29. Sixteenthtone Trombone (View A) (Photo: D. Langarica).

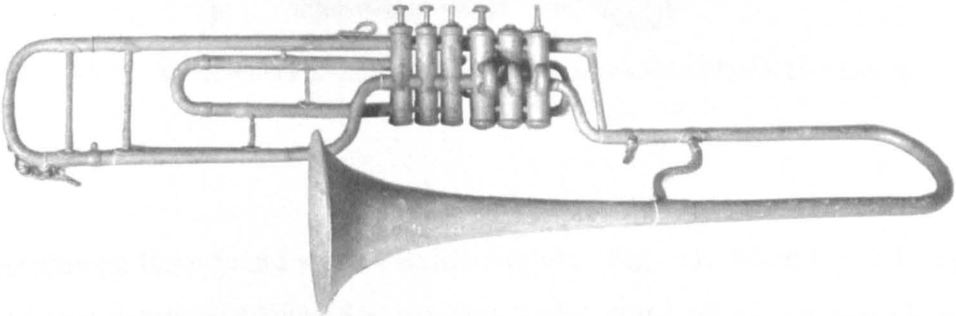


Fig. A1.30. Sixteenthtone Trombone (View B) (Photo: D. Langarica).

[18] Carrillo, Julián. 1925. Refugio Centeno. *El Sonido 13*. vol. 2. no. 8. Mexico. pp. 6-7

Details of the microtonal valves show how small the tubing for the sixteenthtone valve is (Fig. A1.31 and Fig. A1.32). Taking this any further than the sixteenthtone would be very difficult to achieve with precision.

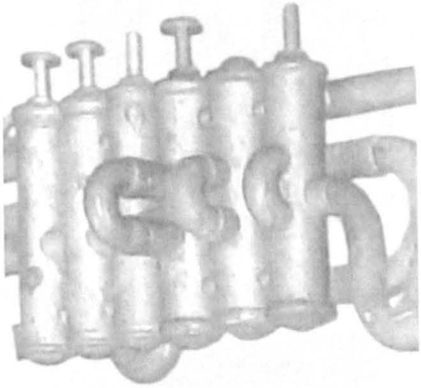


Fig. A1.31. Sixteenthtone Trombone's details of additional valves (Photo: D. Langarica).

The additional tubing for the three microtonal valves is placed (Fig. A1.31) at opposite side than the additional tubing for the semitone, tone and tone-and-half valves (Fig. A1.32).

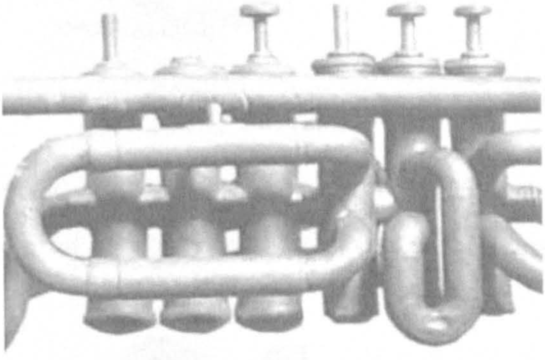


Fig. A1.32. Sixteenthtone Trombone's detail of regular valves (Photo: D. Langarica).

The Sixteenthtone Horn found at the Carrillo Archive (Fig. A1.33 and Fig. A1.34) also has three additional valves and keys (5 at the front and 2 at the back) incorporated to add the additional tubing required to achieve quartertones, eighthtones and sixteenthtones.

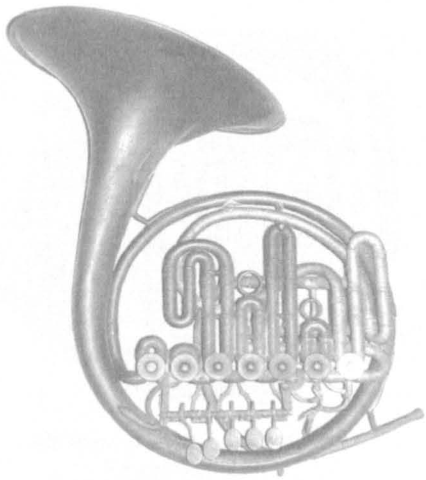


Fig. A1.33. Frontal view of the Sixteenthtone Horn (Photo: D. Langarica).

Fig. A1.34. Back view of the Sixteenthtone Horn (Photo: D. Langarica).

The additional tubing for the sixteenthtone key (Fig. A1.35 and Fig. A1.36) is also here very short and at the very limit of what can be achieved with precision.

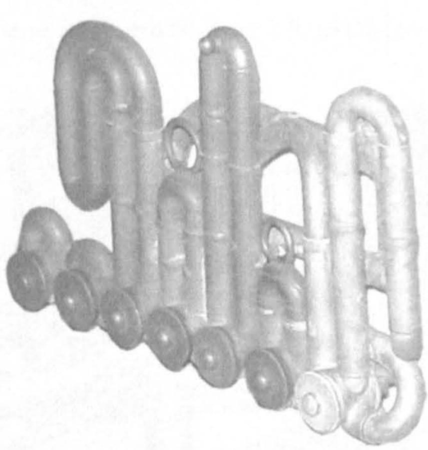


Fig. A1.35. Detail of tubing for the Sixteenthtone Horn (Photo: D. Langarica).

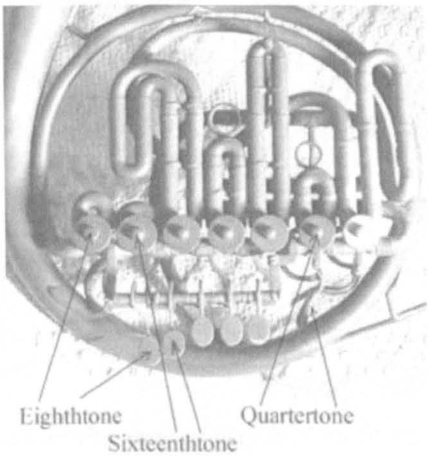


Fig. A1.36. Details of keys and tubing for the Sixteenthtone Horn (Photo: D. Langarica).

It is worthy mentioning here that in the first decade of the 21st century, influenced by the work of Julián Carrillo, a Germany based horn player (Samuel Stoll) had an attachable mechanism built to add quartertone and eighthtone tubing and keys to the F and Bb French horns (from Fig. A1.37 to Fig. A1.41).

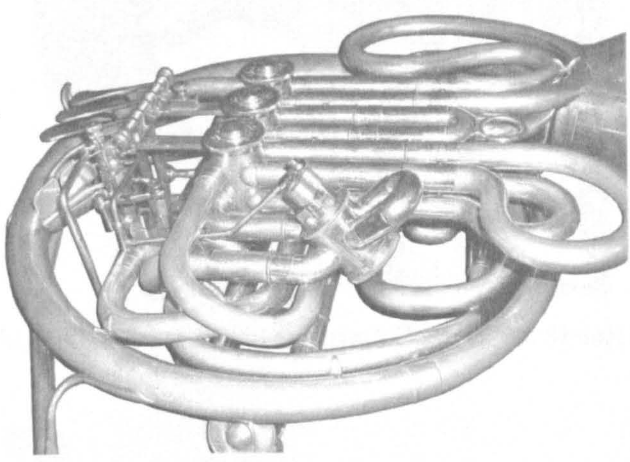


Fig. A1.37. ¼-tone valve on a Bb French horn (Photo: Samuel Stoll).

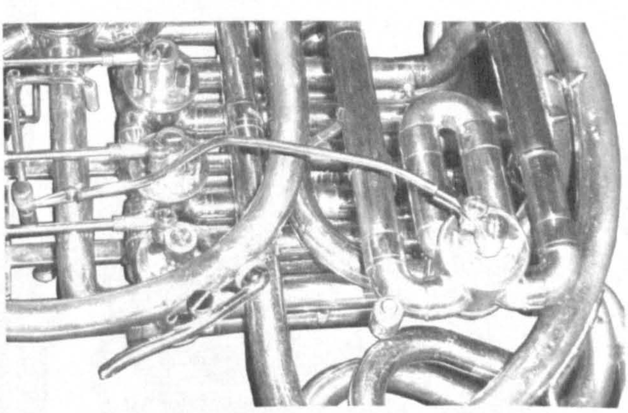


Fig. A1.38. ¼-tone valve on an F French Horn (Photo: Samuel Stoll).

Fig. A1.39. ¼-tone valve on an F French Horn (Photo: Samuel Stoll).

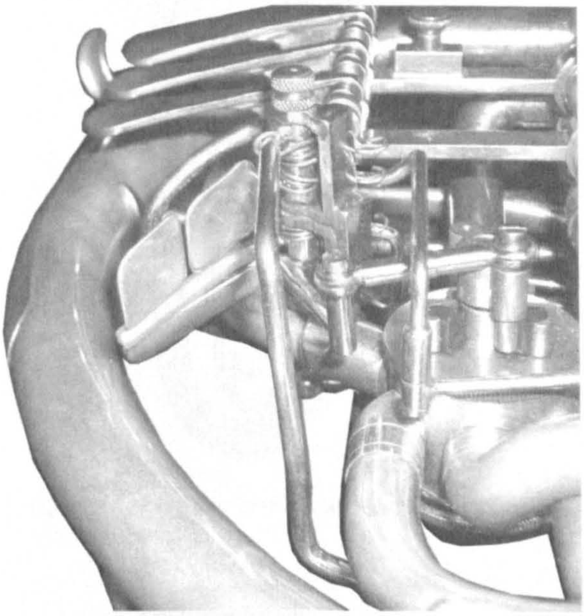


Fig. A1.40. Keys for the 1/8-tone French Horn (Photo: Samuel Stoll).

Fig. A1.41. Detail of the 1/8-tone valve. (Photo: Samuel Stoll).

The Sixteenthtone Trombone also presents an additional set of three microtonal valves for the achievement of quartertones, eighthtones and sixteenthtones (Fig. A1.42 and Fig. A1.43). Due to the position of the regular valves (semitone, tone and minor third), the microtonal valves were placed perpendicular from the regular set, which makes the usage of both sets at the same time almost impossible if fast passages are to be considered. What is important about this design is that it respects the form of the instrument, and therefore the performer does not have to relearn the technique when playing in 12-et.

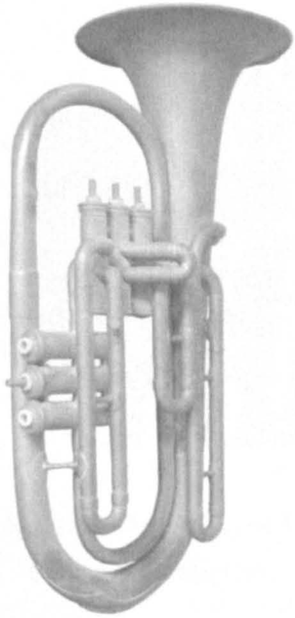


Fig. A1.42. Back view of the Sixteenthtone Trombone (Photo: D. Langarica).

Fig. A1.43. Front view of the Sixteenthtone Trombone (Photo: D. Langarica).

A detail of the additional tubing placed to achieve quartertones, eighthtones and sixteenthtones in Fig. A1.44 shows the minute size of the loop placed to lower the note a sixteenthtone. In fact, the three brasses have approximately the same additional tubing length for lowering the sixteenthtone, the shortest that could be achieved. If an additional length would be desired to lower a thirtysecondtone, instead of the tubing an internal passage would have to be designed for the valve.

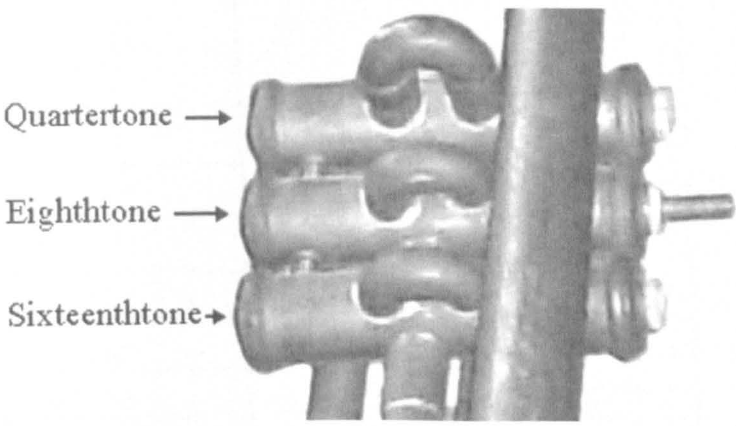
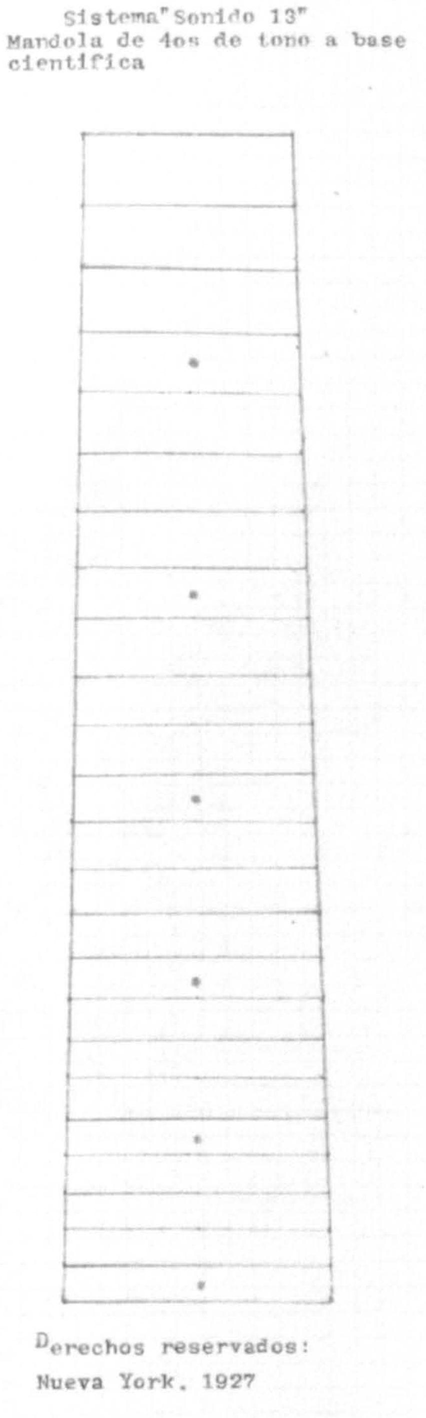


Fig. A1.44. Details of the tubing added to the Sixteenthtone Trombone to achieve the microtones (Photo: D. Langarica).

An adaptation of a standard six-valve F tuba has been designed by Robin Hayward and built by the firm B&S in 2009, incorporating a new valve mechanism (Hayward System), which can lower the tone by a quartertone, eighthtone or sixteenthtone.

The extraordinary investment of time and effort by Carrillo and Centeno, with the sixteenthtone brasses developed at the same time that compositions were being written, between 1922 and 1925, remains a great source of inspiration, not only to composers but also to instrument developers trying to achieve the same with modern brasses. See also the *bass sliding tuba* proposed in Appx 4 (instrument IX_h).

1927: Fretboards for Mandola and Mandolin. These fretboards were designed by Carrillo for his only work written for quartertone mandola and mandolin, a year later in 1928 (Fig. A1.45 and Fig. A1.46)



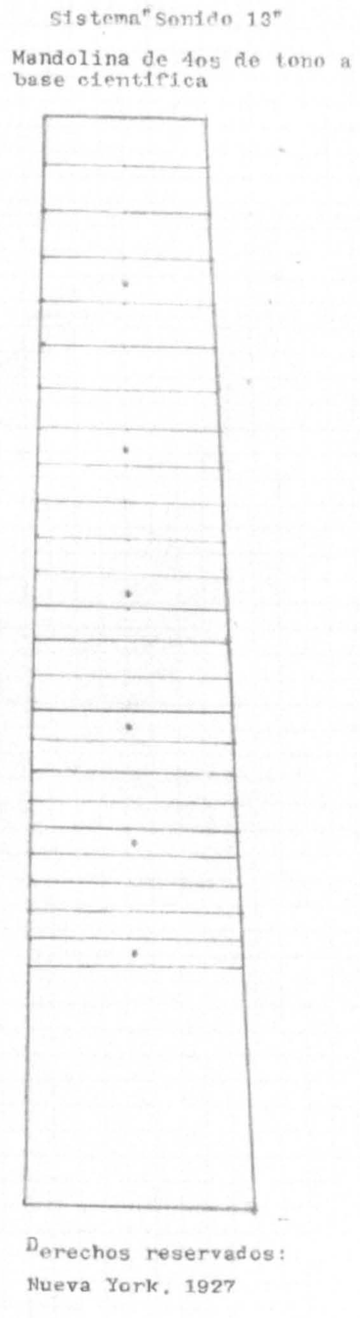


Fig. A1.45. Pictures of Carrillo's fretboard blueprints for Quartertone Mandola (left), and Quartertone Mandolin (right) (C.A.).

Before moving onto Carrillo's compositions,[19] a reference list matching Carrillo's works with the instruments they were written for is described as follows (Fig. A1.46):[20]

[19] Only the compositions that are considered relevant to this research are discussed.
[20] Indefinite pitch instruments (e.g. triangle) are not included in the chart.

Year written	Microtonal Composition Code	Notation format	Voice 1/4	Fl. 1/4	octavina 1/8	Vln. 1/4	Guit. 1/4	C.Harp 1/16	Vc. 1/4	Clar. 1/4	Vc. 1/8	Vla. 1/4	Oboe 1/4+	Basoon 1/4	F.Horn 1/4	Tpt. 1/4	Tbn. 1/4	Tuba 1/4+	Bass 1/4	Str. Qtet 1/16	F.Horn 1/16	Vln. 3-str 1/4	Cor Anglais 1/4	Mandolin 1/4	Mandola 1/4	Vla. 1/16	F.Horn 1/16	Symph.Orch.	Voice 1/8	Tpt.1/8	Strings 1/16	Cornetin 1/16	Baritono 1/16	Tuba 1/16	Harp 1/4 Carr.	Arpa Carrillo	Piano 1/4	Piano 1/3	Piano 1/16	Piano 1/5	Guit.7str. 1/3
1922-5	C 1	BOTH	sopr.	1	1	1	1	1																																	
"	C 2	NUM	satb	1	1	1	1	1	1																																
"	C 3	BOTH	1+4					1																																	
"	C 4	NUM		1	1	1	1	1	1																																
"	C 5	NUM		1			1	1		1	1																														
"	C 1str	NUM	sopr.			2		1	1			1								[1]																					
1924-25	C 6	NUM				2			1			1								[1]																					
1925	C 7 1/2	NUM	1	3/2		1			1	3/2		1	3/2	3/2	4	2	3	1	1	-the second symphony completed 9 months later (1926), both adding reg.harp and strings-																					
"	C 8	STAFF				2			1			1								[1]																					
"	C 9	STAFF				2			1			1								[1]																					
1926	C 10	BOTH																		1																					
"	C 11(')	BO(N)			1	1/8	(1)	1	1/16		1										1/8	-Vc in substituted by guitar in a 1931 arrangement (') which adds a movement-																			
"	C 12	BOTH			1	1	1	1	1												1/16							1/2													
"	C 13	BOTH	8																																						
"	C 14	STAFF				2			1			1								[1]																					
"	C 14v	STAFF	satb																																						
1927	C 15	NUM																	1																						
"	C 16	NUM				1																				1															
"	C 17	NUM							1	or		1																													
"	C 18	NUM																				1																			
"	C 19	NUM		2	1	1		1	1	2			2	2	5	2	3	1					1																		
1928	C 20	NUM					1																	1	1																
"	C 21	BOTH	sopr.	1	1/4	1	1	1/8				1/8																													
"	C 22	NUM										1/16																													
1929	C 23	NUM																									1	1/2													
"	C 24	NUM						1																					2sop	1											
"	C 25	NUM	stbb																																						
1930	C 26	NUM		2				1		2			2	2	4	2	3	1													1										
"	C 27	NUM?		2+p				1		2+b			2	2	4	2	3	1					1					1/16			1										
1931	C 28	NUM		1						1			1	1			1/16				1											1	1	1							
"	C 29	NUM						1																				1							1	1					
"	C 30	NUM					1																																		
"	C 31	NUM					1																																		
	C 32	NUM					1																																		
"	C 33	NUM																																		1/4					
"	C 34	NUM																																	1						
1933	C 35	MIX						1												1																					
1934	C 36	NUM	s	1	1	1	1	1	(partial score only available)																																
"	C 37	NUM			1			1																																	
1942	C 38	NUM	4a4s			1	1	1	2										1																						
1945	C 39	MIX(S)									1																	1													
1947	C 40	MIX				1/8		1			1																	1													
1949	C 41	BOTH				1																						1													
1951	C 42 1/2	NUM					1	(2nd guit.prelude incompleted)																																	
"	C 43	NUM?				2		1	2			1							1	[1]																					
1952	C 44	STAFF									1																	1													
1957	C 45	STAFF?																																			1				
1958	C 46	STAFF?																										1										1			
1959	C 47	STAFF?																										1											1		
"	C 48	STAFF																																						1	
"	C 49	STAFF							1																																
"	C 50	STAFF?																																			1				
1960	C 51	STAFF				1																																			
"	C 52	NUM					1																																		
1961	C 53	STAFF										1																													
"	C 54	STAFF				1																																			
"	C 55	STAFF																																							
1962	C 56	NUM																																							1
"	C 57	STAFF				2			1			1								[1]																					
"	C 58	STAFF	tbb																																						
1964	C 59	STAFF				2			1			1								[1]																					
"	C 60	STAFF				2			1			1								[1]																					
"	C 61	STAFF				1																																			
"	C 62	STAFF										1																													
"	C 63	STAFF										1																													
"	C 64	STAFF				1																						1													
1965	C 65	STAFF	tbb																																						

Fig. A1.46. Carrillo's compositions codes (in chronological order) and corresponding instrumentaria indicated.

1925 (1922-25): First five compositions in sixteenthtones (Op. I, II, II, IV, V). These were composed as the materialisation of Carrillo's publications on microtonality, and as a response to those critics who were underestimating the depth of Carrillo's theoretical postulations. Although this set of five compositions was written between 1922 and 1925, there are only two handwritten copies as a set and by the author, one dating 1931 and the other 1951. These are the works:

Prelude to 'Christopher Columbus' (Op. 1) (C1)[21]
Ave Maria (Op. 2) (C2)
'Tepepan'. Rural scene for voices in 1/4-tones and zither-harp in 1/16-tones (Op.3) (C3)[22]
Quartertone cello prelude No 1 (Op. 4) (C4) *8ᵒˢ*
Album page (Op. 5) (C5)
Prelude to Columbus (version for string quartet) (C1str)

Since *Prelude to Columbus* is a version for string quartet of *Prelude to Christopher Columbus*, it is considered here an arrangement of an existent work rather than a new work. These first five microtonal works use different groupings of the following instruments: voices (quartertones), Quartertone Flute, *octavina* (eighthtones), violin (quartertones), Quartertone Guitar, *sixteenthtone 'Carrillo' harp*, cello (quartertones and eighthtones), viola (quartertones) and clarinet (quartertones). It is noticeable that the only composition in which the cello plays eighthtones, the *octavina* (in eighthtones) is not used at all. As a matter of fact, in a recent recording of Carrillo's music,[23] the *octavina* was replaced by a cello.

The next five works to follow also date from 1925 and were probably completed after the previous set of five. What is interesting is that this is an intensive block of microtonal works produced in a short period of time, with an emphasis on strings:

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[21] In addition to what is mentioned in the main text there is a 1930 handwritten using numerical notation, a 1934 version using numerical notation (by New Music Society), a 1960 version using staff notation (with original microtonal accidentals), and a 1969 version (by Jobert editions) using staff notation. Also notice that C1 refers to the first microtonal work of Carrillo.

[22] Although the work is written for soprano solo, soprano, alto, tenor, bass and *'Carrillo'* harp, there is a note in the cover of the 1924 handwritten original version explaining that several alternative instrumentations can be considered for this work: (1) oboe instead of soprano solo with four saxophones, (2) Bb bugle and saxophones, (3) clarinet and saxophones (baritone and bass), and (4) oboe and muted strings. There is also a 1958 version of this work in staff notation with his original microtonal accidentals, which is titled '*Tepepan, bucolic scene*'.

[23] A 2009 recording of *'I think of you'* by AFMM orchestra (PITCH label), under the direction and production of Johnny Reinhard.

1924-1925 *Quartertone string quartet No 1* (C6)

1925 '*Colombia' symphony No 1 for orchestra "grande" in sixteenthtones* (C7-1)

1925 '*Colombia' symph. No 2 for orchestra "grande" in 1/4,1/8 and 1/16-tones* (C7-2)

1925 *Quartertone string quartet No 2* (C8)

1925 *Quartertone string quartet No 3* (C9)

The 'Colombia' Symphonies No 1 and 2 are classified under the same year, but the second was written in 1926 (completed 9 months later). These two works have almost the same orchestration and their relation remain unknown to this study, not having had a chance to check the scores.

Carrillo used numerical notation with numbers 0 to 95 to indicate the pitch within an octave in the sixteenthtone system and the octave indicated by the position of the number within a single line, rather than five. The first two quartertone string quartets were an exception, in which he used staff notation with diagonal lines attached to the top or the bottom of the noteheads according to whether the pitch was supposed to be raised or lowered respectively by the portion of a tone indicated (Fig. A1.47).

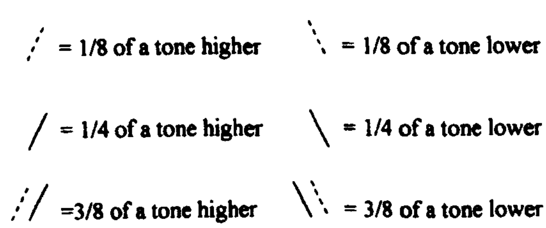

Fig. A1.47. Carrillo's eighthtone symbols used with staff notation (C.A.).

The usage of staff notation is a contradiction against what Carrillo considers one of the most important discoveries within his '*Sound Thirteen*' theory, which postulates the use of numerical as explained above, and, including the compositions in 12-et, since the system simplifies the stave, is intuitive and logical. For the first two quartertone string quartets, Carrillo might have seen himself struggling to have their performances prepared in time using numerical notation, plus these string instruments do require the performer to be able to hear the notes in order to play them with precision. Numerical notation has the inconvenience of being linear unlike staff notation, where it is easy to intuitively spot the direction in which the pitch is going or to visualise pitch contours for phrases. As a matter of fact, all the string quartets are notated in staff notation, which means the string players that played them probably never got used to Carrillo's numerical notation.

As for the '*Colombia*' *Symphony No 1*, Carrillo did not think about tuning restrictions of the instruments and sometimes uses eighthtones for all the members of the strings apart from the double bass (in quartertones). In this work, Carrillo also writes for woodwinds using eighthtones, while the brasses all play semitones and occasional quartertones. The '*Colombia*' *Symphony No 2* has almost the same orchestration and employment of tunings, and since both are classified under the same year,[24] but the second was written in 1926 in New York, the relation remains unknown to this study, not having had a chance to check the scores.

After this bubble period in which Carrillo started his instrument development-led compositional work by introducing new instruments, adapted instruments and new techniques, he kept a steady build up of instrument development composition work from 1926 until 1934, introducing gradually new or adapted instruments and techniques, and no more than one or two at the time. During this period the following works were composed:

- 1926 *Babbling for muted string quartet in quartertones, with exceptional use of eighthtones and sixteenthtones* (C10)
- 1926 *Sonata 'quasi fantasia' (in quarter, eighth and sixteenthtones)* (C11 and C11')
- 1926 *Concertino in quarter, eighth and sixteenthtones* (C12)
- 1926 *2 quartets for humming voices in quartertones* (C13)
- 1926 *Quartertone string quartets No 4 and No 5: 'Meditation' and 'Secretly'* (C14)
- 1926 *'Meditation' and 'Secretly' (for voices)* (C14')
- 1927 *70 exercises for double bass (a new technique in quartertones)* (C15)
- 1927 *70 exercises in quartertones for violin solo* (C16)
- 1927 *Quartertone exercises for viola or cello* (C17)
- 1927 *3 quartertone studies for the 3-string violin in sonatina form* (C18)
- 1927 *Orchestra "grande" nocturne in sixteenthtones* (C19)
- 1928 *Prelude for mandolin, mandola and guitar in quartertones. 'Illusion'* (C20)

[24] Hernández-Hidalgo, Omar. 2000. *Catálogo integral del archivo Julián Carrillo.* Instituto de Cultura de San Luis Potosí. Editorial Ponciano Arriaga. México. p. 53.

1928 *'I think of you' (romance for voices & instruments in 1/4 and 1/16-tones)* (C21)

1928 *Caprice for solo viola in tones, semi, quarter, eighth and sixteenthtones* (C22)

1929 *Caprice for French horn in sixteenthtones and orchestra* (C23)

1929 *Impromptu for 2 sopranos in eighthtones, trumpet in eighthtones and zither-harp in sixteenthtones* (C24)

1929 *Quartertone chorus* (C25)

1930 *'Colombia' symphony No 3 in quarter, eighth and sixteenthtones* (C26)

1930 *'Penumbras'. At "Reforma" Walk* (C27)

1931 *'Sound 13' fantasy (four cadences)* (C28)

1931 *Lento-Allegro-Lento* (C29)

1931 *Quartertone guitar study No 5. 'Midnight at the Oriental'* (C30)

1931 *Impromptu suite for quartertone guitar* (C31)

1931 *Quartertone guitar study No 1* (C32)

1931 *Dawn in 'Berlin 13'* (C33)

1931 Mystery. *'Impromptu' prelude* (C34)

1933 *'Whispers'* (C35)

1934 *Six 'Europe' preludes* (C36)

1934 *Romance* (C37)

There is a 6-year period here noticed, in which Carrillo did not compose music. It corresponds to the post-depression in Mexico and to the period in which the president Cardenas was president of Mexico. It has also been observed that this is the period Harry Partch was hitchhiking around USA and homeless (leaving not much music written either), and it corresponds to the period of the *Great Depression* that hit the USA the hardest.

1930s: Patent of the *'Carrillo' metamorphosing pianos*.

Although there are not any records of Carrillo composing in the second half of the 1930s, he must have sketched the piano demonstrations while designing his *metamorphosing pianos*, which later on his daughter would play at exhibitions. No records have been found of these works, though designing and working on a patent (Fig. A1.48) for fifteen different pianos can be considered a major achievement for this period.

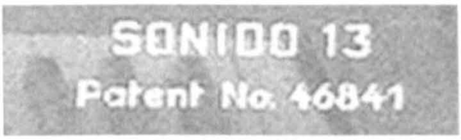

Fig. A1.48. Patent mark used for the 15 *metamorphosing pianos* (Photo: D. Langarica).

1942 VSO for '*The brunette Virgin*' (VSO) (C38)

A productive period of intensive composing for orchestra follows between 1945 and 1949, in which Carrillo explored the orchestra as a microtonal body of instruments in quartertones supporting a solo instrument (a cello in eighthtones, a *Carrillo piano* in sixteenthtones and a violin in quartertones), within the following works:

1945 *Concertino for cello in quarter and eighthtones* (C39)
1947-1951 *Horizons* (work ordered by Leopold Stokowski) (C40)
1949 *Quartertone violin concerto No 1* (C41)

This was followed by two preludes for guitar in numerical notation, and two orchestral works with the Cello as a solo instrument, all completed within two years:

1951 *Quartertone guitar preludes No 1* and *No 2 (for the 'Carrillo' guitar)* (No 2 left incomplete) (C42)
1951 *Quartertone cello prelude No 2* (C43)
1952 *Fantasy for cello in quarter and eighthtones, accompanied by symphony orchestra accidentally in quartertones* (C44)

1956: Carrillo published *Two Laws of Musical Physics.* This work constitutes a revelation in the theories of Carrillo, who until this point only seemed to be concerned with the simplification of staff notation and the expansion of the intervallic vocabulary, employing extensive equal division of the octave, and specifically of the 12-et tone. This work is the testimony of Carrillo's interest in just intonation, and the language of ratios as an ideal theory to guide the fine adjustments in his *ultrachromatic* theories. Carrillo used the term *ultrachromatic* to refer to equal temperaments subdividing the 12-et tone in smaller equal steps than a semitone. Therefore, his tunings always included the 12-et whole tone scale, ending up with divisions of the octave that are multiples of six.

In *Two Laws of Musical Physics*, Carrillo stated that tempered intervals are not found but in the harmonic series, but approximated.[25] Then he provides a list of the intervals from the harmonic series that are close to each interval constituting the chromatic step of each equal-step division of the 12-et tone from 1 through to 16 (1 being the 12-et tone), or in other words, the chromatic step for each of his *metamorphosing pianos* (if we consider the regular piano as part of the set). Surprisingly, most of these values do not seem to be the closest approximations if the lowest number ratio is mostly desired. Whether Carrillo had a different criteria or he did not choose the appropriately, it remains unknown. The ratios suggested by Carrillo are listed below, with some observations suggesting other harmonic intervals considerably closer to the n-equal-step division of the 12-et tone (with n taking all the natural values from 1 to 16), as follows:

Ratio 9/8 for the tone. According to Carrillo, the interval between the harmonics 8 and 9 approximates to the 12-et tone (200 ¢). The ratio 9/8 (203.910 ¢), also named the major whole tone, is the result of adding two pure just fifths minus one octave, or the result of subtracting a pure fourth (4/3) from a pure fifth (3/2). The ratio 9/8 is 3.910 ¢ above the 12-et tone, which is a considerably low number ratio and seems the appropriate choice, which is why no alternative value is offered in *Proposal I* (Fig. A1.49, on page A36). If more precision is required and higher number ratios is not minded (proposal II in Fig. A1.50, p. A37), the ratio 55/49 (199.980 ¢) is only 0.020 ¢ below, being 194 times closer (in both charts referred to as *reduction ratio*).

Ratio 18/17 for the semitone. According to Carrillo, the interval between the harmonics 17 and 18 approximates to the 12-et semitone (100 ¢). The ratio 18/17 (98.955 ¢), also called the *Arabic lute index finger,* is 1.045 ¢ below the 12-et tone and it seems the appropriate ratio among the low number ratios. If more precision is required, ratio 89/84 (100.099 ¢) is only 0.099 ¢ above, being 10.5 times closer.

Ratio 27/26 for the thirdtone. According to Carrillo, the interval between the harmonics 26 and 27 approximates to one third of the 12-et tone (66.666 ¢). The ratio 27/26 (65.337 ¢), also called the *tridecimal comma,* is 1.329 ¢ below one third of the 12-et tone, while the

[25] Bellamy, Sr. L. 1973. *The Sonido Trece Theoretical works of Julián Carrillo: A translation with commentary*. PhD dissertation. Indiana University. Page 527 (as part of the translation of Julián Carrillo's *Two Laws in Musical Physics*).

ratio 26/25 (67.900 ¢), situated one contiguous interval below 27/26 in the harmonic series, is slightly closer to one third of the 12-et tone (1.234 ¢ above), and therefore more appropriate (this time by an insignificant amount, but not from here onwards). If a ratio closer to the one third of the 12-et was required, further up in the harmonic series, the ratio 53/51 (66.594 ¢) is only 0.073 ¢ below, which is 18.3 times closer to the third of the 12-et tone than the ratio proposed by Carrillo. From this ratio onwards, Carrillo seems to have chosen a ratio in the harmonic series that is slightly above or below a nearby alternative ratio that is much closer to the equal-step division of the 12-et tone considered (from 3 steps to 16 steps, which happen to be the microtonal steps).

Ratio 37/36 for the quartertone. According to Carrillo, the interval between the harmonics 36 and 37 approximates to one quarter of the 12-et tone (50 ¢). The ratio 37/36 (47.434 ¢) is 2.566 ¢ below one quarter of the 12-et tone, while the ratio 35/34 (50.184 ¢), situated two contiguous intervals below 37/36 in the harmonic series, is only 0.184 ¢ above one quarter of the 12-et tone (almost 14 times smaller). If a ratio closer to a quarter of the 12-et tone is required, further up in the harmonic series, the ratio 246/239 (49.977 ¢) is only 0.023 ¢ below, being around 112.7 times closer to the quarter of the 12-et tone than the ratio proposed by Carrillo.

Ratio 45/44 for the fifthtone. According to Carrillo, the interval between the harmonics 44 and 45 approximates to one fifth of the 12-et tone (40 ¢). The ratio 45/44 (38.906 ¢) is 1.094 ¢ below one fifth of the 12-et tone, while a lower ratio 44/43 (39.800 ¢), situated one contiguous interval below 45/44 in the harmonic series, is only 0.200 ¢ below a fifth of the 12-et tone (5.5 times closer). If a ratio closer to a fifth of the 12-et tone is required further up in the harmonic series, the ratio 175/171 (40.030 ¢) is only 0.030 ¢ above, being 36.1 times closer than the ratio proposed by Carrillo.

Ratio 54/53 for the sixthtone. According to Carrillo, the interval between the harmonics 53 and 54 approximates to one sixth of the 12-et tone (33.333 ¢). The ratio 54/53 (32.360 ¢) is 0.973 ¢ below one sixth of the 12-et tone, while the ratio 52/51 (33.617 ¢), situated two contiguous intervals below 54/53 in the harmonic series, is only 0.284 ¢ below one sixth of the 12-et tone (3.4 times closer). If a ratio closer to a quarter of the 12-et tone is required, further up in the harmonic series, the ratio 105/103 (33.294 ¢) is only 0.039 ¢ below, being around 24.7 times closer than the ratio proposed by Carrillo.

Ratio 63/62 for the seventhtone. According to Carrillo, the interval between the harmonics 62 and 63 approximates to one seventh of the 12-et tone (28.571 ¢). The ratio 63/62 (27.700 ¢) is 0.871 ¢ below one seventh of the 12-et tone, and the ratio 61/60 (28.616 ¢), while situated two contiguous intervals below 63/62 in the harmonic series, is only 0.045 ¢ above one seventh of the 12-et tone, being 19.5 times closer than the ratio proposed by Carrillo.

Ratio 72/71 for the eighthtone. According to Carrillo, the interval between the harmonics 71 and 72 approximates to one eighth of the 12-et tone (25 ¢). The ratio 72/71 (24.213 ¢) is 0.786 ¢ below one eighth of the 12-et tone, while the ratio 70/69 (24.91 ¢), situated two contiguous intervals below 72/71 in the harmonic series, is only 0.090 ¢ below one eighth of the 12-et tone, being 8.8 times closer than the ratio proposed by Carrillo.

Ratio 81/80 for the ninthtone. According to Carrillo, the interval between the harmonics 81 and 82 approximates to one ninth of the 12-et tone (22.222 ¢). The ratio 81/80 (21.506 ¢) is 0.716 ¢ below one ninth of the 12-et tone. This interval is called the *syntonic comma*, which is the difference between the Pythagorean third (ratio 531441/524288) and the just major third (ratio 5/4). Situated three contiguous intervals below in the harmonic series is the ratio 78/77 (22.339 ¢), which is only 0.117 ¢ above one ninth of the 12-et tone, which is 6.1 times closer than the *syntonic comma* proposed by Carrillo. If an interval contained in the harmonic series that approximates to 22.222 ¢, and which is closer than 0.117 ¢ is required, then the perfect candidate would be 392/387 which is 0.002 ¢ apart from 22.222 ¢, being 380.1 times closer than the ratio proposed by Carrillo.

Ratio 90/89 for the tenthtone. According to Carrillo, the interval between the harmonics 89 and 90 approximates to one tenth of the 12-et tone (20 ¢). The ratio 90/89 (19.344 ¢) is 0.656 ¢ below one tenth of the 12-et tone, while the ratio 87/86 (20.014 ¢), situated three contiguous intervals below 90/89 in the harmonic series, is only 0.014 ¢ above one tenth of the 12-et tone, being 45.3 times closer than the ratio proposed by Carrillo.

Ratio 99/98 for the eleventhtone. According to Carrillo, the interval between the harmonics 98 and 99 approximates to one eleventh of the 12-et tone (18.181 ¢). The ratio 99/98 (17.576 ¢) is 0.606 ¢ below one ninth of the 12-et tone. This interval is called the *small undecimal comma.* Situated three contiguous intervals below in the harmonic series is the ratio 96/95 (18.128 ¢), which is only 0.054 ¢ above one eleventh of the 12-et tone, which is 11.3 times closer than the *syntonic comma* proposed by Carrillo. The ratio 96/95 is called the *19th-partial comma.*

Ratio 108/107 for the twelfthtone. According to Carrillo, the interval between the harmonics 107 and 108 approximates to one twelfth of the 12-et tone (16.666 ¢). The ratio 108/107 (16.105 ¢) is 0.562 ¢ below one twelfth of the 12-et tone. Four contiguous intervals below in the harmonic series is the ratio 104/103 (16.727 ¢), which is only 0.060 ¢ above one twelfth of the 12-et tone, being 9.3 times closer than the ratio proposed by Carrillo.

Ratio 117/116 for the thirteenthtone. According to Carrillo, the interval between the harmonics 116 and 117 approximates to one thirteenth of the 12-et tone (15.384 ¢). The ratio 117/116 (14.860 ¢) is 0.524 ¢ below one thirteenth of the 12-et tone. Four contiguous intervals below in the harmonic series is the ratio 113/112 (15.389 ¢), which is only 0.004 ¢ above the thirteenth of the 12-et tone, being 123.8 times closer than the ratio proposed by Carrillo.

Ratio 126/125 for the fourteenthtone. According to Carrillo, the interval between the harmonics 125 and 126 approximates to one fourteenth of the 12-et tone (14.285 ¢). The ratio 126/125 (13.795 ¢) is 0.491 ¢ below one fourteenth of the 12-et tone. Four contiguous intervals below in the harmonic series is the ratio 122/121 (14.249 ¢), which is only 0.036 ¢ below one fourteenth of the 12-et tone, being 13.3 times closer than the ratio proposed by Carrillo.

Ratio 135/134 for the fifteenthtone. According to Carrillo, the interval between the harmonics 134 and 135 approximates to one fifteenth of the 12-et tone (13.333 ¢). The ratio 135/134 (12.872 ¢) is 0.461 ¢ below one fifteenth of the 12-et tone. Five contiguous intervals below in the harmonic series is the ratio 130/129 (13.369 ¢), which is only 0.035 ¢ below one fifteenth of the 12-et tone, being 13 times closer than the ratio proposed by Carrillo.

Ratio 144/143 for the sixteenthtone. According to Carrillo, the interval between the harmonics 143 and 144 approximates to one sixteenth of the 12-et tone (12.5 ¢). The ratio 144/143 (12.0643976 ¢) is 0.4356024 ¢ below one sixteenth of the 12-et tone. Five contiguous intervals below in the harmonic series is the ratio 139/138 (12.4999391 ¢), which is only 0.00006 ¢ below one sixteenth of the 12-et tone, being over 7156.8 times closer than the ratio proposed by Carrillo. As a matter of fact, 96 intervals of ratio 139/138 make an interval, which is 0.005 ¢ below the octave. To imagine how insignificant this error would be, if we build up a 10-octave range with this interval, the tenth octave would carry a 0.05 ¢ error, which is the 4000th division of the tone and the 24000th division of the octave.

The ratios proposed can be divided into two groups: those which are lower in the harmonic series than the ones Carrillo proposed and seem to be better approximations for the closest low number ratio criteria (*Revision I* in Fig. A1.49), and those which, although they are above in the harmonic series compared to the ratios Carrillo proposed, are extraordinarily closer (*Revision II* in Fig. A1.50).

Steps-per-tone/Name		Carrillo's proposal			Revision I			
		Ratio	Cents (¢)	Deviation (¢)	Ratio	Cents (¢)	Deviation (¢)	Reduct. ratio
1	Tone	9 / 8	203.9100017	3.910001731				
2	Semitone	18 / 17	98.95459223	1.04540777				
3	Thirdtone	27 / 26	65.33734083	1.32932584	26 / 25	67.90023404	1.233567373	1.07762727
4	Quartertone	37 / 36	47.43403702	2.565962976	35 / 34	50.18421083	0.184210834	13.92949003
5	Fifthtone	45 / 44	38.90577323	1.094226769	44 / 43	39.80023672	0.199763278	5.477617208
6	Sixthtone	54 / 53	32.36045712	0.972876213	52 / 51	33.6172514	0.28391807	3.426608997
7	Seventhtone	63 / 62	27.70033574	0.871092836	61 / 60	28.61609035	0.044661774	19.50421486
8	Eighthtone	72 / 71	24.21345833	0.786541675	70 / 69	24.9102722	0.0897278	8.765863813
9	Ninthtone	81 / 80	21.5062896	0.715932626	78 / 77	22.3388138	0.116591579	6.140517455
10	Tenthtone	90 / 89	19.34359844	0.656401564	87 / 86	20.01448938	0.014489376	45.30226588
11	Eleventhtone	99 / 98	17.57613116	0.605687025	96 / 95	18.12827087	0.053547314	11.31124943
12	Twelfthtone	108 / 107	16.10461891	0.562047752	104 / 103	16.72702915	0.060362483	9.311209945
13	Thirteenthtone	117 / 116	14.86046935	0.524146038	113 / 112	15.38884843	0.004233044	123.8224876
14	Fourteenthtone	126 / 125	13.79476661	0.49094768	122 / 121	14.24892035	0.03679394	13.34316684
15	Fifteenthtone	135 / 134	12.87168791	0.461645422	130 / 129	13.36866913	0.035335793	13.06452701
16	Sixteenthtone	144 / 143	12.0643976	0.435602403	139 / 138	12.49993913	0.000060866	7156.791406

Fig. A1.49. Carrillo's proposed harmonic series ratio approximations compared to this study's *revision I*, suggesting ratios from the harmonic series, which approximate better while using lower number ratios.

Carrillo's stated relations between ratios from the harmonic series and the intervals contained in his *metamorphosing pianos* seemed to have had a slight error when choosing the ratio, and they have now been corrected in Fig. A1.49, that can be used for studying the just intonation capabilities of each of the pianos. Now let us look for higher ratios in the series that approximate with more accuracy (Fig. A1.50).

Divisions/Name		Carrillo's proposal			Revision II			
		Ratio	Cents (¢)	Deviation (¢)	Ratio	Cents (¢)	Deviation (¢)	Reduct. ratio
1	Tone	9 / 8	203.9100017	3.910001731	55 / 49	199.9798433	0.020156709	193.9801679
2	Semitone	18 / 17	98.95459223	1.04540777	89 / 84	100.0992098	0.099209825	10.53734111
3	Thirdtone	27 / 26	65.33734083	1.32932584	53 / 51	66.59413511	0.072531557	18.32755151
4	Quartertone	37 / 36	47.43403702	2.565962976	246 / 239	49.97723683	0.02276317	112.7243261
5	Fifthtone	45 / 44	38.90577323	1.094226769	175 / 171	40.03031634	0.030316336	36.09363544
6	Sixthtone	54 / 53	32.36045712	0.972876213	105 / 103	33.29398858	0.039344754	24.72696148
7	Seventhtone	63 / 62	27.70033574	0.871092836				
8	Eighthtone	72 / 71	24.21345833	0.786541675				
9	Ninthtone	81 / 80	21.5062896	0.715932626	392 / 387	22.22410556	0.001883343	380.1393194
10	Tenthtone	90 / 89	19.34359844	0.656401564				
11	Eleventhtone	99 / 98	17.57613116	0.605687025				
12	Twelfthtone	108 / 107	16.10461891	0.562047752				
13	Thirteenthtone	117 / 116	14.86046935	0.524146038				
14	Fourteenthtone	126 / 125	13.79476661	0.49094768				
15	Fifteenthtone	135 / 134	12.87168791	0.461645422				
16	Sixteenthtone	144 / 143	12.0643976	0.435602403				

Fig. A1.50. Carrillo's proposed harmonic series ratio approximations compared to this study's *revision II*, suggesting ratios from the harmonic series, which approximate extraordinarily better, although they use much higher number ratios.

1957-8: The *'Carrillo' metamorphosing pianos* were built by Hans Sauter (Germany). Carrillo designed and patented fifteen (*'Carrillo'*) *metamorphosing pianos* (Patent No 46841), each using a traditional keyboard shortened or extended according to the needs of the equal temperament to which it was tuned: the piano with the purpose of playing in tones (6-et), and the others with the purpose of dividing the 12-et tone into thirdtones (18-et), quartertones (24-et), fifthtones (30-et), sixthtones (36-et), seventhtones (42-et), eighthtones (48-et), ninthtones (54-et), tenthtones (60-et), eleventhtones (66-et), twelfthtones (72-et), thirteenthtones (78-et), fourteenthtones (84-et), fifteenthtones (90-et), and sixteenthtones (96-et). The division of the tone into semitones was not included, since that is the already existent 12-et piano.

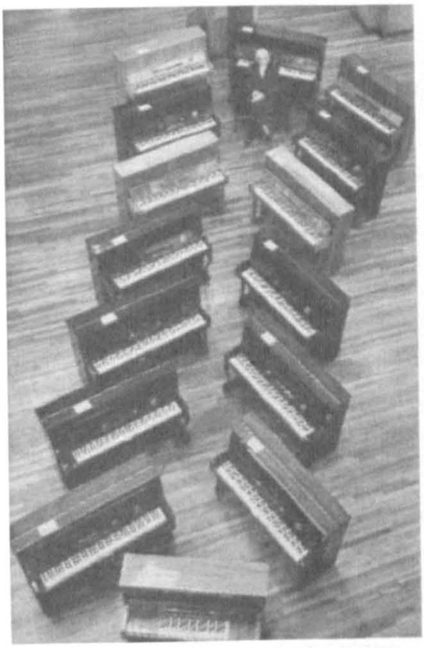

Fig. A1.51. 15 *metamorphosing pianos* (C.A.).

Fig. A1.52. Carrillo behind the tone piano (C.A.).

Fig. A1.53. Dolores Carrillo playing (C.A.).

Fig. A1.54. Julián Carrillo playing (C.A.).

The pictures above (Fig. A1.51 - Fig. A1.54), show the fifteen (*'Carrillo'*) *metamorphosing pianos* with Dolores Carrillo (Carrillo's daughter) and Julián Carrillo playing them in the last two pictures respectively.

The diagram below (Fig. A1.55), shows the value in cents of each division of the 12-et tone with the name of the interval and the name of the tuning expressed in equal divisions of the octave.

Eq. divisions of 12-et tone	Interval		Equal divisions of the octave
	Nomination	Size (¢)	
1	Tone	200	6 - et (edo)
2	Semitone	100	12 - et (edo)
3	Thirdtone	66.66666667	18 - et (edo)
4	Quartertone	50	24 - et (edo)
5	Fifthtone	40	30 - et (edo)
6	Sixthtone	33.33333333	36 - et (edo)
7	Seventhtone	28.57142857	42 - et (edo)
8	Eighthtone	25	48 - et (edo)
9	Ninthtone	22.22222222	54 - et (edo)
10	Tenthtone	20	60 - et (edo)
11	Eleventhtone	18.18181818	66 - et (edo)
12	Twelfthtone	16.66666667	72 - et (edo)
13	Thirteenthtone	15.38461538	78 - et (edo)
14	Fourteenthtone	14.28571429	84 - et (edo)
15	Fifteenthtone	13.33333333	90 - et (edo)
16	Sixteenthtone	12.5	96 - et (edo)

Fig. A1.55. Size in cents for the chromatic step of each *metamorphosing piano* with divisions of the octave.

Let us have a close at Carrillo's *metamorphosing pianos* (Figs. A1.56-A1.106), which is followed by the list of Carrillo's microtonal works (Fig. A1.107), and the author's translation of these works into English.

Fig. A1.56. The '*Carrillo' tone metamorphosing piano* by Bushmann (label detail) (Photo: D. Langarica).

Fig. A1.57. The *'Carrillo' tone metamorphosing piano* by Bushmann (lateral perspective) (Photo: A. Madrid).

Fig. A1.58. The *'Carrillo' tone metamorphosing piano* by Bushmann (frontal view) (Photo: D. Langarica).

A paper indicating the note numbers was found placed behind the black keys (Figs. A1.59 and A1.60), and in the photograph the notation number with the line indicating the octave has also been placed to show the six note octaves (from 0 to 5).

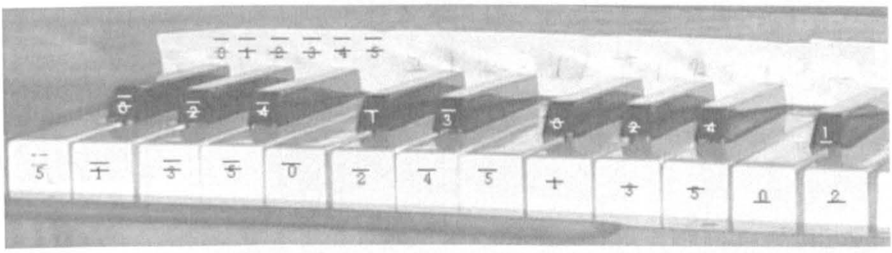

Fig. A1.59. Keyboard for the *'Carrillo' tone metamorphosing piano* by Bushmann (Photo: D. Langarica).

Fig. A1.60. The *'Carrillo' tone metamorphosing piano* by Sauter (Photo: D. Langarica).

Fig. A1.61. The *'Carrillo' thirdtone metamorphosing piano* by Buschmann (label detail)

(Photo: D. Langarica).

Fig. A1.62. The *'Carrillo' thirdtone metamorphosing piano* by Buschmann (lateral view)

(Photo: D. Langarica).

Fig. A1.63. The *'Carrillo' thirdtone metamorphosing piano* by Buschmann (frontal view) (Photo: D. Langarica).

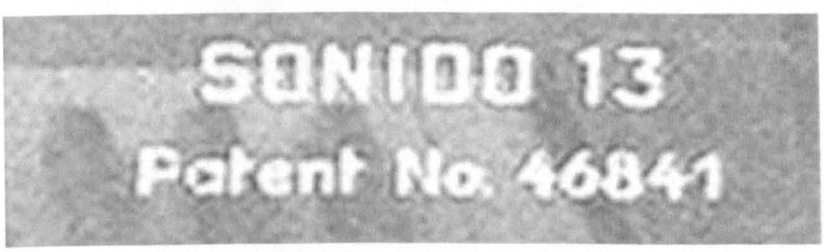

Fig. A1.64. The *'Carrillo' thirdtone metamorphosing piano* by Sauter (patent label) (Photo: D. Langarica).

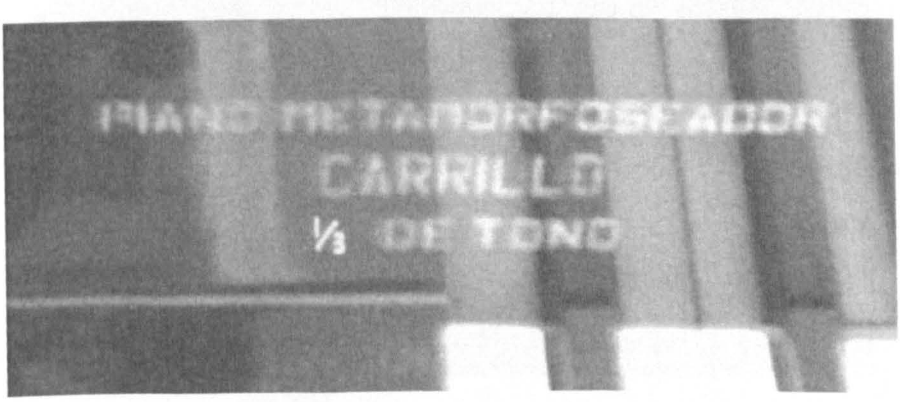

Fig. A1.65. *The 'Carrillo' thirdtone metamorphosing grand piano* by Sauter (label detail) (Photo: D. Langarica).

Fig. A1.66. The *'Carrillo' thirdtone metamorphosing grand piano* by Sauter (Photo: D. Langarica).

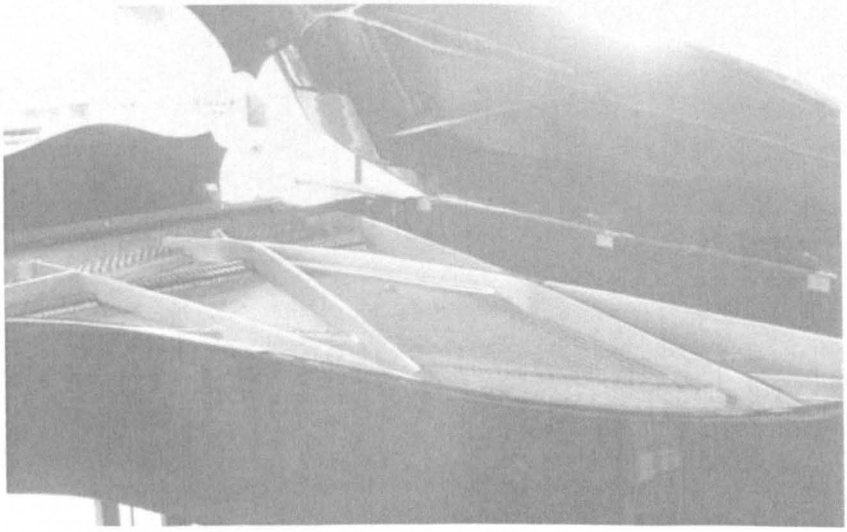

Fig. A1.67. The *'Carrillo' thirdtone metamorphosing grand piano* by Sauter (Photo: D. Langarica).

Fig. A1.68. The *'Carrillo' thirdtone metamorphosing grand piano* by Sauter (Photo: D. Langarica).

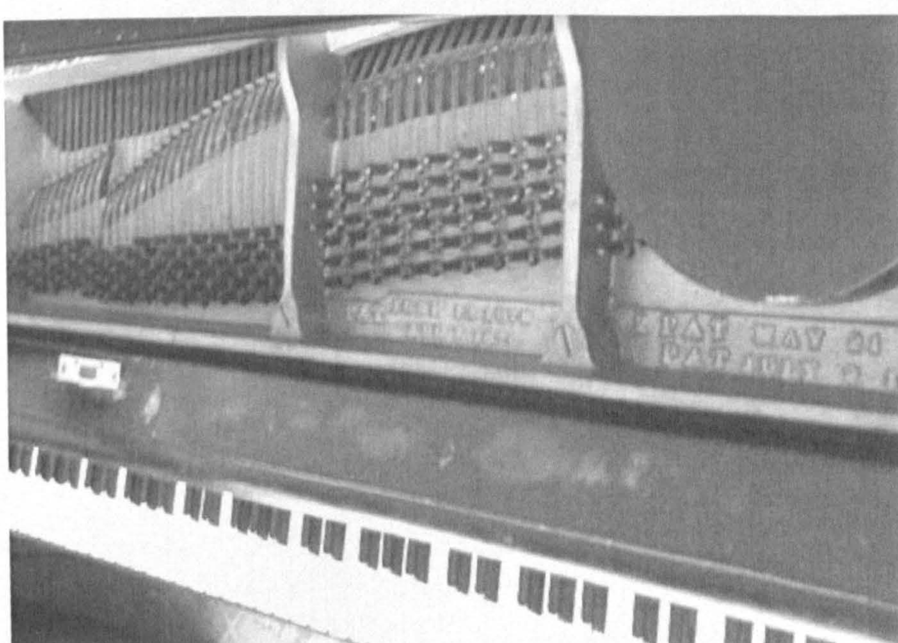

Fig. A1.69. The *'Carrillo' thirdtone metamorphosing grand piano* by Sauter (Photo: D. Langarica).

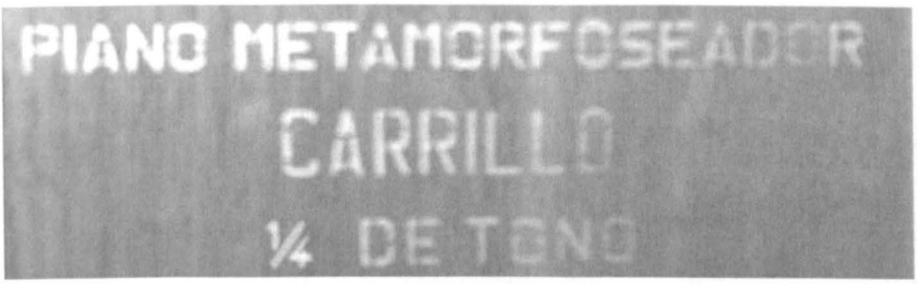

Fig. A1.70. The *'Carrillo' quartertone metamorphosing piano* by Sauter (label detail) (Photo: D. Langarica).

Fig. A1.71. The *'Carrillo' quartertone metamorphosing piano* by Sauter (Photo: D. Langarica).

Fig. A1.72. The *'Carrillo' quartertone metamorphosing piano* by Sauter (Photo: D. Langarica).

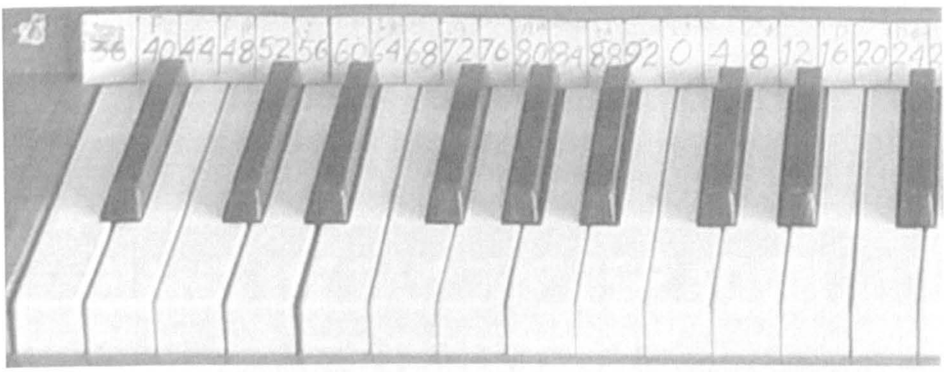

Fig. A1.73. The *'Carrillo' quartertone metamorphosing piano* by Sauter (Photo: D. Langarica).

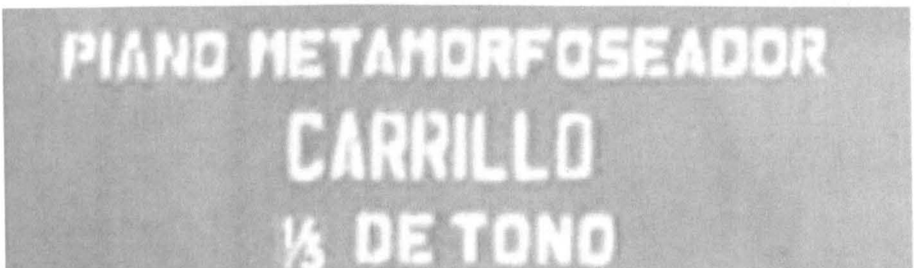

Fig. A1.74. The *'Carrillo' fifthtone metamorphosing piano* by Sauter (label detail) (Photo: D. Langarica).

Fig. A1.75. The *'Carrillo' fifthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

Fig. A1.76. The *'Carrillo' sixthtone metamorphosing piano* by Sauter (label detail) (Photo: D. Langarica).

Fig. A1.77. The *'Carrillo' sixthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

Fig. A1.78. The *'Carrillo' seventhtone metamorphosing piano* by Sauter (label detail) (Photo: D. Langarica).

Fig. A1.79. The *'Carrillo' seventhtone metamorphosing piano* by Sauter (Photo: D. Langarica).

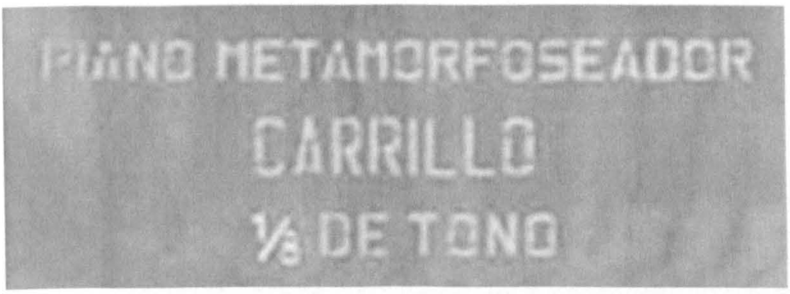

Fig. A1.80. The *'Carrillo' eighthtone metamorphosing piano* by Sauter (label detail) (Photo: D. Langarica).

Fig. A1.81. The *'Carrillo' eighthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

Fig. A1.82. The *'Carrillo' eighthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

Fig. A1.83. The *'Carrillo' ninthtone metamorphosing piano* by Sauter (label detail) (Photo: D. Langarica).

Fig. A1.84. The *'Carrillo' ninthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

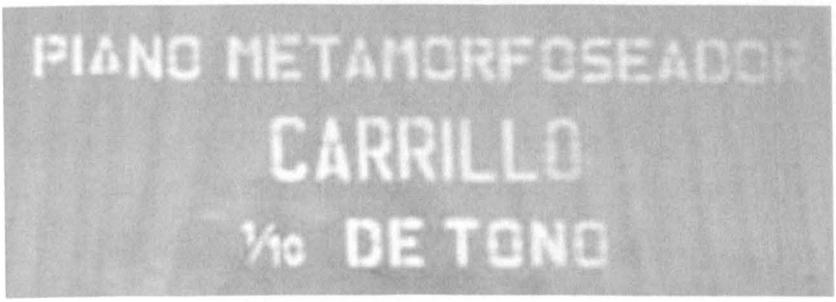

Fig. A1.85. The *'Carrillo' tenthtone metamorphosing piano* by Sauter (label detail) (Photo: D. Langarica).

Fig. A1.86. The *'Carrillo' tenthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

Fig. A1.87. The *'Carrillo' tenthtone metamorphosing piano* by Sauter by Sauter (Photo: D. Langarica).

Fig. A1.88. The *'Carrillo' eleventhtone metamorphosing piano* by Sauter (label detail) (Photo: D. Langarica).

Fig. A1.89. The *'Carrillo' eleventhtone metamorphosing piano* by Sauter (Photo: D. Langarica).

Fig. A1.90. The *'Carrillo' eleventhtone metamorphosing piano* by Sauter (Photo: D. Langarica).

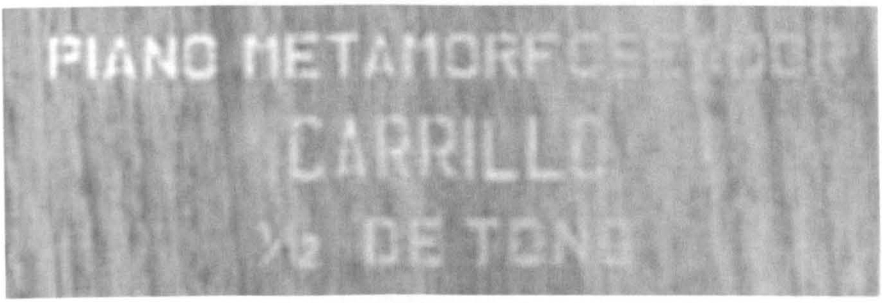

Fig. A1.91. The *'Carrillo' twelthtone metamorphosing piano* by Sauter (label detail) (Photo: D. Langarica).

Fig. A1.92. The *'Carrillo' twelthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

Fig. A1.93. The *'Carrillo' twelthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

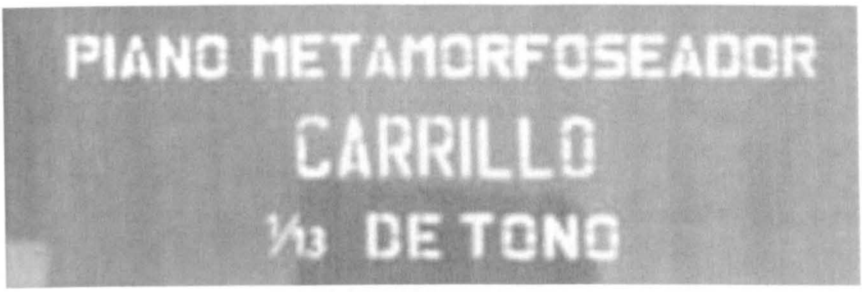

Fig. A1.94. The *'Carrillo' thirteenthtone metamorphosing piano* by Sauter (label detail) (Photo: D. Langarica).

Fig. A1.95. The *'Carrillo' thirteenthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

Fig. A1.96. The *'Carrillo' thirteenthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

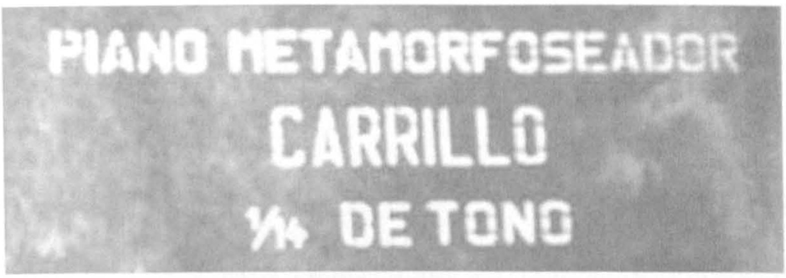

Fig. A1.97. The *'Carrillo' fourteenthtone metamorphosing piano* by Sauter (label detail) (Photo: D. Langarica).

Fig. A1.98. The *'Carrillo' fourteenthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

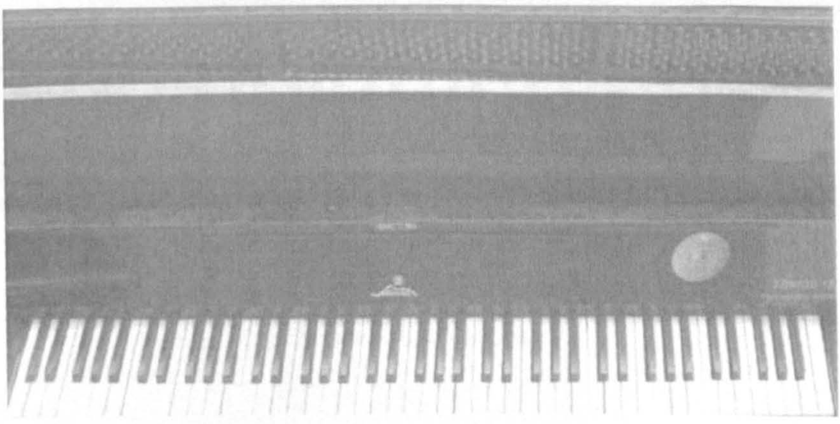

Fig. A1.99. The *'Carrillo' fourteenthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

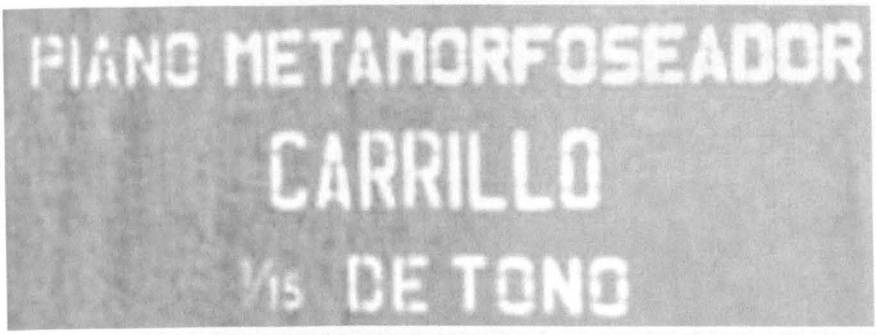

Fig. A1.100. The *'Carrillo' fifteenthtone metamorphosing piano* by Sauter (label detail) (Photo: D. Langarica).

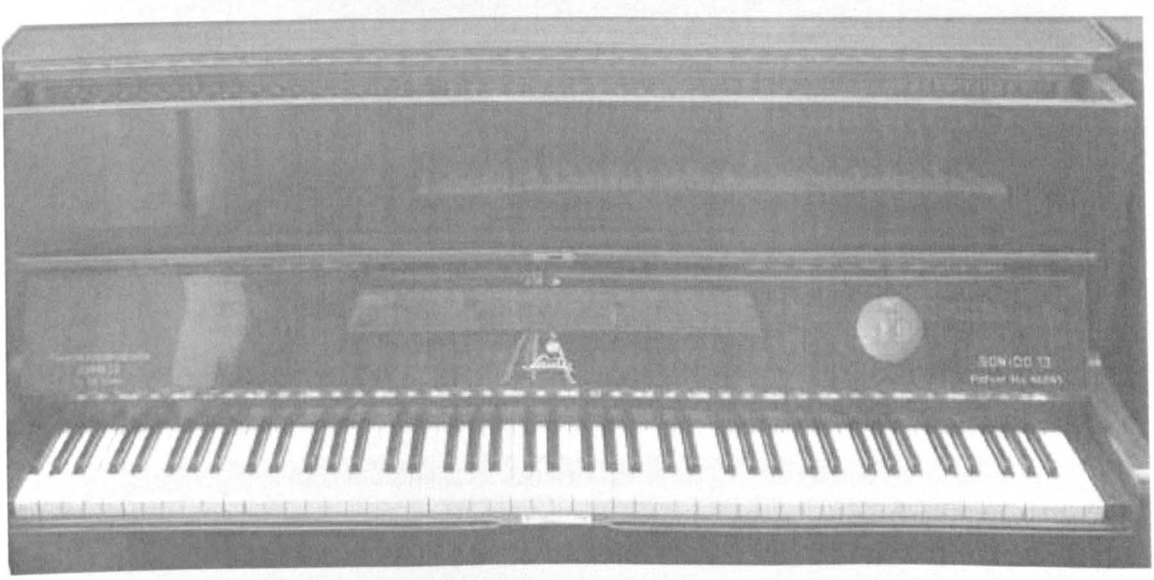

Fig. A1.101. The '*Carrillo' fifteenthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

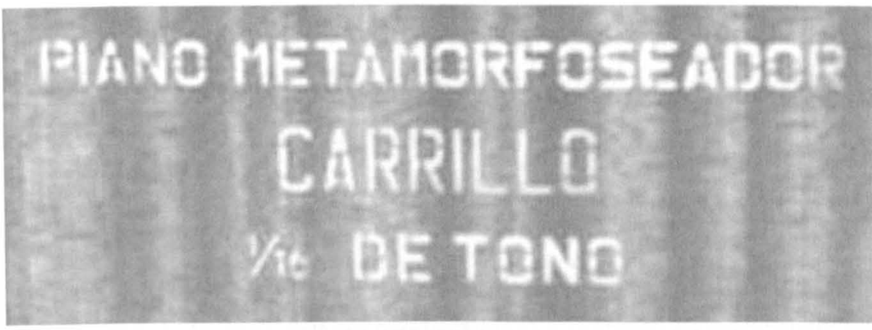

Fig. A1.102. The *'Carrillo' sixteenthtone metamorphosing piano* by Sauter (label detail) (Photo: D. Langarica).

Fig. A1.103. The *'Carrillo' sixteenthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

Fig. A1.104. The *'Carrillo' sixteenthtone metamorphosing piano* by Sauter (Photo: D. Langarica).

After a five-year break from composing microtonal music, Carrillo started another intense microtonal period mostly incorporating his *metamorphosing pianos* (1957-1959). These are the works he composed during this period:

1957 *Prelude for the 'Carrillo' quartertone metamorphosing piano* (C45)
1958 *Concertino for thirdtone piano* (with orchestra in semitones) (C46)
1959 *Babbling for the 'Carrillo' sixteenthtone metamorphosing piano* (C47)
1959 *Studies for the 'Carrillo' fifteenthtone metamorphosing piano* (C48)
1959 *Quartertone cello quasi-sonatas (1 to 6)* (C49)
1959 *Caprice* for the *'Carrillo' quartertone metamorphosing piano* (C50)

Carrillo, in the last six years of his life (1960-1965), apart from two masses (C58 and C65), a Concerto (C64) and the last of the string quartets (C59), also composed for solo instruments, exploring new instrumental techniques. Although only one instrument was developed in this period (a thirdtone 7-string guitar), his output demanding extended techniques towards the achievement of microtones was predominant. These are the compositions of this concluding period of his career:

1960 Quartertone violin quasi-sonata No 1 (C51)
1960 Quartertone guitar sonata No 2. 'Sunset in Chapultepec' (C52)
1961 Quartertone viola quasi-sonata No 1 (C53)
1961 Quartertone violin quasi-sonata No 2 (C54)
1961 Quartertone viola quasi-sonata No 2 (C55)
1962 7-strings thirdtone guitar study (C56)
1962 Quartertone string quartet No 6 (C57)
1962 Quartertone mass No 1, to John XXIII (C58)
1964 Quartertone string quartet No 7 (C59)
1964 Quartertone string quartet No 8 (C60)
1964 Quartertone violin quasi-sonata No 3 (C61)
1964 Quartertone viola quasi-sonata No 3 (C62)
1964 Quartertone viola sonata No 4 (C63)
1964 Quartertone violin concerto No 2 (C64)
1965 Quartertone mass No 2, 'a capella' (C65) (followed by Carrillo's decease)

One of Carrillo's instruments made it to the manufacturing sector, leading to worldwide performance of Carrillo's work and the work of new composers also composing for it, giving prosperity to the work of Carrillo. Here are the details:

1998: Sauter buys the *'Carrillo' metamorphosing piano* patent No 46841 and starts manufacturing the a modern version of the *sixteenthtone metamorphosing piano* under the name *mikroton piano*, which is sold as a part of their regular catalogue still in 2013.

Fig. A1.105. *Mikroton piano* by Sauter (Courtesy of Sauter).

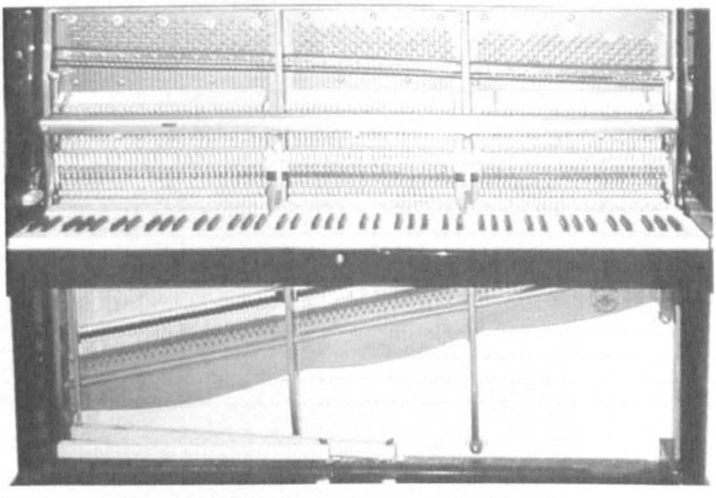

Fig. A1.106. *Mikroton piano* (frame details) (Courtesy of Sauter).

Year	Code	Notation	Work (title with annotations in English. See next page for original Spanish title)
1922 – 1925	C 1	BOTH	*Prelude to 'Critopher Colombus'* (Op. 1)
	C 2	NUM	*Ave Maria* (Op. 2)
	C 3	BOTH	*'Tepepan'. Rural scene for voices in quartertones and zither-harp in sixteenthtones* (Op. 3)
	C 4	NUM	*Quartertone cello prelude No 1* (Op. 4)
	C 5	NUM	*Album page* (Op. 5)
	C 1str	NUM	*Prelude to Colombus*
1924-5	C 6	NUM	*Quartertone string quartet No 1*
1925	C 7|2	NUM	*'Colombia' symphonies No 1&2 for orchestra "grande" in quarter, eighth and sixtennthtones*
"	C 8	STAFF	*Quartertone string quartet No 2*
"	C 9	STAFF	*Quartertone string quartet No 3*
1926	C 10	BOTH	*Babbling for muted string quartet in quartertones, with exceptional use of eighth and sixteenthtones*
"	C 11(')	BO(N)	*Sonata 'quasi fantasia' in 1/4, 1/8 and 1/16-tones* (cello replaced by guitar in 1931 arrangement with additional movement: Op. 6)
"	C 12	BOTH	*Concertino in quarter, eighth and sixteenthtones*
"	C 13	BOTH	*2 quartets for humming voices in quartertones*
"	C 14	STAFF	*Quartertone string quartets No 4 and No 5: 'Meditation'* and *'Secretely'*
"	C 14v	STAFF	*'Meditation' and 'Secretely' (for voices)*
1927	C 15	NUM	*70 exercises for double bass (a new technique in quartertones)*
"	C 16	NUM	*70 exercises in quartertones for violin solo*
"	C 17	NUM	*Quartertone exercises for viola or cello*
"	C 18	NUM	*3 quartertone studies for the 3-string violin in sonatina form*
"	C 19	NUM	*Orchestra "grande" nocturne in sixteenthtones*
1928	C 20	NUM	*Prelude for mandolin, mandola and guitar in quartertones. 'Illusion'*
"	C 21	BOTH	*'I think of you' (romance for voices and instruments in quarter and sixteenthtones)*
"	C 22	NUM	*Caprice for solo viola in tones, semitones, quarter, eighth and sixteenthtones (with open strings tuned in fifths)*
1929	C 23	NUM	*Caprice for French horn in sixteenthtones and orchestra*
"	C 24	NUM	*Impromptu for 2 sopranos in eighthtones, trumpet in eighthtones and zither-harp in sixteenthtones*
"	C 25	NUM	*Quartertone chorus*
1930	C 26	NUM	*'Colombia' symphony No 3 in quarter, eighth and sixteenthtones*
"	C 27	NUM?	*'Penumbras'. At "Reforma" Walk*
1931	C 28	NUM	*'Sound 13' fantasy (four cadences)*
"	C 29	NUM	*Lento-Allegro-Lento*
"	C 30	NUM	*Quartertone guitar study No 5. 'Midnight at the Oriental'*
"	C 31	NUM	*'Impromptu' suite for quartertone guitar*
"	C 32	NUM	*Quartertone guitar study No 1*
"	C 33	NUM	*Dawn in 'Berlin 13'*
"	C 34	NUM	*Mistery. 'Impromptu' prelude*
1933	C 35	MIX	*'Whispers'*
1934	C 36	NUM	*6 'Europe' preludes*
"	C 37	NUM	*Romance*
1942	C 38	NUM	*'The brunette Virgin' (VSO)*
1945	C 39	MIX(S)	*Concertino for cello in quarter and eighthtones*
1947	C 40	MIX	*Horizons*
1949	C 41	BOTH	*Quartertone violin concerto No 1*
1951	C 42|2	NUM	*Quartertonbe guitar preludes No 1 and No 2 (for the 'Carrillo' guitar)*
"	C 43	NUM?	*Quartertone cello prelude No 2*
1952	C 44	STAFF	*Fantasy for cello in quarter and eighthtones accompanied by symphony orchestra accidentally in quartertones*
1957	C 45	STAFF?	*Prelude for the 'Carrillo' quartertone metamorphosing piano*
1958	C 46	STAFF?	*Concertino for thirdtone piano*
1959	C 47	STAFF?	*Babbling for the 'Carrillo' sixteenthtone metamorphosing piano*
"	C 48	STAFF	*Studies for the 'Carrillo' fifthtone metamorphosing piano*
"	C 49	STAFF	*Quartertone cello quasi-sonatas (No 1 to 6)*
"	C 50	STAFF?	*Caprice for the 'Carrillo' quartertone metamorphosing piano*
1960	C 51	STAFF	*Quartertone violin quasi-sonata No 1*
"	C 52	NUM	*Quartertone guitar sonata No 2. 'Sunset in Chapultepec'*
1961	C 53	STAFF	*Quartertone viola quasi-sonata No 1*
"	C 54	STAFF	*Quartertone violin quasi-sonata No 2*
"	C 55	STAFF	*Quartertone viola quasi-sonata No 2*
1962	C 56	NUM	*7-strings thirdtone guitar study*
"	C 57	STAFF	*Quartertone string quartet No 6*
"	C 58	STAFF	*Quartertone mass No 1, to John XXIII*
1964	C 59	STAFF	*Quartertone string quartet No 7*
"	C 60	STAFF	*Quartertone string quartet No 8*
"	C 61	STAFF	*Quartertone violin quasi-sonata No 3*
"	C 62	STAFF	*Quartertone viola quasi-sonata No 3*
"	C 63	STAFF	*Quartertone viola sonata No 4*
"	C 64	STAFF	*Quartertone violin concerto No 2*
1965	C 65	STAFF	*Quartertone mass No 2, 'a capella'*

Fig. A1.107. List of Carrillo's microtonal compositions.

Year	Code	Notation	*Spanish*	*English*
1922 – 1925	C 1	BOTH	*Preludio a "Cristobal Colón"* (Op. 1)	*Prelude to 'Critopher Colombus'* (Op. 1)
	C 2	NUM	*Ave Maria* (Op. 2)	*Ave Maria* (Op. 2)
	C 3	BOTH	*"Tepepan". Escena campestre para voces en 4^{os} de tono y arpa-citara de 16^{avos}* (Op. 3)	*'Tepepan'. Rural scene for voices in quartertones and zither-harp in sixteenthtones* (Op. 3)
	C 4	NUM	*Preludio para violonchelo* (Op. 4)	*Quartertone cello prelude No 1* (Op. 4)
	C 5	NUM	*Hoja de álbum* (Op. 5)	*Album page* (Op. 5)
	C 1str	NUM	*Preludio a Colón* (Op. 1)	*Prelude to Colombus*
1924-5	C 6	NUM	*1^{er} cuarteto de cuerdas en 4^{os} de tono*	*Quartertone string quartet No 1*
1925	C 7 1|2	NUM	*1^{a} y 2^{a} sinfonía "Colombia" para grande orquesta a base de 4^{os}, 8^{os} y 16^{avos} de tono*	*'Colombia' symphonies No 1&2 for orchestra "grande" in quarter, eighth and sixtennthtones*
"	C 8	STAFF	*2^{o} cuarteto de cuerdas en 4^{os} de tono*	*Quartertone string quartet No 2*
"	C 9	STAFF	*3^{er} cuarteto de cuerdas en 4^{os} de tono*	*Quartertone string quartet No 3*
1926	C 10	BOTH	*Balbuceos para cuarteto de instr. de arco con sordina en 4^{os} de tono, y excepcionalmente en $8^{os}/16^{avos}$*	*Babbling for muted string quartet in quartertones, with exceptional use of eighth and sixteenthtones*
"	C 11(')	BO(N)	*Sonata casi fantasía en 4^{os}, 8^{os} y 16^{avos} de tono* (chelo substituido por guitarra en arreglo de 1931 con movimiento adicional, Op. 6)	*Sonata 'quasi fantasia' in 1/4, 1/8 and 1/16-tones* (cello replaced by guitar in 1931 arrangement with extra movement: Op. 6)
"	C 12	BOTH	*Concertino en 4^{os}, 8^{os} y 16^{avos} de tono*	*Concertino in quarter, eighth and sixteenthtones*
"	C 13	BOTH	*2 cuartetos para voces a boca cerrada en 4^{os} de tono*	*2 quartets for humming voices in quartertones*
"	C 14	STAFF	*4^{o} y 5^{o} cuarteto de cuerdas en cuartos de tono: "Meditación" y "En secreto"*	*Quartertone string quartets No 4 and No 5: 'Meditation'* and *'Secretely'*
"	C 14v	STAFF	*"Meditación" y "En secreto" (para voces)*	*'Meditation' and 'Secretely' (for voices)*
1927	C 15	NUM	*70 ejercicios para contrabajo (una nueva técnica en 4^{os} de tono)*	*70 exercises for double bass (a new technique in quartertones)*
"	C 16	NUM	*70 ejercicios en 4^{os} de tono para violín solo*	*70 exercises in quartertones for violin solo*
"	C 17	NUM	*Ejercicios en 4^{os} de tono para viola o violoncelo*	*Quartertone exercises for viola or cello*
"	C 18	NUM	*3 estudios a base de 4^{os} de tono en forma de "sonatina" para violín de 3 cuerdas*	*3 quartertone studies for the 3-string violin in sonatina form*
"	C 19	NUM	*Nocturno para grande orquesta a base de 16^{avos} de tono*	*Orchestra "grande" nocturne in sixteenthtones*
1928	C 20	NUM	*Preludio para mandolina, mandola y guitarra de 4^{os} de tono. "Ensueño"*	*Prelude for mandolin, mandola and guitar in quartertones. 'Illusion'*
"	C 21	BOTH	*"I think of you" (romanza para canto e instrumentos en 4^{os} y 16^{avos} de tono)*	*'I think of you' (romance for voices and instruments in quarter and sixteenthtones)*
"	C 22	NUM	*Capricho para viola sola en tonos, 2^{os}, 4^{os}, 8^{os} y 16^{avos} de tono (con afinación de las 4 cuerdas por 5^{as})*	*Caprice for solo viola in tones, semitones, quarter, eighth and sixteenthtones (with open strings tuned in fifths)*
1929	C 23	NUM	*Capricho para corno de 16^{avos} de tono y orquesta*	*Caprice for French horn in sixteenthtones and orchestra*
"	C 24	NUM	*Impromptu para 2 sopranos en 8^{os}, trompeta de 8^{os} y arpa-citara de 16^{avos} de tono*	*Impromptu for 2 sopranos in eighthtones, trumpet in eighthtones and zither-harp in sixteenthtones*
"	C 25	NUM	*Coro en cuartos de tono*	*Quartertone chorus*
1930	C 26	NUM	*3^{ra} sinfonía "Colombia" en 4^{os}, 8^{os} y 16^{avos} de tono*	*'Colombia' symphony No 3 in quarter, eighth and sixteenthtones*
"	C 27	NUM?	*"Penumbras". En el Paseo de la Reforma*	*'Penumbras'. At "Reforma" Walk*
1931	C 28	NUM	*Fantasía "Sonido 13" (cuatro cadencias)*	*'Sound 13' fantasy (four cadences)*
"	C 29	NUM	*Lento-Allegro-Lento*	*Lento-Allegro-Lento*
"	C 30	NUM	*Estudio V, guitarra 4^{os} de tono."A media noche en Oriental"*	*Quartertone guitar study No 5. 'Midnight at the Oriental'*
"	C 31	NUM	*Suite ("Impromptu") para guitarra de 4^{os} de tono*	*'Impromptu' suite for quartertone guitar*
"	C 32	NUM	*Estudio No 1 para guitarra de 4^{os} de tono*	*Quartertone guitar study No 1*
"	C 33	NUM	*Amanecer en "Berlin 13"*	*Dawn in 'Berlin 13'*
"	C 34	NUM	*Misterio. Preludio "Impromtu"*	*Mistery. 'Impromptu' prelude*
1933	C 35	MIX	*"Murmullos"*	*'Whispers'*
1934	C 36	NUM	*6 preludios "Europa"*	*6 'Europe' preludes*
"	C 37	NUM	*Romanza*	*Romance*
1942	C 38	NUM	*"La Virgen morena"*	*'The brunette Virgin' (VSO)*
1945	C 39	MIX(S)	*Concertino para violonchelo en 4^{os} y 8^{os} de tono*	*Concertino for cello in quarter and eighthtones*
1947	C 40	MIX	*Horizontes*	*Horizons*
1949	C 41	BOTH	*Concierto para violín en 4^{os} de tono*	*Quartertone violin concerto No 1*
1951	C 42 1|2	NUM	*Preludio I y II para guitarra "Carrillo"*	*Quartertonbe guitar preludes No 1 and No 2 (for the 'Carrillo' guitar)*
"	C 43	NUM?	*2^{o} preludio para violonchelo de cuartos de tono*	*Quartertone cello prelude No 2*
1952	C 44	STAFF	*Fantasía para violonchelo en $4^{os}/8^{os}$ de tono con acompañamiento de orquesta sinfónica accidentalmente en 4^{os}*	*Fantasy for cello in quarter and eighthtones accompanied by symphony orchestra accidentally in quartertones*
1957	C 45	STAFF?	*Preludio para piano metamorfoseador "Carrillo" de 4^{os} de tono*	*Prelude for the 'Carrillo' quartertone metamorphosing piano*
1958	C 46	STAFF?	*Concertino para piano de 3^{os} de tono*	*Concertino for thridtone piano*
1959	C 47	STAFF?	*Balbuceos para piano metamorfoseador "Carrillo" de 16^{avos} de tono*	*Babbling for the 'Carrillo' sixteenthtone metamorphosing piano*
"	C 48	STAFF	*Estudios para piano metamorfoseador "Carrillo" de 5^{os} de tono*	*Studies for the 'Carrillo' fifthtone metamorphosing piano*
"	C 49	STAFF	*Casi sonatas para violonchelo solo en cuartos de tono (I a VI)*	*Quartertone cello quasi-sonatas (No 1 to 6)*
"	C 50	STAFF?	*Capricho para piano metamorfoseardor "Carrillo" de 4^{os} de tono*	*Caprice for the 'Carrillo' quartertone metamorphosing piano*
1960	C 51	STAFF	*1^{a} casi sonata en 4^{os} de tono para violín solo*	*Quartertone violin quasi-sonata No 1*
"	C 52	NUM	*2^{a} sonata para guitarra de 4^{os} de tono."Atardecer en Chapultepec"*	*Quartertone guitar sonata No 2. 'Sunset in Chapultepec'*
1961	C 53	STAFF	*Casi sonata en 4^{os} de tono para viola sola*	*Quartertone viola quasi-sonata No 1*
"	C 54	STAFF	*2^{a} casi sonata en 4^{os} de tono para violín solo*	*Quartertone violin quasi-sonata No 2*
"	C 55	STAFF	*2^{a} casi sonata para viola en 4^{os} de tono*	*Quartertone viola quasi-sonata No 2*
1962	C 56	NUM	*Estudio para guitarra 7a (de siete cuerdas) en 3^{os} de tono*	*7-strings thirdtone guitar study*
"	C 57	STAFF	*6^{o} cuarteto de cuerdas en 4^{os} de tono*	*Quartertone string quartet No 6*
"	C 58	STAFF	*Misa a S.S. Juan XXIII en cuartos de tono*	*Quartertone mass No 1, to John XXIII*
1964	C 59	STAFF	*7^{o} cuarteto de cuerdas en 4^{os} de tono*	*Quartertone string quartet No 7*
"	C 60	STAFF	*8^{o} cuarteto de cuerdas en 4^{os} de tono*	*Quartertone string quartet No 8*
"	C 61	STAFF	*3^{a} casi sonata en 4^{os} de tono para violín*	*Quartertone violin quasi-sonata No 3*
"	C 62	STAFF	*3^{a} casi sonata en 4^{os} de tono para viola*	*Quartertone viola quasi-sonata No 3*
"	C 63	STAFF	*4^{a} sonata en 4^{os} de tono para viola sola*	*Quartertone viola sonata No 4*
"	C 64	STAFF	*Segundo concierto en 4^{os} de tono para violín (y orquesta sinfónica)*	*Quartertone violin concerto No 2*
1965	C 65	STAFF	*2^{a} Misa "a capella" en 4^{os} de tono*	*Quartertone mass No 2, 'a capella'*

Fig. A1.108. Author's translation of Carrillo's microtonal compositions.

Appendix Two

Appendix Two: An annotated chronological overview of the output of Harry Partch

Harry Partch was involved with music from childhood, and is most likely to have been self-taught in these early days. He started considering microtonality in his early twenties, but did not follow an academic route and destroyed all the compositions of this early period, including a string quartet that was not in 12-et, but in just intonation. This section consists of a chronological review of Partch's compositions and instrument developments from as early as records are available.

The names of instruments are underlined when they are first introduced following the invention date. This appendix ends with Fig. A2.23 (p. 336), which can be used as a reference chart to follow it. Notice that in this chart 'In' refers to the invented (II and III for derived versions of the instrument), 'R' for the reconstruction of the relevant instruments that did not change the prototype, and 'nR' for a reconstruction that led to a substantially new or derived version of the instrument, which happened to include the term 'new' as part of the instrument name rather than a Roman numeral. In the same diagram the compositions are also represented with the letter Pn (P refers to Partch), where 'n' is the number of the composition. Where not otherwise indicated, the data stems from the second edition of Partch's *Genesis of a Music.*[1]

1925: Partch started to consider the possibility of creating a just intonation string instrument, based on a few years of theoretical research. Although he had incomplete training as a pianist, he began to study the violin and the viola. It was at that time when he started experimenting marking fingerboards markings with paper. Partch's acquaintance with the strings was supported by playing the violin with the University of California Symphony Orchestra in San Francisco.[2]

1928-30: Adapted Viola was invented. The fingerboard was completed in Santa Rosa (1928) and attached to a viola body in New Orleans (1930). This early version had tiny bradheads driven into the fingerboard beside the strings, providing guides for the microtonal degrees of his microtonal scale. The marking system was a refinement of the

[1] Partch, Harry. 1949. *Genesis of a Music.* Second edition (1974). New York: Da Capo Press.
[2] Gilmore, B. 1998. *Harry Partch: A biography.* New Haven: Yale University. pp. 51-53.

paper fingerboard coverings he had devised for the string quartet composed around 1925.[3] It may be that the experience of composing the string quartet and drawing microtonal fingerboards led Partch to think that the fingerboards of the violin and viola did not provide enough space to place visual guides for his scales. This led him to use a longer string length, providing: a wider finger spacing when playing small intervals;[4] and, a range wide enough to cover the human voice's range comfortably. The creation of the Adapted Viola was for Partch a tool towards: the experimentation of sliding pitch, that led him to imitate speech, and; the performance of precise sustained microtones.

1933: Model of the Ptolemy (Pasadena). As part of a proposal to the Carnegie Foundation, Partch built this model, intending to develop it in Europe.

1930-33: *Seventeen Lyrics by Li Po* (P1) – for Adapted Viola and intoning voice. Partch started composing in November 1930 from the moment he had the cello fingerboard adapted to a viola. This implies that it is most likely that Partch used the Adapted Viola to compose. During this period of composition, Partch also showed a general interest in imitating speech, with consequent use of small sliding pitch contours and sustained microtonal intervals in just intonation. The melismatic character of Partch's output during this period deserves special attention. Partch's just intonation theories were mostly proposed during this period, while he was playing for UCSO.[5] Having focused during his early twenties on piano pedagogy, and particularly on technique, the pressure of his work being compared with well-established schools and conventions was relieved when taking a different direction with this work for Adapted Viola and intoning voice. Developing instrumental technique was implicit in the instrument development, composing and performing processes with which he was already involved. It can be observed that such freedom opens more doors to new techniques and consequently to new sounds when composing, a unique characteristic of an instrument development-led compositional approach. As a consequence of the speech imitation in his compositions for Adapted Viola, Partch initiated a new one-finger gliding technique. This sometimes calls for a second finger as support, much as in the *veena* technique,[6] in which the index and middle fingers firmly support each other when gliding up and down the neck, especially when a

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[3] Gilmore, B. 1998. *Harry Partch: A biography*. New Haven: Yale University. pp. 51-53.
[4] Note that the Adapted Viola had a cello neck. The cello strings used were tuned *G, d, a, e'*, an octave below the strings of the violin.
[5] University of California Symphony Orchestra.
[6] Gilmore, B. 1992. On Harry Partch's "Seventeen Lyrics by Li Po". *Perspectives of New Music*. vol. 30, no. 2 (Summer). p. 30.

rapid wide glide is required. When Partch worked with a cello player and asked him to play the Adapted Viola, one-finger technique was employed.

Seventeen Lyrics by Li Po was not only the first composition Partch composed using his original speech music, but is also the work that uses the widest range of techniques for the Adapted Viola. The richness of the work benefited from its having been composed during a four-year period in which three other works exploring the speech music style were either composed or initiated. This is referred to in the main text as layered approach to composition that is induced in this research with a method. Such concurrent composing enriches the experience and therefore the composition process. The development of Partch's just intonation theories, having employed schemes of twenty-nine, fifty-five, thirty-seven and finally forty-three tones during the period 1928-35, cannot be detached from the compositional practice between 1930-33, and particularly this work which covers the full period.[7] It is clear that Partch's compositional practice with the Adapted Viola, which is not a stable pitch instrument, had a great impact in his developing intuitively the microtonal palette for his compositions and, eventually, the forty-three-tone palette, which he used for the rest of his career.

Partch's speech music is influenced by Chinese vocal music, where glides are incorporated into and away from the apparent pitch, starting or ending with indefinite pitch.[8] This is also found in Okinawan folk music where, in a more melodic style, some notes are approached with *numi*, a guttural effect used to attack the notes at the beginning of phrases, using a transition from speaking the word to singing it. The *numi* is notated with a double-lined triangle symbol accompanying the target note.[9] Partch was interested in particular musical traditions of Japan, but he did not mention in his writings about Okinawan folk music. As for the notation of these attacks or transitions between definite and indefinite pitch, since Partch did not specify them, the recording of this work with his own voice can be considered to be the guidance tool towards the interpretation of the score.

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[7] Gilmore, B. 1992. On Harry Partch's "Seventeen Lyrics by Li Po". *Perspectives of New Music*. vol. 30, no. 2 (Summer). p. 27.
[8] Strang, G. 1945. Sliding Tones in Oriental Music. *Bulletin of the American Musicological Society*. no. 8 (October). pp. 29-30.
[9] LaRue, J. 1951. The Okinawan Notation System. *Journal of the American Musicological Society*. vol. 4, no. 1 (Spring). p. 32.

Partch's speech music combines free-rhythm and speech styles commanded by words, adding fixed-rhythms for Adapted Viola at times. These elements constitute the stylistic components of the vocal-music sections in *Noh* theatre.[10] Partch's interest in the traditional Japanese theatrical forms *Noh* and *Kabuki* might have only been musical at this stage, but movements from these theatrical forms were later on incorporated in his performances. Due to the rhythmical freedom, in contrast with the demanding accuracy of his notated ratios, performances of Partch's speech music vary substantially from performer to performer, allowing for a freedom of interpretation that gives important weight to the performer in the music-making process. Representing Partch's speech music period, *Seventeen Lyrics by Li Po* symbolises a refined compromise between many dual elements, including: the development of music theory and its practice, composing in conjunction with developing a musical instrument, developing instrumental and vocal technique, conjunction of non-Western musical traditions and Western musical traditions, music and poetry, recitation and singing, timbre and pitch, dynamic and stable pitch, fixed and stretchable rhythm, composer and performer, and pitch determinacy and rhythmical indeterminacy.

1931 *Two Psalms* (P2) – for Adapted Viola and intoning voice.

The Lord is my Shepherd, Psalm 23 (1931) (P2a)

By the Rivers of Babylon, Psalm 137 (1931-41) (P2b) – original version for Adapted Viola and intoning voice. A posterior version uses Chromelodeon I, Kithara II.

Both Psalms are based on the spoken inflections of a cantor and explore inflections of Hebraic intonation.[11] The composition of *Seventeen Lyrics by Li Po* and *Two Psalms* overlapped. Considering that both works use the Adapted Viola, it is likely that the instrumental technique Partch developed in composing one work affected the other.

The Lord is my Shepherd was composed directly from the cantor's transcription of Psalm 23, borrowing elements from Hebraic intonation.[12] *By the Rivers of Babylon* also explores

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[10] Minagawa, T. 1957. Japanese "Noh" Music. *Journal of the American Musicological Society*. vol. 10, no. 3 (Autumn). p. 182.
[11] Harlan, B. T. 2007. *One voice: A reconciliation of Harry Partch's disparate theories*. PhD dissertation. University of Southern California, Los Angeles. p. 40.
[12] *Ibid.*

the intonation resources of Hebraic chanting in an American English context, but is based on information gathered from the model created for *The Lord is my Shepherd.*

Since the rest of Partch's compositions employing speech music only explore intonation aspects of American English. *Two Psalms* in an exception since it imitates the intonation of Hebraic chanting in American English. The phenomenon of exploring the intonation of one language in another also happens in Japanese Shigin, where Chinese intonation is explored through poetic recitation in Japanese using musical scales. Poems by Li Po are frequently used in the Shigin repertoire. Although Partch did not mention about Shigin in his writings, there is no doubt there were many Chinese and Japanese influences on Partch's music from this very early stage in his career as a composer.

A posterior version of *Two Psalms* was written for voice, cello, Kithara II and Chromelodeon, which suggests the possibility that this piece in its original version might have affected, or suggested the development of the Chromelodeon (as a new conception of the concept behind the Ptolemy).

Fig. A2.1 shows a pitch-versus-time graph under the score of the first two verses of Partch's *By the Rivers of Babylon.*[13] It is shown that Partch notated the Chromelodeon part by representing the note on the keyboard to be played. Fig. A2.2 shows the pitches corresponding to each key in the Chromelodeon. The vocal part is notated (at sounding pitch), indicating the closest pitch in 12-et, allowing the vocalist to make adjustments by ear. From A to D ('By the rivers of') the voice part follows the same changes of direction as the Chromelodeon's right-hand part, at exactly the same points (indicated with vertical lines). From D to F ('Babylon') the movement is slightly different, but since the ratio between the parts is easy to recognise and the descending movement (not indicated in Partch's notation, but suggested in Harlan's diagram) has an improvisatory style, the whole phrase presents few difficulties in performance.

The notation of sliding pitch for the voice part (in staff notation) does not imply precision, unlike the ratio notation, to which each note of the vocal part must be adjusted with

[13] Score and pitch-versus-time representation from B. T. Harlan's *One voice: A reconciliation of Harry Partch's disparate theories* (2007, PhD dissertation. University of Southern California, p. 184). Synchronising lines and letters from A to R, indicating inflection points (change of curvature of direction) in the graph of the vocal part (the thickest line), similar to the matching one in the Chromelodeon part, which is represented by the other two thinner lines, have been added.

accuracy (see also Fig. A2.2, where the interval values in cents are provided for each note compared to: 96-et, 400-800 harmonic series, and Partch's 43-note just intonation): 'By', sounding a just fourth (4/3; ~498 ¢) below the left-hand note; 'the', sounding a just major third below the left-hand note (5/4; 386.3 ¢); 'Ri-', sounding a just major tone (9/8; 203.9 ¢) below the left-hand note and a pure major fifth (3/2; ~702 ¢) below the right-hand note; '-vers' a major semitone (16/15; 111.7 ¢) above the left-hand note, which might be difficult to adjust in a short time, but in this case the vocal note is sounded a just fifth (3/2; ~702 ¢) below the right-hand note; and 'of' is harmonised like 'Ri-'. The resolution of the phrase (D, E and F in Fig. A2.2), does not move parallel to the Chromelodeon, but the harmony still uses low-number rations: 'Ba-' a just fourth (4/3; ~498 ¢) below the left-hand note; '-by-' an octave below the right-hand note; and '-lon' a pure major sixth (6/5, ~933 ¢) below the left-hand note.

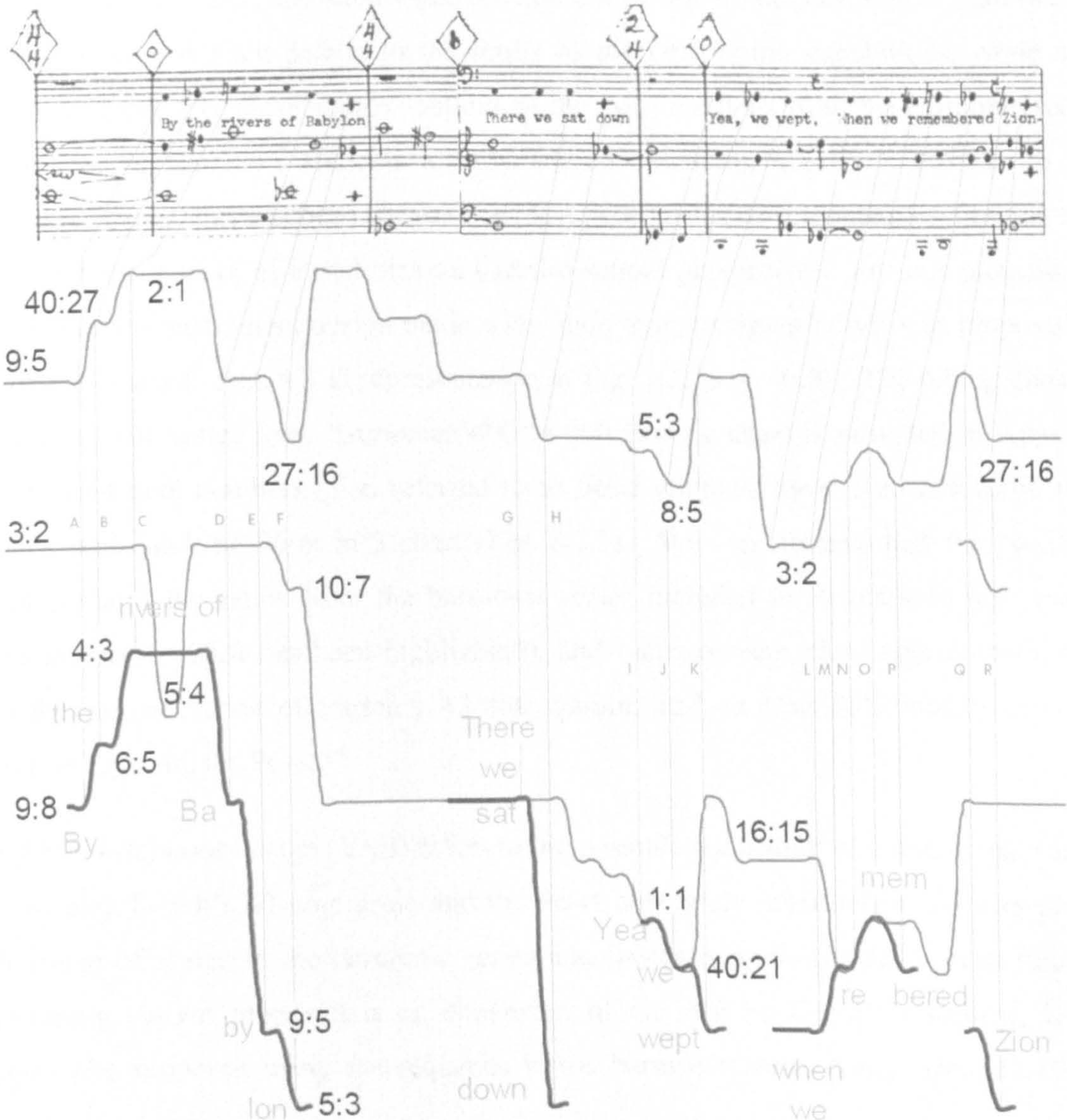

Fig. A2.1. *By the Rivers if Babylon* (bars 1-6, Partch's original score) above, and the corresponding pitch-versus-time graph below (by T. Harlan) with original text and matching-lines annotated.

Was the process of pioneering a wide range of new harmonies, available within a 43-note just intonation system, compromised by using simple low number ratios for the vocalist to harmonise with the instruments? This might have been the case here, where Partch was careful to provide sustained and easy to adjust intervals (low number ratio) to the vocalist, but there is no doubt that he pioneered far more complicated just intonation harmonies when he started using fixed and stable-pitch instruments later on in his work.

As Partch's work is reviewed, the need to integrate ideas developed by both Carrillo and Partch arises. They are both instrument development composers, and they both have a consistent fascination for pioneering new sounds through incorporating tuning theory into their work. Both composers acknowledged the harmonic series, and while Partch started from scratch and adopted them (together with the subharmonic series), Carrillo tried to departure from the 12-et, and subdivided the 200 ¢ tone into equal parts higher than two, in order to enrich the pitch palette to the limits of the performing capabilities, while also being able to get very close approximations of the ratio-intervals from the harmonic series desired. Since Carrillo's students already started extending Carrillo's theories to the language of ratios, this has been chosen here as a path for the development of a tuning that could look at the work of Partch from a Carrillo-school perspective. For this purpose, an original musical instrument design made with finely tuned singing bowls was proposed as part of this research (see a 3-D representation in Fig. A3.76, p. 460). The tuning consists of the harmonic series from harmonics 400 to 800 (tuning chart is provided in Appx 4). The relevant note numbers (also referred to as bowl number) have been compared with Partch's scale and the 96-et in a chart (Fig. A2.2). We can observe that the proposed tuning contains the ratios from the harmonic series included in Partch's 43-note gamut (deviation zero, which has been highlighted), and includes very close approximations to the subharmonic ratios of Partch's 43-note gamut, and to Carrillo's mostly explored microtonal system, the 96-et.[14]

The *440-bowlophone* design (VMI) refers to the possible realisation of a tuning that can be used to play Partch's 43-note scale and the 96-et accurately, although it can also play a wide range of scales in the harmonic series and basically approximate to most tunings. This tuning system proposed is an expansion of an idea by Carrillo's student, David Espejo, who proposed using the sequence in the harmonic series from harmonic 100 to

[14] In the chart the 96-edo note names with computer-friendly sharp accidentals (from 1 to 15 commas sharp: ', ", "', +, +', +", +"', #, # ', # ", # "', ^, ^', ^", ^"').

200.[15] In the *440-bowlophone*, 17 notes are tuned to ratios included in Partch's 43-note scale (*o-tonality*),[16] 15 notes differ in less than one cent, 10 notes are slightly over one cent and 1 note differs 2 ¢. If we select the closer 96 bowls to form a 96-et starting from the root of this just intonation scale, then the average deviation from the 96-et is 0.79 ¢ and all the deviations are under 2 ¢. If we select the closer 43 bowls to form Partch's 43-note-just-intonation scale starting from the same note, the average deviation from the 96-et is 0.59 ¢ and all the deviations are under 2 ¢. Having defined the *440-bowlophone*, the review of Partch's work continues making references to its tuning (or bowl numbers when required). Conceiving a tuning as a physical instrument,[17] towards the consolidation of theoretical ideas without necessarily having the instrument built, but anticipating it, is inspired on the work of Partch. This was observed during Partch's period of speech music composition (1930-1933), arising from concern about obtaining the required pitches without reference to a stable-pitch instrument, but merely to theory. The stopping positions of the Adapted Viola, indicated by dots, are merely guides for fine adjustments to be done by ear, a process that requires training and practice.[18] As a matter of fact, in parallel to his work, Partch started his research towards the development of a stable pitch instrument (The Ptolemy) in 1930, the same year he started composing for the Adapted Viola, and completed The Ptolemy's development in 1933, the same year that he finished the speech music composition period consisting of works for voice and Adapted Viola. What is even more interesting is that one of his vocal works was extended and re-conceived towards the incorporation of a stable-pitch reed keyboard instrument that in 1941 (year in which the composition was completed) it became the Chromelodeon I (as an alternative to the Ptolemy).[19] This work incorporated also a string stable-pitch instrument: the Kithara I. The proposed *440-bowlophone*'s VMI not only helps the study of Partch's work and its comparison with the one of Carrillo's, but also has the potential to inspire future arrangements or expansions of works included in this research, which could make use of just intonation, specially when using microdiscrete realisations of gliding tones.

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[15] Carrillo's student, Oscar Vargas, materialised this by building harps of up to nine-octaves range employing such tuning.

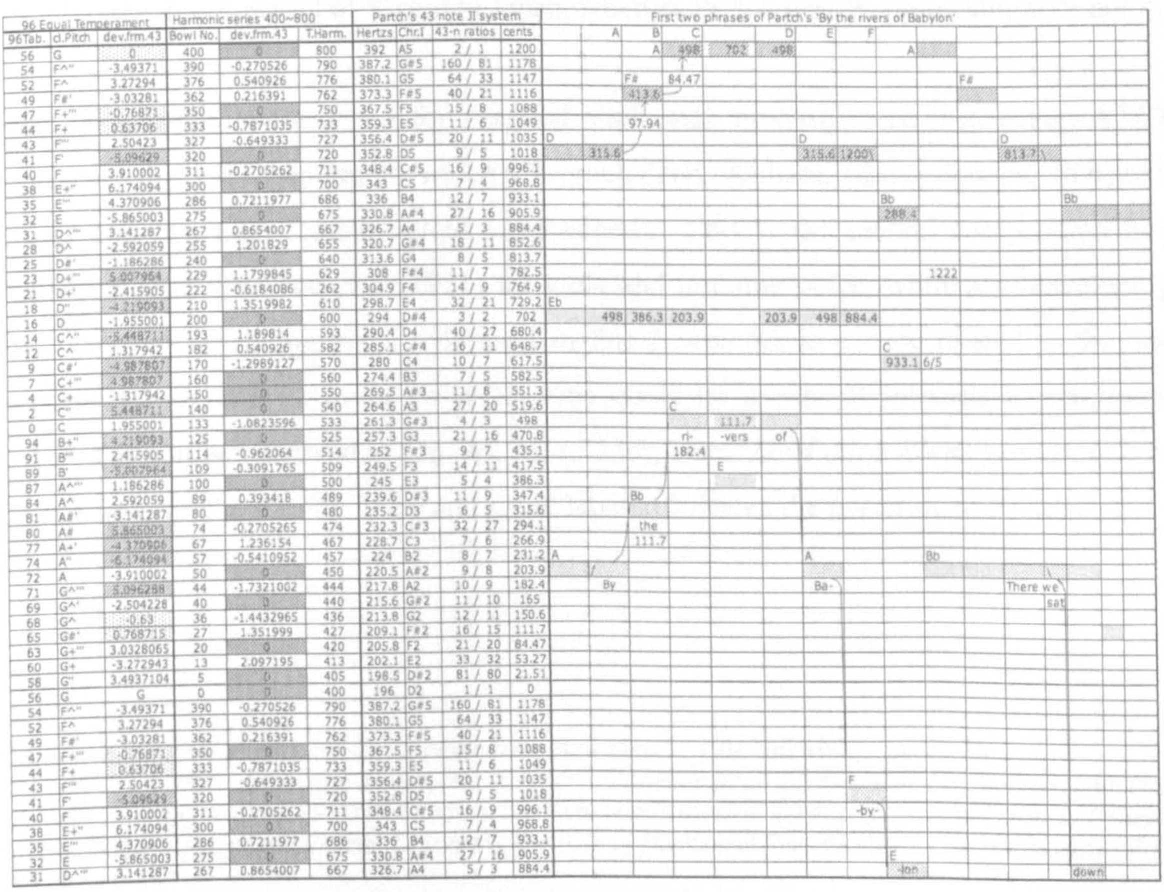
[16] Partch defines *o-tonality* as a group of ratios from the harmonic series as opposed to *u-tonality*, which consists of a group of ratios in the subharmonic series (the harmonic series' mirror image).

[17] And in the case of the 440-bowlophone, as a VMI (visual musical instrument), that has been recreated with 3-D software, for possible future upgrade to MAVMI (MIDI audio-visual musical instrument) (see p.40).

[18] And they also indicate the required lengths of the pitch glides.

[19] *By the Rivers of Babylon*, Psalm 137 (1931-41) (P2b) for intoning voice, Chromelodeon I, Kithara II, which was originally written for Adapted Viola and intoning voice (P2a).

During this early period (1930-33), Partch left the rhythm free for the words to be intoned following the natural rhythms of spoken delivery.[20] Although he progressed to a more rhythmical style later on in his career, he kept the freedom of sliding pitch contours when notating them. Partch taught himself to perform his early vocal works, from which he must have benefited greatly in composing, especially due to the fact that he could play the Adapted Viola and sing while composing. Partch only performed the vocal part while playing the Adapted Viola, when he could not find a singer to perform with.[21] This fact suggests that playing Adapted Viola and singing simultaneously for these early vocal works was too complex to consider it for performance. Considering the elements of improvisation involved in these works, suggested by the pitch contours, working with several singers must have enriched and defined an ideal conception and performing style for each of the works. The recordings Partch left behind offer a precise guide to the intended intonation at a mature stage of these works through multiple performances and interactions with singers.



96 Equal Temperament			Harmonic series 400~800			Partch's 43 note JI system				
96Tab.	cl.Pitch	dev.frm.43	Bowl No.	dev.frm.43	T.Harm.	Hertzs	Chr.I	43-n ratios	cents	
56	G	0	400	0	800	392	A5	2 / 1	1200	
54	F^''	-3.49371	390	-0.270526	790	387.2	G#5	160 / 81	1178	
52	F^	3.27294	376	0.540926	776	380.1	G5	64 / 33	1147	
49	F#'	-3.03281	362	0.216391	762	373.3	F#5	40 / 21	1116	
47	F+'''	-0.76871	350	0	750	367.5	F5	15 / 8	1088	
44	F+	0.63706	333	-0.7871035	733	359.3	E5	11 / 6	1049	
43	F'''	2.50423	327	-0.649333	727	356.4	D#5	20 / 11	1035	D
41	F'	-5.09629	320	0	720	352.8	D5	9 / 5	1018	
40	F	3.910002	311	-0.2705262	711	348.4	C#5	16 / 9	996.1	
38	E+''	6.174094	300	0	700	343	C5	7 / 4	968.8	
35	E'''	4.370906	286	0.7211977	686	336	B4	12 / 7	933.1	
32	E	-5.865003	275	0	675	330.8	A#4	27 / 16	905.9	
31	D^'''	3.141287	267	0.8654007	667	326.7	A4	5 / 3	884.4	
28	D^	-2.592059	255	1.201829	655	320.7	G#4	18 / 11	852.6	
25	D#'	-1.186286	240	0	640	313.6	G4	8 / 5	813.7	
23	D+'''	5.007964	229	1.1799845	629	308	F#4	11 / 7	782.5	
21	D+'	-2.415905	222	-0.6184086	262	304.9	F4	14 / 9	764.9	
18	D''	-4.219093	210	1.3519982	610	298.7	E4	32 / 21	729.2	Eb
16	D	-1.955001	200	0	600	294	D#4	3 / 2	702	
14	C^''	-5.448711	193	1.189814	593	290.4	D4	40 / 27	680.4	
12	C^	1.317942	182	0.540926	582	285.1	C#4	16 / 11	648.7	
9	C#'	-4.987807	170	-1.2989127	570	280	C4	10 / 7	617.5	
7	C+'''	4.987807	160	0	560	274.4	B3	7 / 5	582.5	
4	C+	-1.317942	150	0	550	269.5	A#3	11 / 8	551.3	
2	C''	5.448711	140	0	540	264.6	A3	27 / 20	519.6	
0	C	1.955001	133	-1.0823596	533	261.3	G#3	4 / 3	498	
94	B+''	4.219093	125	0	525	257.3	G3	21 / 16	470.8	
91	B'''	2.415905	114	-0.962064	514	252	F#3	9 / 7	435.1	
89	B'	-5.007964	109	-0.3091765	509	249.5	F3	14 / 11	417.5	
87	A^'''	1.186286	100	0	500	245	E3	5 / 4	386.3	
84	A^	2.592059	89	0.393418	489	239.6	D#3	11 / 9	347.4	
81	A#'	-3.141287	80	0	480	235.2	D3	6 / 5	315.6	
80	A#	5.865003	74	-0.2705265	474	232.3	C#3	32 / 27	294.1	
77	A+'	-4.370906	67	1.236154	467	228.7	C3	7 / 6	266.9	
74	A''	-6.174094	57	-0.5410952	457	224	B2	8 / 7	231.2	A
72	A	-3.910002	50	0	450	220.5	A#2	9 / 8	203.9	
71	G^'''	5.096288	44	-1.7321002	444	217.8	A2	10 / 9	182.4	
69	G^'	-2.504228	40	0	440	215.6	G#2	11 / 10	165	
68	G^	-0.63	36	-1.4432965	436	213.8	G2	12 / 11	150.6	
65	G#'	0.768715	27	1.351999	427	209.1	F#2	16 / 15	111.7	
63	G+'''	3.0328065	20	0	420	205.8	F2	21 / 20	84.47	
60	G+	-3.272943	13	2.097195	413	202.1	E2	33 / 32	53.27	
58	G''	3.4937104	5	0	405	198.5	D#2	81 / 80	21.51	
56	G	G	0	0	400	196	D2	1 / 1	0	
54	F^''	-3.49371	390	-0.270526	790	387.2	G#5	160 / 81	1178	
52	F^	3.27294	376	0.540926	776	380.1	G5	64 / 33	1147	
49	F#'	-3.03281	362	0.216391	762	373.3	F#5	40 / 21	1116	
47	F+'''	-0.76871	350	0	750	367.5	F5	15 / 8	1088	
44	F+	0.63706	333	-0.7871035	733	359.3	E5	11 / 6	1049	
43	F'''	2.50423	327	-0.649333	727	356.4	D#5	20 / 11	1035	
41	F'	-5.09629	320	0	720	352.8	D5	9 / 5	1018	
40	F	3.910002	311	-0.2705262	711	348.4	C#5	16 / 9	996.1	
38	E+''	6.174094	300	0	700	343	C5	7 / 4	968.8	
35	E'''	4.370906	286	0.7211977	686	336	B4	12 / 7	933.1	
32	E	-5.865003	275	0	675	330.8	A#4	27 / 16	905.9	
31	D^'''	3.141287	267	0.8654007	667	326.7	A4	5 / 3	884.4	

Fig. A2.2. Three Tunings comparison for the previously analysed extract of 'By the rivers of Babylon'.

[20] Gilmore, B. 1992. *Harry Partch: The Early Vocal Works 1930-33*. PhD Thesis. Queen's University, Belfast. p. 10.
[21] *Ibid*. p. 6.

Having music performed while composing it,[22] and especially while techniques for new instruments were being developed, was, from the beginning, a satisfactory process for Partch's output as an instrument development-led composer.

Shigin, traditional Japanese recitation of ancient Chinese poems, follows a similar principle to Partch's speech music. Since the end of the nineteenth century, this recitation adopted an extensively melismatic style, using traditional Japanese pentatonic scales as a base for a large variety of vibrato and pitch contours. This musical movement is probably inspired by the wide range of pitch contours found in Chinese language (a range of a twelfth has been observed in Chinese speech).[23] Partch showed an interest in the smooth inflections of American English, for example in *17 Lyrics by Li Po*, when reciting or hearing a recitation of Obata's translation of Li Po poems.[24] Since American English recitation and speech patterns were important elements in Partch's exploration of microtonality and sliding pitch contours in his early vocal works, a parallelism can be traced to the development of Shigin in Japan, whether Partch was aware of Shigin or not.[25]

1931: *The Potion Scene* (P3) – for Adapted Viola and intoning voice (P3' in Fig. A2.23 represents the 1955 version in which Chromelodeon, Kithara, bass marimba, Marimba Eroica and two high female voices were added). This is the second composition that Partch wrote in the same year (1931) for viola and intoning voice, while also developing two others. The sliding-pitch style used in *The Potion Scene* can be related to the one initiated with *17 Lyrics by Li Po* (P1). This could be a case of interactive composing (layered as can be observed in Fig. A2.23, p. 336), since *The Potion Scene* was completed 2 years before *17 Lyrics by Li Po* and could have influenced the posterior Li Po settings.

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22 Gilmore, B. 1998. *Harry Partch: A biography*. New Haven: Yale University. pp. 85-86.

23 Ayers, L. 1994. *Exploring microtonal tunings: A kaleidoscope of extended just tunings and their compositional applications*. PhD dissertation. University of Illinois at Urbana-Champaign. p. 441. Original source: Beijing Language Institute, *Chinese Today* (China Books and Periodicals Inc. San Francisco, 1991), Dialog 9. p. 65.

24 Obata, S. 1922. *The works of Li Po, the Chinese poet*. New York: E.P. Dutton and Company.

25 His interest in Japanese Music can only be traced to Noh and Kabuki (parallels movements to Shigin in Japan if we look chronologically to their developments), but no mention of Shigin has been traced in his writings. In fact, Partch did apply for a grant, unfortunately not received, to research Noh and Kabuki in Japan in his late fifties. And although both Kabuki and Noh strongly influenced Partch's conception of musical theatre, the melismatic elements of Kabuki and Noh are not as predominant as in his early works.

By looking at the 1955 version of *The Potion Scene,* it is easy to understand that Partch felt the need to improve his compositional ideas, creating stable-pitch instruments that offered precise discrete pitches, such as the Chromelodeon. Initially this offered a complementary approach to sliding pitch and just intonation, but it was gradually substituted for the sliding style associated with the Adapted Viola, as in the new version of *The Potion Scene* (1941).

1934-35: The Ptolemy (v.1) was completed in London. It was shipped to Santa Barbara where it was stored and then lost. Partch was not very proud of his results with the Ptolemy, as he indicated in *Genesis of a Music* (2nd edition), where he omitted the picture and diagrams from the first edition, declaring that the instrument was a failure due to lack of skills, money and equipment.[26] Partch obtained a small grant for a project involving the development of the Ptolemy and went to London for research.[27] Considering that this project led Partch to develop Chromelodeon I and Chromelodeon II a few years later, the development of the Ptolemy can be considered a process of sorting his research and experimentation with keyboard reed instruments towards the posterior conception of the Chromelodeons; indeed, Partch used the reeds from the Ptolemy for the Chromelodeon I.[28] The just intonation pattern (11-limit *tonality diamond*)[29] explored through the Ptolemy layout may be considered a precursor of the posterior diamond marimba layout. 'Not levers, but cords connect the keys with the reed (the air valves for the individual reeds), which allow the reads to speak'.[30] Partch also comments on the mechanical difficulties of squeezing 168 keys (Fig. A2.3 - Fig. A2.6),[31] into such a small space, which made this instrument impractical for performances.

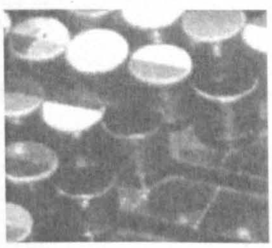

Fig. A2.3. A zoom on the Ptolemy's keys showing they were simple buttons (Photo: Harry Partch) (Courtesy of HPSA).[32]

[26] Partch, Harry. 1949. *Genesis of a Music*. Second edition (1974). New York: Da Capo Press. p. 219.
[27] Gilmore, B. 1998. *Harry Partch: A biography*. New Haven: Yale University. p. 103.
[28] *Ibid*. p. 138.
[29] Partch, Harry. 1949. *Genesis of a Music*. Second edition (1974). New York: Da Capo Press. p. 158.
[30] Partch, Harry. 1935. *Musical Opinion*. June 1935 (Blackburn, Philip. 1997. *Harry Partch: Enclosure Three*. St. Paul, MN: American Composers Forum. p. 49).
[31] Blackburn, Philip. 1997. *Harry Partch: Enclosure Three*. St. Paul, MN: American Composers Forum.
[32] Photos from the Harry Partch Estate Archive (HPSA) appeared in *Enclosure Three: Harry Partch* (American Composers Forum/ Innova), Philip Blackburn, ed. Used by permission of Philip Blackburn representing the archive.

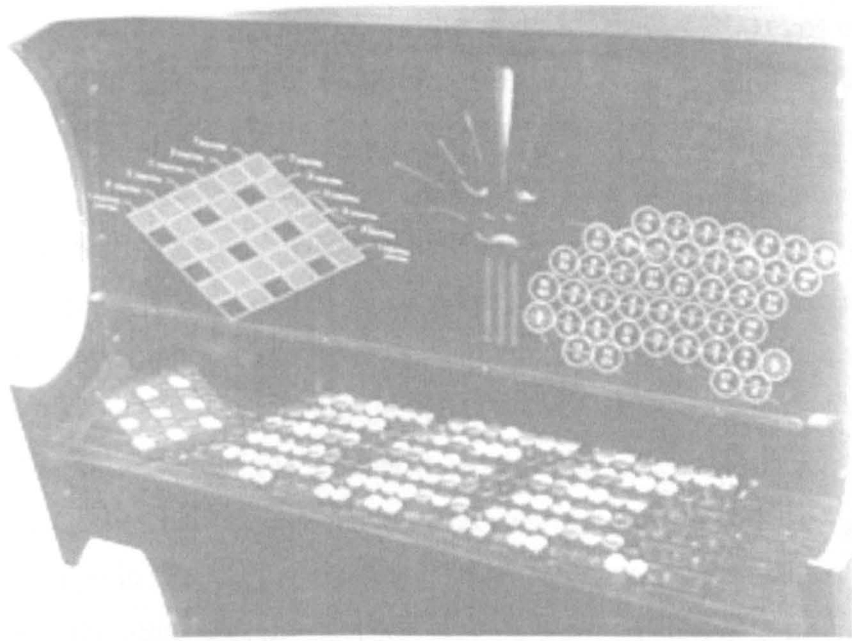

Fig. A2.4. The Ptolemy's keyboard and charts. Photo appeared in Musical Opinion, June 1935, p.764. Inset left: *Tonality diamond* from *Genesis of a Music*, 1st edition (1949), p. 207, Univ. of Wisconsin Press. Inset right: One 2/1 of keyboard layout, *ibid.*, p. 206. (Courtesy of HPSA).

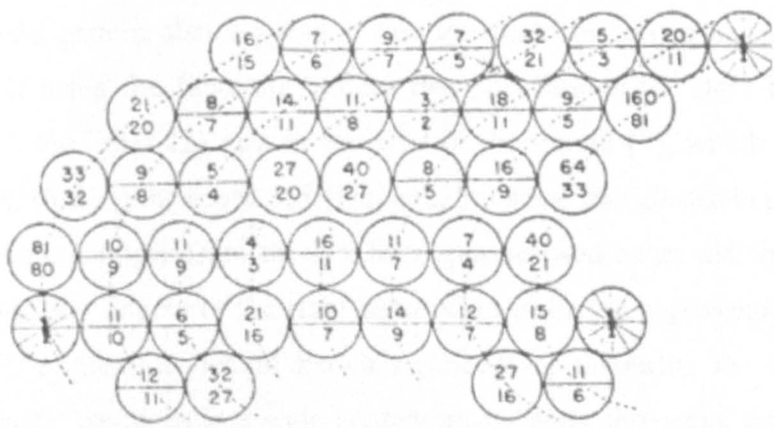

Fig. A2.5. The Ptolemy's ratios. Diagram 18, *Genesis of a Music*, *ibid.* p. 206. (Courtesy of HPSA).

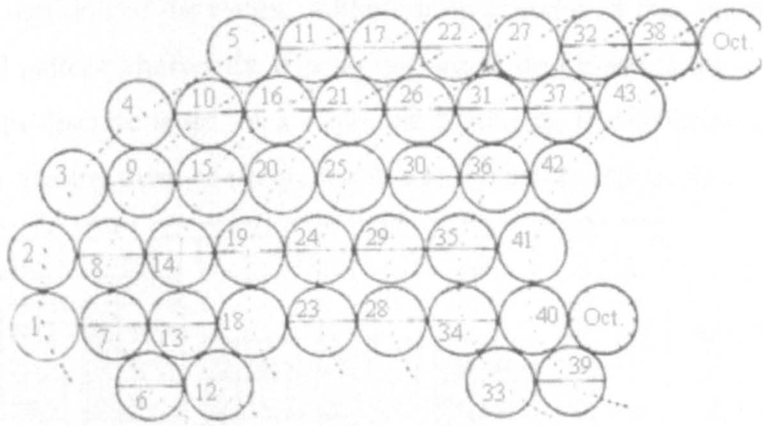

Fig. A2.6. *Ibid.*, digitally processed to show the scale degrees instead of the ratios. (Courtesy of HPSA).

The pitches used for the Ptolemy are laid in the keyboard design in groups of five or six typewriter-size keys (Fig. A2.5), following a curve in a plane, in a comfortable disposition for the fingertips of a relaxed right hand. Fig. A2.7 shows the degree position within the 43-tone just intonation scale used. A chromatic 43-tone just intonation scale can be performed using the five right-hand fingers when the curve contains five keys, and three plus three (thumb, index and middle) when playing a six-key curve, allowing a simpler chromatic scale digitation pattern than the one found on a piano's chromatic scale. Partch's interest on keyboard digitation probably stem from his previous piano teaching experience. The pattern is unique, in that it requires the player to sit very close to the keyboard, with the shoulders almost above the keyboard, so as to have the right hand in a comfortable position to execute the chromatic scale, enabling it to sound like a pitch slide. Fig. A2.7 shows the scale degrees for each curve pattern (represented in columns), with cents values next to them, and the finger pattern suggested by Partch (five or three-plus-three) at the head of the column. It is possible that the first and second keys for each pattern of six notes was intended to be played sliding the thumb, since they are always adjacent. The second pattern also suggests a fast glissando technique particular to this keyboard design. If using the fingering pattern two-plus-four in the right hand (finger coding 1-2-1-2-3-4), the index (2) gets in the way of the thumb (1), which requires the index to act as pivot, slowing the speed of movement, but since this glissando pattern is not ideal for the left hand, a finger from the left hand can be used as an aid for the 6-note patterns, so as to use five fingers of the right hand when imitating a glissando by playing discrete pitches. The intention behind Partch's concept of favouring the shape of the fingertips for chromatic passages in a scale containing so many tiny steps was an attempt to simulate the pitch glides of the Adapted Viola while allowing a comprehensible disposition and recognition of the ratios. Although he abandoned this instrument and did not use this curved pattern afterwards, it is an important step towards the achievement of pitch glides through discrete steps on a keyboard favouring the differing lengths of the fingers, rather than treating them as equal, and it is still the only one of its kind.

5		3+3		3+3		5		5		5		3+3		3+3	
		11	266.9	17	435.1							38	1035	oct	1200
5	111.7	10	231.2	16	417.5	22	582.5	27	729.2	32	884.4	37	1017.6	43	1178.5
4	84.5	9	203.9	15	386.3	21	551.3	26	702	31	852.6	36	996.1	42	1146.7
3	53.5	8	182.4	14	347.4	20	519.6	25	680.5	30	813.7	35	968.8	41	1115.5
2	21.5	7	165	13	315.6	19	498	24	648.7	29	782.5	34	933.1	40	1088.3
1	0	6	150.6	12	294.1	18	470.8	23	617.5	28	764.9	33	905.9	39	1049.4

Fig. A2.7. Finger patterns for The Ptolemy's keyboard (note degrees and cents values).

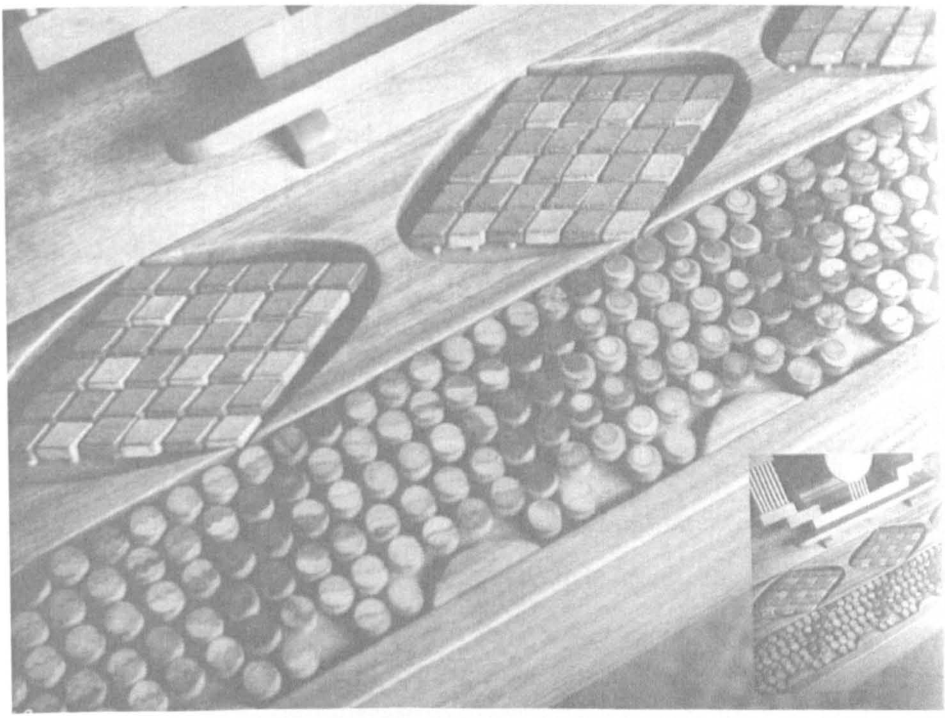

Fig. A2.8. A model of a compact version of the Ptolemy, and probably the latest considered by Partch but never completed. Photo by Carmel Pine Cone, 1941 (Courtesy of HPSA).

Although experimentation is a very important process in developing a new instrument, Partch, like Carrillo, seems not to have been very interested in publishing information about his experimentation during his lifetime. In the method and used proposed in this thesis, experimentation is considered a crucial stage of the instrument development and its legacy to future researchers.

1934-42: Adapted Guitar was created. Eventually named Adapted Guitar I, this had a fingerboard with frets in just intonation. It was rebuilt many times, most significantly at Carmel (1941). Partch continued working on this first guitar adaptation as part of the composition process in 1941 (while composing *Barstow*) and in 1945, three years before composing three works employing this instrument (the last two of the *Eleven Intrusions* and *Ring around the Moon*). In 1952, while composing *Oedipus* and *Even Wild Horses*, a re-conceived version of the guitar was built, ultimately substituting the Adapted Guitar I and adopting its name, since Partch hesitated in naming it Adapted Guitar II. Partch's use of Roman numerals can be confusing: this is a typical example of them not following a chronological order, which their sequence might have been expected to have implied.

1938: First version of Kithara I was conceived in a Los Angeles high school. Major reconstruction followed at: Carmel (1941), Ithaca (1943), Madison (1945) and Urbana (1959). The redesigns, reconstruction and tuning arrangements for this instrument continued for many years, as did the compositions and performances responsible for its development. Kithara I covers the alto range, and Kithara II (created in 1952) the bass range. A re-conceived version of the Kithara I, resolving some resonance problems, was built in 1972 and named New Kithara I. It did in fact replace the Kithara I but unlike the Adapted Guitar I, this version adopts the adjective 'new' so the original instrument can be referred to with a name. Thirty-seven years of development may seem a long time, but considering that this instrument is one of the most sophisticated developed by Partch, in interaction with both composition and performance processes, it is, perhaps, understandable. All the efforts in experimenting, designing and building other instruments, in parallel and in interaction with the development and composition for the Kithara, are a very good example of the layered instrument development adopted in the instrument development-led composition method proposed and used in this research. The Kithara was first invented while improvements for the Adapted Guitar were being carried out. This is an example of multiple instrument development in the same area, in this case with chordophones (string instruments), and shows how multiple projects can both benefit each other and create an organisation and focus on one area, at an early stage, as it did for Harry Partch.

1940: The Ptolemy (Los Angeles). This was a new model of the previous Ptolemy. This version integrated a complete case. It was abandoned uncompleted in Carmel a year later.

1941: Chromelodeon I was invented (although research started in 1935, London). This is an example of research being chronologically layered with parallel instrument developments, compositional and performance practice. In 1941, Partch was improving the Kithara I and the Adapted Guitar I, while completing the Chromelodeon, which means that one invention could have provided inspiration for the others. He was also applying the knowledge and experience acquired with the Ptolemy to the development of the Chromelodeon. In 1941, Partch added the Chromelodeon and the Kithara to a new version of *By the Rivers of Babylon,* keeping the intoning voice and Adapted Viola in the instrumentation. At the same time Partch was composing *Barstow* (see below) for guitar and voice. The Chromelodeon I is one of the very few instruments that Partch composed for while building it, or at the least in the same year that he built it. This is not surprising, due to Partch's skills with the piano, as the Chromelodeon's keyboard remained the same as that of the original melodeon's keyboard, and the notation indicated the key to be played, making it possible for Partch to compose while playing the instrument and at the same time develop the Chromelodeon, with one process consequently affecting the other. The construction of the Chromelodeon I also meant the re-conception of a work that had probably waited for such an instrument to be rewritten, namely *By the Rivers of Babylon.*

1941: *Barstow.* (P4a) (from *The Wayward,* which is the P4 set) – original version for Adapted Guitar I and voice. The Adapted Guitar I was finished a year after composing *Barstow,* although Partch had already been experimenting, reconstructing and developing this guitar for eight years. Partch seemed to have taken his time to feel comfortable playing and adapting the instrument before composing for it. Making changes on this guitar soon after its first performance is a significant fact to highlight here, since feedback from performance is a very important feature to the instrument development-led composition proposed and used in this research.

It is difficult to say that the Adapted Guitar I that was used in *Barstow* was reconstructed as part of an interaction process with the composition, since most of the sketches for this work were done while travelling. What is sure is that Partch's completion of the Adapted Guitar I in 1942 must have been influenced by the *Barstow* performances, which started in November 1941, soon after his arrival in Chicago.[33] It is also interesting that Partch managed to work on another composition in the same year involving a new invention and the reconstruction of an existing instrument (see P2b above), both compositions using totally different instruments (apart from voice). This work and P2b can be considered preparation for a new work in 1942 (see P5 below), employing all of the instruments used before (for P2b and P4a).

1942-43: *Dark Brother* (P5) – for intoning voice, Chromelodeon I, Adapted Viola and Kithara I; bass marimba was added later. Considering that *By the Rivers of Babylon* was arranged to add Chromelodeon I and Kithara I, but not originally conceived for these instruments, *Dark Brother* can be considered the first work originally written for Chromelodeon I, for Kithara I (with its first changes made in 1941), and for the first reconstruction of Adapted Guitar I (completed in 1942). It has a very obscure quality (as the title suggests) and it reflects a period of Partch's life in which he was reintegrating into society after being a homeless traveller, still in extreme poverty, and taking jobs washing dishes in restaurants, whilst in very ill health.[34] This surely affected the harmonic content

[33] Gilmore, B. 1998. *Harry Partch: A biography.* New Haven: Yale University. pp. 134-137.
[34] *Ibid.* pp. 140-141.

of the work, in which the intervals of the chords employed are very narrow and responsible for this obscure sound. During the period in which Partch wrote *Dark Brother,* he was also composing new sections of *The Wayward*: *US Highball, San Francisco* and *The Letter,* all using the Kithara I which was reconstructed again in 1943. This year represents a productive time in Partch's output, due to the fact that he composed several works for the same instruments (the few he had built), while the composition process served as a test for the new versions of the instruments.

1943: *San Francisco* (P4b) (from *The Wayward*) – for two baritones, Adapted Viola, Kithara I and Chromelodeon I.

1943: *The Letter* (P4c) – original version was lost, but a posterior version was written for intoning voice, Kithara I, harmonic canon I, Surrogate Kithara (built in 1953 to share the Kithara I part), diamond marimba and bass marimba.

1943: *U.S. Highball* (P4d) – original version for voice, Adapted Guitar I, Kithara I and Chromelodeon I. Partch wrote a new version of *U.S. Highball* in 1955, for subjective voice (tenor-baritone), several objective voices (mostly baritones), Kithara II, Surrogate Kithara, harmonic canon II, Chromelodeon I, diamond marimba, Boo, Spoils of War, cloud-chamber bowls and bass marimba. In this version the Surrogate Kithara has an alternative tuning, which is also used in *The Letter.*[35] This strongly influences the sound quality of the earliest version of the Surrogate Kithara, since the second version would adopt a different tuning. Toshie Kakinuma, in her doctoral thesis,[36] calls them respectively Surrogate Kithara A and Surrogate Kithara B to differentiate not only the new version but also the new tuning.

1944: Tin whistles (or tin flutes) were retuned (or extended techniques used). Partch did not specify the tuning for the tin whistle in C but, according to Toshie Kakinuma,[37] the tin whistle in E is a commercial instrument that has the following tuning in open holes: E (12/7), F# (64/33), G# (16/15), A (7/6), B (9/7), C# (7/5), D# (8/5), then it doubles with octaves up to two octaves above the lowest B (9/7). According to Bob Gilmore, the

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[35] Kakinuma, T. 1989. *The Musical Instruments of Harry Partch as an apparatus of production in musical theater.* PhD dissertation. University of California, San Diego. p. 105.
[36] *Ibid.*
[37] *Ibid.*

pitches are measured playing the Chromelodeon.[38] It is likely that Henry Brant, the virtuoso who played this instrument for Partch, made the fine adjustments by embouchure and finger adjustments. No evidence has been found about how Henry Brant adjusted the tuning, but several options have been proposed, and showed in Fig. A2.9 (the adjustments for each note are in cents). In a regular E tin whistle (indicated as 'reg.'), when sounding concert E when all holes are closed, each note would require a substantial amount of adjustment to be done with embouchure and the aid of finger adjustment, especially the A that needs to be raised more than a quartertone, unless alternative fingering is found for that specific note. This requires a virtuoso performer, and Partch employed Henry Brant for this occasion.

In order to perform a physical tonehole correction[39] on the tin whistle, the length of the pipe can be reduced (from the non-blowing end) to raise the pitch with all the holes covered, by 36 ¢ (Fig. A2.9), and then the other notes adjusted by filing the holes (to raise the pitch) or placing tape in the holes (to lower the pitch). This might bring some complications. Filing the first hole to raise F# 10 ¢ is not a problem, but covering the second hole (which might already be very small due to its proximity to the third hole)[40] to lower the G# 24 ¢ might not allow the finger to adjust properly. Also the third hole, which requires extensive filing to raise the A 30 ¢, might end up very close to the second hole, making the playing cumbersome. Another alternative enabling the physical tonehole correction without using tape (in other words, without lowering pitches) would be to reduce the pipe (from the non-blowing end) in order to raise the pitch, when all holes are covered, by 12 ¢ (Fig. A2.9). Then the G# would not need to be altered (nor, consequently, would the second hole, which is very close to the third). The rest of the notes only need to be raised since the G# also is the note that requires less pitch raise in the original instrument.

The last option seems more sensible, since the tape adjustments, which keep the pitch stable, cannot last for too long, due to the fact that the tape loses tension. Considering the fast passages that Partch asked Henry Brant to play on the tin whistle, raising the pitch of the whistle by 12 ¢ with all the holes covered might have been the easiest solution.

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[38] Gilmore, B. 1998. *Harry Partch: A biography.* New Haven: Yale University. p. 149.
[39] Hopkin, Bart. 1992-99. *Air, Columns and Toneholes. Principles for Wind Instrument Design.* Revised Edition. Experimental Musical Instruments. USA. p. 24.
[40] *Ibid.* p. 19.

Pitch	Ratio	Cents (reg.)	Cents (+$12^{.05}$¢)	Cents (+$36^{.45}$¢)
E	12/27	$36^{.45}$	$24^{.40}$	0
F#	64/33	$46^{.62}$	$34^{.58}$	$10^{.18}$
G#	16/15	$12^{.05}$	0	$-24^{.40}$
A	7/6	$67^{.14}$	$55^{.10}$	$30^{.70}$
B	9/7	$35^{.12}$	$23^{.07}$	$-1^{.33}$
C#	7/5	$17^{.45}$	$5^{.40}$	$19^{.00}$
D#	8/5	$13^{.75}$	$1^{.70}$	$-22^{.70}$

Fig. A2.9. Possible tunings of tin whistles (as they could have been approached by Henry Brant) in ratios and cents deviations from 12-et with different roots.

1944: Tin Oboe was adopted. This instrument originally suggested by composer Henry Brant. It is a commercial tin whistle with a Moroccan oboe reed added on top.

Since Brant and Partch had a close working relationship it is likely that Brant suggest to Partch the use of this instrument. Brant's skill as a tin whistle performer had a strong influence in the virtuoso passages that Partch wrote this instrument.[41] Partch's concept of using the space with the instruments and movements (*corporeality*) might have influenced Henry Brant gradual move from commercial music to spatial music from the 50's onwards, culminating in 2002, where he received Pulitzer Music Prize with a spatial music work titled *Ice Field*). In other words, this collaboration between composers seems to have had a strong mutual inspiration.

Kakikuma's thesis provides the ratios played with this tin whistle (in D): D (3/2), F (9/5), G (160/81), A (11/10), C (21/16), and the corresponding octaves.[42] In Fig. A2.10, a table with these ratio intervals (using 196Hz as 1/1 root, which Partch refers to as G-196), explains the cent deviation from the concert standard pitches (indicated on the left), and two possible transpositions follow to ease the pitch adjustment in a similar way to that suggested above for the tin whistles (also called tin flutes). Toshie Kakinuma only provides five pitches and the hint that a full diatonic scale is played in E,[43] but this might be to do with the fact that Partch only used five specific pitches; the lack of an extant instrument makes it difficult to be completely sure.

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[41] Harlan, B. T. 2007. *One voice: A reconciliation of Harry Partch's disparate theories*. PhD dissertation. University of Southern California, Los Angeles. p. 143.
[42] Kakinuma, T. 1989. *The Musical Instruments of Harry Partch as an apparatus of production in musical theater*. PhD dissertation. University of California, San Diego. p. 164.
[43] *Ibid.* p. 165.

T.O.Pitch	Ratio	Dev.12-et@440	Dev.12-et,raised $1^{.98}$ ¢	Dev.12-et, raised $34^{.98}$¢
D	3/2	$1^{.98}$ ¢	0 ¢	$33^{.00}$ ¢
F	9/5	$17^{.62}$ ¢	$15^{.64}$ ¢	$15^{.64}$ ¢
G	160/81	$-21^{.49}$ ¢	$-19^{.51}$ ¢	$-19^{.51}$ ¢
A	11/10	$-34^{.98}$ ¢	$-33^{.00}$ ¢	0 ¢
C	21/16	$29^{.20}$ ¢	$27^{.22}$ ¢	$27^{.22}$ ¢

Fig. A2.10. Partch's Tin Oboe tuning chart in concert G with reference (0 ¢) placed in 3 positions.

1944: *Flex-a-tone* was used. This indirectly struck idiophone appears in the 1922-23 British Patent Records, which means it must have been a relatively new instrument. The combination of the bending of the metal sheet with the action of shaking to activate the attached strikers gives total control of the tremolo effect and the pitch bending with one hand. Partch used the commercial instrument and did not make any changes. Devices to produce gliding tones were considered for all the chordophones that he designed (a pyrex rod used in all cases apart from the bamboo frame for the Ektharas). This is not the case for the idiophones designed by Partch, since they all have fixed pitches. The *flex-a-tone* (Fig. A2.11) is not a fixed-pitch instrument, but it can be used to achieve a glissando using tremolo for a comfortable range of two octaves. This gliding struck property can be compared to a pizzicato tremolo with glissando on a string instrument, but not to any other idiophone designed by Partch. Chromatic glides can also be performed on instruments such as the Harmonic Canons Partch designed, and considering that a year later after having composed for the *flex-a-tone*, he invented the first of the Harmonic Canons (Harmonic Canon I), it is very likely that the experience of orchestrating for an instrument rich in chromatic glides might have led him to create instruments with such property. It is also arguable that the use of tremolo with glissando on the Adapted Guitar I might have suggested to Partch using an instrument that allows a similar action but with a brighter tone, such as the one of the *flex-a-tone*.

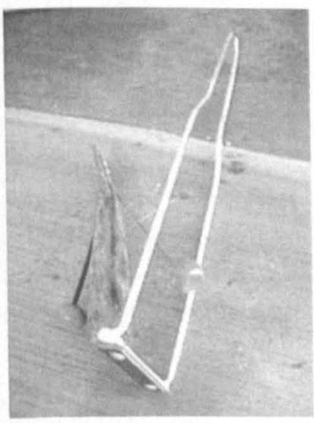

Fig. A2.11. Standard *flex-a-tone*.

In *Yankee Doodle Fantasy* Partch notates high and low 5/3, which is 884.36 ¢ above the closest 1/1, and high and low 9/5, which is 1117.6 ¢ above the closest 1/1,[44] covering a gliding range of two octaves.

1944: *Yankee Doodle Fantasy* (P6) – for soprano, tin flutes, tin oboe, *flex-a-tones* and Chromelodeon I. The tin flutes were commercial tin whistles with six finger holes, while the tin oboe was another tin whistle with a reed from a Moroccan oboe.[45] The high pitch used by the soprano and tin whistles, in combination with the clusters used in the Chromelodeon I, produces a cartoon music style very different to the rest of Partch's compositions. This comical music represents Partch's good sense of humour, and occurs during a period of experimentation and composition for the Chromelodeon I, just a year before he decided to rebuild it.

A month before the 22 April concert in New York, Partch, inspired by the composer Henry Brant's virtuosity with the tin whistle (Brant was organising the concert for Partch), composed this work (also named *Y.D. Fantasy*). Brant had composed for the cinema (including *The Marx Brothers*), and it seems they must have worked very closely together, since the composition indeed resembles the soundtrack of an animated silent film. This close cooperation with the performer (also composer) is a unique case in Partch's repertoire, and although most of the aerophones Partch used were either rare or adapted, the high range glissandi predominant in the piece might have influenced the need for the chromatic disposition in posterior inventions among chordophones and idiophones.

T.W.Pitch	T.O.Pitch	Ratio	Dev.12ET	Dev.12ET^12$^{.05}$¢	Dev.12ET^36$^{.4}$¢
	D	3/2	$1^{.98}$ ¢		
E		12/27	$36^{.45}$ ¢	$24^{.40}$ ¢	0 ¢
	F	9/5	$17^{.62}$ ¢		
F#		64/33	$46^{.62}$ ¢	$34^{.58}$ ¢	$10^{.18}$ ¢
	G	160/81	$-21^{.49}$ ¢		
G#		16/15	$12^{.05}$ ¢	0 ¢	$-24^{.40}$ ¢
	A	11/10	$-34^{.98}$ ¢		
A		7/6	$67^{.14}$ ¢	$55^{.10}$ ¢	$30^{.70}$ ¢
B		9/7	$35^{.12}$ ¢	$23^{.07}$ ¢	$-1^{.33}$ ¢
	C	21/16	$29^{.20}$ ¢		
C#		7/5	$17^{.45}$ ¢	$5^{.40}$ ¢	$19^{.00}$ ¢
D#		8/5	$13^{.75}$ ¢	$1^{.70}$ ¢	$-22^{.70}$ ¢

Fig. A2.12. Tuning of two instruments used by Partch compared: retuned tin whistle, and Tin Oboe.

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[44] Kakinuma, T. 1989. *The Musical Instruments of Harry Partch as an apparatus of production in musical theater*. PhD dissertation. University of California, San Diego. p. 71.

[45] *Ibid.* pp. 160-165.

Toshie Kakinuma says that the Tin Oboe plays the Yankee Doodle tune towards the end of the composition using the E diatonic scale of the tin whistle (Fig. A2.12).[46] The two instruments do not have any notes in common and, considering that the tune is played extremely fast, the adjustments had to be achieved on the spot when performing (by finger adjustment and embouchure). It is a virtuoso composition, although no more precision than the human ear can appreciate is expected.

1944: *Double flageolet* was temporarily adopted for a new composition. The *double flageolet* was invented in 1805 by William Bainbridge in England, and therefore is a case of Partch incorporating and researching historical instruments. This small model of *double flageolet* (duct flute with inverse conical bores) is historically referred to as 'Octave' and is pitched in G.[47] The *double flageolet*'s mouth-piece has a structure designed to remove any embouchure problem, which means it is an ideal instrument for sustaining pitches accurately.

Having worked so close with Henry Brant, Partch continued absorbing ideas from this highly creative composer and performer and ended up composing for a *double flageolet* that Brant had borrowed. According to Toshie Kakinuma's thesis,[48] the specific *double flageolet* Partch instrumented for is a European *double flageolet* (instrument on the left side of Fig. A2.13 obtained from Kakinuma's thesis), with two pipes tuned to G and A (right hand and left hand respectively). Considering that this instrument was only manufactured in London, Dublin, Germany and North America for fifty years after its invention, it is difficult to confirm that all the models shared the same tuning, but it is possible. William Waterhouse defines a similar instrument as a double duct-flute (with also inverse conical bores), an invention of William Bainbridge named *octave double flageolet* (instrument on the right side of Fig. A2.13). Waterhouse describes both pipes as being a third apart when playing the same fingering, and that particular holes partially plugged with ebony 'serve to tune the scale to the desired intervals and to act as register holes'. This system of tuning the holes is an interesting feature, as is the ivory beak

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46 Kakinuma, T. 1989. *The Musical Instruments of Harry Partch as an apparatus of production in musical theater.* PhD dissertation. University of California, San Diego. p. 71.
47 Waterhouse, W. 1999. The Double Flageolet - Made in England. *The Galpin Society Journal.* vol. 52 (Apr., 1999). p. 172.
48 Kakinuma, T. 1989. *The Musical Instruments of Harry Partch as an apparatus of production in musical theater.* PhD dissertation. University of California, San Diego. p. 161.

mouthpiece that 'removes any problem of embouchure'. [49] The model used by Partch is likely to have kept (or prepared) the thirds between the pipes in just intonation, and if that was the case, it might have been the reason for Partch's attraction towards using it.

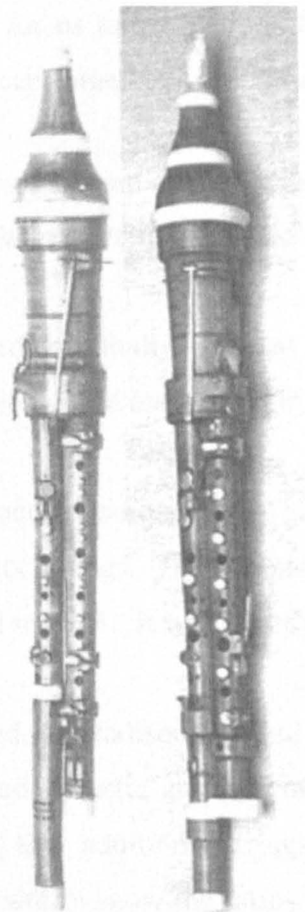

Fig. A2.13. *Double Flageolets* (Used by Partch on left, and Bainbridge's Octave model on right).

1944: *Two Settings from Joyce's Finnegan's Wake* (P7) – for soprano, Kithara and *double flageolet* (or two flutes). Partch later arranged this piece for two transverse flutes to play the *double flageolet* part. An interesting aspect of this piece is that the scales of an old forgotten instrument are recycled and revived. When using a 12-et instrument in a different tuning, there is the danger of creating a familiar sound in an odd tuning, which might at first be automatically rejected by the listener as something strange or erroneous. However, after listening to a recording of this piece with two flutes, the tuning deviations played in the flutes to imitate the intonation of the *double flageolet* do not sound out of tune, and this is probably due to the fact that the sliding harmonies of the Kithara I blended

[49] Waterhouse, W. 1999. The Double Flageolet - Made in England. *The Galpin Society Journal*. vol. 52 (Apr., 1999). p. 172-174.

with the sound of these flutes create an overall sound that subverts the listener's usual expectations of a flute. In general it can be said that Partch's tuning theories are backed up with his instruments and compositions, and since his music is perceived as having a new timbre, the tuning which is so different from the conventional is perceived as a component of the new timbre, and it is easier for us to accept it as being in tune than if played on musical instruments which we are accustomed to hearing in 12-et.

1945: New Chromelodeon was invented and finally renamed Chromelodeon I. It was adapted and tuned in Madison, and later on retuned in Gualala in 1949.

1945: Harmonic Canon was invented and finally renamed Harmonic Canon I. It was built at Madison with 44 strings, and re-conceived and rebuilt in Urbana (1959).

1945: Adapted Guitar I was developed. A smooth fingerboard and electronic amplification were used. It was used in several recordings. The Adapted Guitar I adopted the tuning of the other guitar as rebuilt in Carmel in 1941. It was eventually lost in 1956 in Sausalito.

1945: Adapted Guitar II was created (in Madison). It had 10 strings and has kept its name ever since. This is a manufactured acoustic guitar, which was transformed to have 10 strings. The nut is placed higher, four additional strings added, a narrow wood plate is attached to the side of the fingerboard to show the ratios of the third highest string, and a large trapezoid board is attached to its back in order to strengthen the neck to compensate for the extra tension of the tenor guitar string added.

In the same year, an electric guitar with pinheads and small rivets on the fingerboard was produced and named Adapted Guitar I. This was abandoned, however, together with the original Adapted Guitar I, when a third guitar, also named Adapted Guitar I, was produced in 1952, and which has remained in usage under that name ever since.[50]

1945: *I'm very happy to be telling you about this...* (P8) – for soprano, baritone, Kithara I and Indian drum (score has been lost). It uses the text from a broadcast transcription of gliding pilot Warren Ward. This was the only score composed in 1945 while Partch was creating Adapted Guitar II and harmonic canon I (plus improving Adapted Guitar I,

[50] Kakinuma, T. 1989. *The Musical Instruments of Harry Partch as an apparatus of production in musical theater.* PhD dissertation. University of California, San Diego. p. 134.

Kithara I and Chromelodeon I). Considering Partch's history of destroying works he was not happy with, there is a chance that Partch destroyed this work, rather than it simply being lost. This, added to the fact that no other works were composed in this period of intensive instrument development, suggest the possibility that Partch might have decided to complete the instruments before getting involved with further composing. Also considering that Partch played and when necessary also taught the parts he composed for, suggests that he composed better whilst playing the instruments (having gained some confidence after building them). This raises the question whether an instrument development-led compositional process can benefit more by this long process of self-training on the instruments and posterior training of the performers, or simultaneous composing while developing the instruments so as to obey the ultimate creation in the composer's mind without any compromise.

1946: Diamond marimba (Fig. A2.14) was invented (in Madison),[51] and most of the blocks were replaced with Pernambuco wood in Gualala between 1949 and 1950. This invention occurred in the same year as the Chromelodeon II. It consists of two instruments of totally different nature. This shows how Partch was able to work in different areas of instrument development simultaneously, while composing for totally different instruments at the same time (see below). Little relation is found between these simultaneous processes, and consequently the compositional output of this year was discrete.

This instrument's layout was chiefly devised to achieve diagonal movements together with a systematic placement of *o-tonality* and *u-tonality* ratios. These diagonal movements produce arpeggio patterns based on four notes per octave. Even considering how wide these intervals are for producing sliding pitch effects, the ergonomics of its layout suggest many ways in which sliding patterns could be achieved in bar instruments. Considering movements across the layout inspired several instruments proposed in this research. This also applies to movements containing diagonal patterns, such as the *cyclic Whitechapel bellophone,*[52] the *rotary hojureiphone*,[53] and also the ultimate instrument development result in this research project, the *conic bellophone*.[54]

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[51] Partch, H. 1949. *Genesis of a Music*. Second edition (1974). New York: Da Capo Press. pp. 260-266.
[52] Detailed on pp. 375-377.
[53] *Ibid.*
[54] *Ibid.*

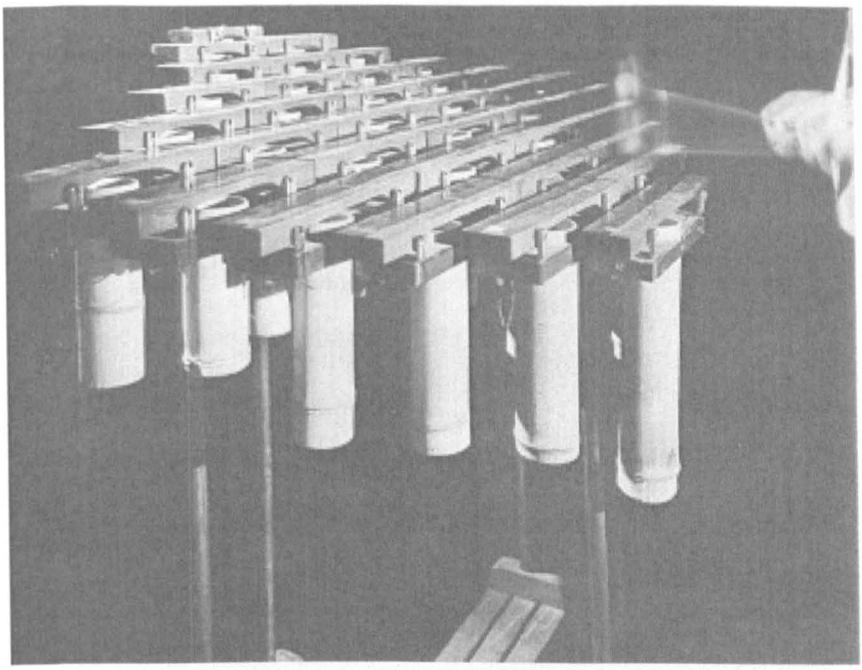

Fig. A2.14. Diamond Marimba (Photo by Fred Lyon, Sausalito, 1954) (Courtesy of HPSA).

1946: Old Chromelodeon II was invented. Its pattern added a few extra keys to compress the 43-note pattern into two octaves range in the physical keyboard, allowing it to play a wider range of harmonies employing two hands. Unfortunately, like the Ptolemy, it had inconsistent keys and design, and a shortage of budget (and consequent lack of specialist assistants) to improve it. The keyboard was replaced after three years and disappeared after being on loan.

1946: *Two Studies on Ancient Greek Scales* (P9) – original version for harmonic canon I; bass marimba added later. The theory reflected in the design of the diamond marimba, constructed in the same year that this work was composed, might have influenced the theory used for the harmonic cannon I in the compositional process. This work is of modal nature, and the tune can easily be remembered, unlike most of the compositions of Partch. The simplicity and modality of this work brings a new colour to Partch's output.

1949-50 Bass marimba was invented (Gualala) (Fig. A2.15). Rebuilt in Oakland in 1951, and all the Sitka-spruce blocks were replaced at Encinitas in 1971. Due to its size, it requires either heavy mallets, very difficult to handle at fast speeds, or hand tapping as an alternative, both of which need spacing before the attack.

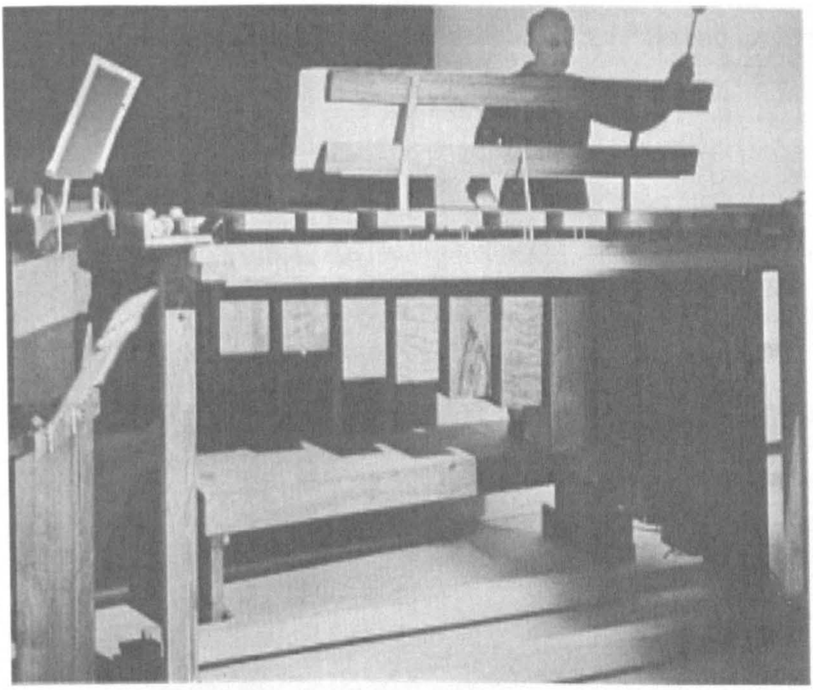

Fig. A2.15. Bass Marimba (Photo by Fred Lyon, Sausalito, 1954) (Courtesy of HPSA).

1949-50: *Eleven Intrusions* (P10)

(1 and 2) *Two Studies on Ancient Greek Scales* (P10a&b) with Bass Marimba added. (3) *The Rose* (P10c) – text by Ella Young, for intoning voice, Adapted Guitar II and Diamond Marimba. (4) *The Crane* (P10d) – text by Tsuryuki-Waley, for intoning voice, Adapted Guitar II and Diamond Marimba. (5) *The Waterfall* (P10e) – text by Ella Young, for intoning voice, Adapted Guitar II and Diamond Marimba. (6) *The Wind* (P10f) – text by Ella Young and Lao-tze, for intoning voice, Harmonic Canon I and Bass Marimba. (7) The Street (P10g) – text by Willard Motley, for intoning voice, Harmonic Canon I and Bass Marimba. (8) *Lover* (P10h) – text by George Leite, for intoning voice, soprano, two Adapted Guitars II, Cloud Chamber Bowls and Bass Marimba. (9) *Soldiers-War-Another War* (P10i) – text by Ungaretti, for intoning voice, harmonic canon I, Adapted Guitar II, Diamond Marimba, Cloud Chamber Bowls and Bass Marimba. (10) *Vanity* (P10j) – text by Ungaretti, for intoning voice and three Adapted Guitars II. (11) *Cloud-Chamber Music with Canción de los Muchachos* (P10k) – from the Zuni Indian, for intoning voice, Adapted Viola, two Adapted Guitars II, Kithara I, Diamond Marimba, Cloud Chamber Bowls, Bass Marimba, *deer-hoof rattle* and chorus of musicians.

1949-50: *Ring around the Moon* (P11) – text by Harry Partch, for baritone, Harmonic Canon II, two Adapted Guitars (I and II), Chromelodeon I, Diamond Marimba, Cloud Chamber Bowls, Bass Marimba, Marimba Eroica and cymbal.

1950: Cloud Chamber Bowls (Fig. A2.16) were invented (Gualala). They were rebuilt in Oakland in 1951. The bowls were replaced continuingly, following breakage.

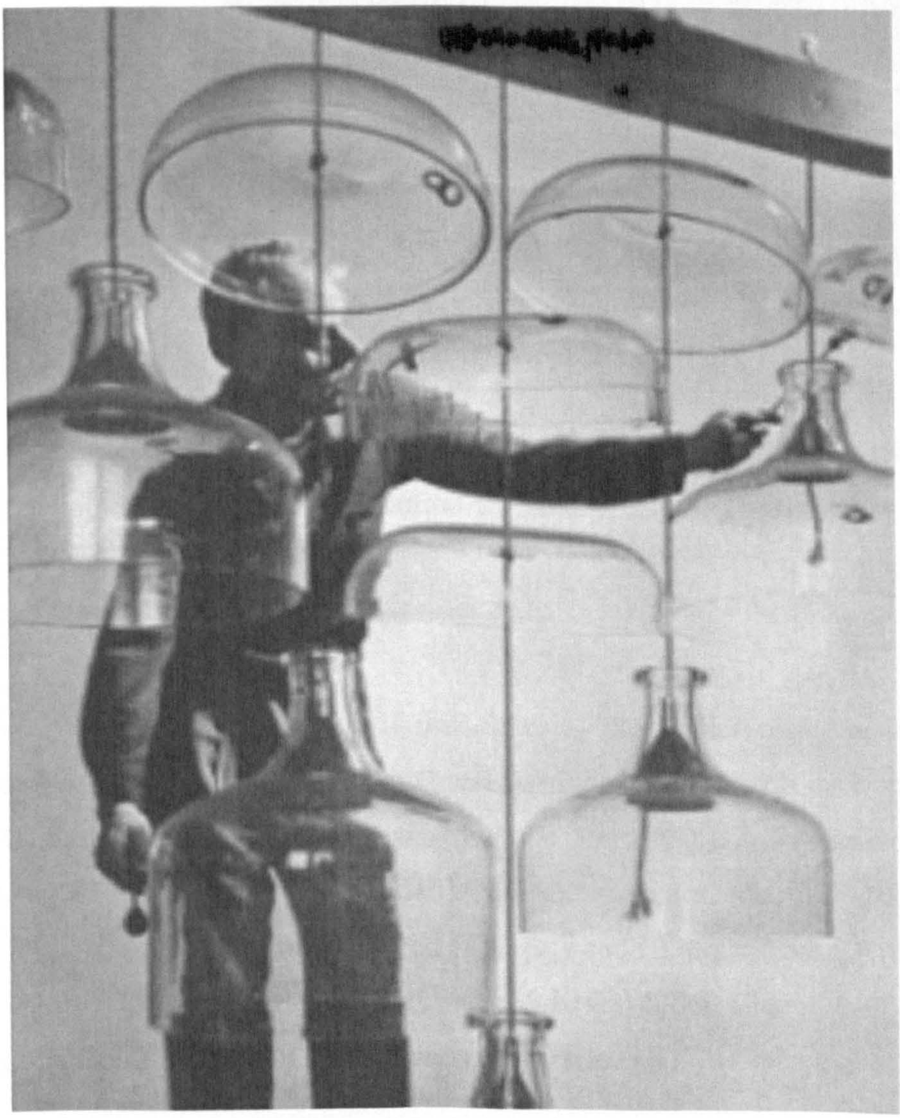

Fig. A2.16. Cloud Chamber Bowls (photo by Fred Lyon, Sausalito, 1954) (Courtesy of HPSA).

1950: Spoils of war (Fig. A2.17) were invented (in Gualala). A variety of sounds were added between 1951 and 1965 in Oakland, Urbana, Petaluma and Van Nuys.

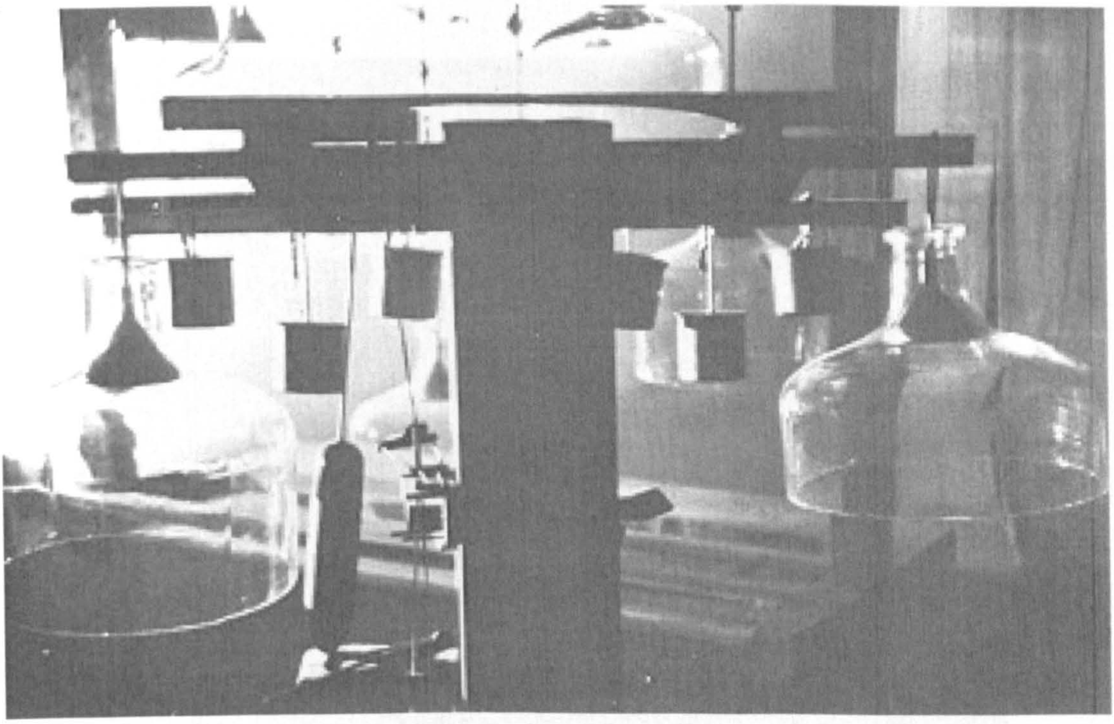

Fig. A2.17. Spoils of War (photo by Fred Lyon, Sausalito, 1954) (Courtesy of HPSA).

1950: New Chromelodeon II was invented. It was rebuilt and retuned in Sausalito in 1954 without great improvements, but a resolution was found with the satisfactory adaptation and tuning realised at Urbana in 1959.

1950/1952-4/1967: *Oedipus* (P12) – text from play by Sophocles; first version: libretto adapted from William Butler Yeats; second and third versions: libretto by Harry Partch – for bass (Oedipus), bass-baritone (Tiresias and the Herdsman), low soprano (Jocasta), tenor-baritone (Chorus Spokesman), chorus of six sopranos, clarinet, bass clarinet, Adapted Viola, Adapted Cello, two Adapted Guitars (I and II), double bass, Kithara II, two Harmonic Canons I, Chromelodeons (I, II and sub-bass), Cloud Chamber Bowls, Gourd Tree with Cone Gongs, Diamond Marimba, Bass Marimba and Marimba Eroica.

1951: Marimba Eroica (Fig. A2.18) was invented in Oakland and re-conceived in Sausalito in 1954, changing the vertical redwood blocks for horizontal Sikta-spruce blocks and adding new resonators. It was improved at Champaign-Urbana in 1960 and again at Petaluma in 1963. This instrument has to be played with very heavy padded mallets or padded gloves.

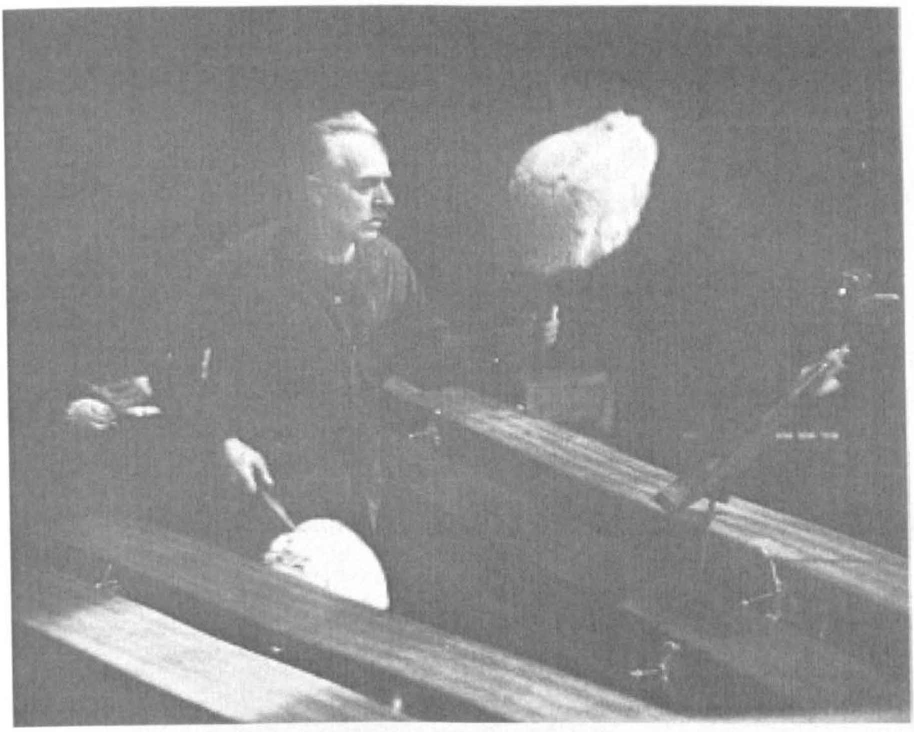

Fig. A2.18. Marimba Eroica (photo by Fred Lyon, Sausalito, 1954) (Courtesy of HPSA).

1952: Re-conceived Adapted Guitar I. This guitar has also been named Adapted Guitar III but the only differences were the elimination of the high frets (played by sliding a plastic rod) and the aid of a pick for playing.

1952: *Castor and Pollux* (P13) – for Kithara II, Surrogate Kithara, Harmonic Canon II, Diamond Marimba, Cloud Chamber Bowls and Bass Marimba (two players: low marimba and high marimba).

1952: *Even Wild Horses* (P14) – text from Rimbaud's A Season in Hell – for baritone, Adapted Viola, Adapted Guitar I, Kithara II, four Harmonic Canons II (four bridge settings), Chromelodeon I, Diamond Marimba, Bass Marimba, Cloud Chamber Bowls, Spoils of War, Japanese temple bell.

1953: Surrogate Kithara was invented (Sausalito)

1953: Harmonic canon II was invented (Sausalito). Also named Castor and Pollux. It has the same base as the Harmonic Canon I (which was given a new Plexiglas base at Champaign-Urbana, 1959).

1954: Kithara II (Sausalito). Improved in 1959 at Urbana.

1954: *Two Studies from Lewis Carroll.* (P15)

The Mock Turtle Song (P15a) – for singing-intoning voice, Surrogate Kithara and Spoils of War.

O Frabjous Day! (*The Jabberwock*) (P15b) – for intoning voice, Harmonic Canon II and Bass Marimba.

1955: Boo I was created (in Sausalito) (Fig. A2.19). Rebuilt at Yellow Springs in 1957, and later on in Petaluma.

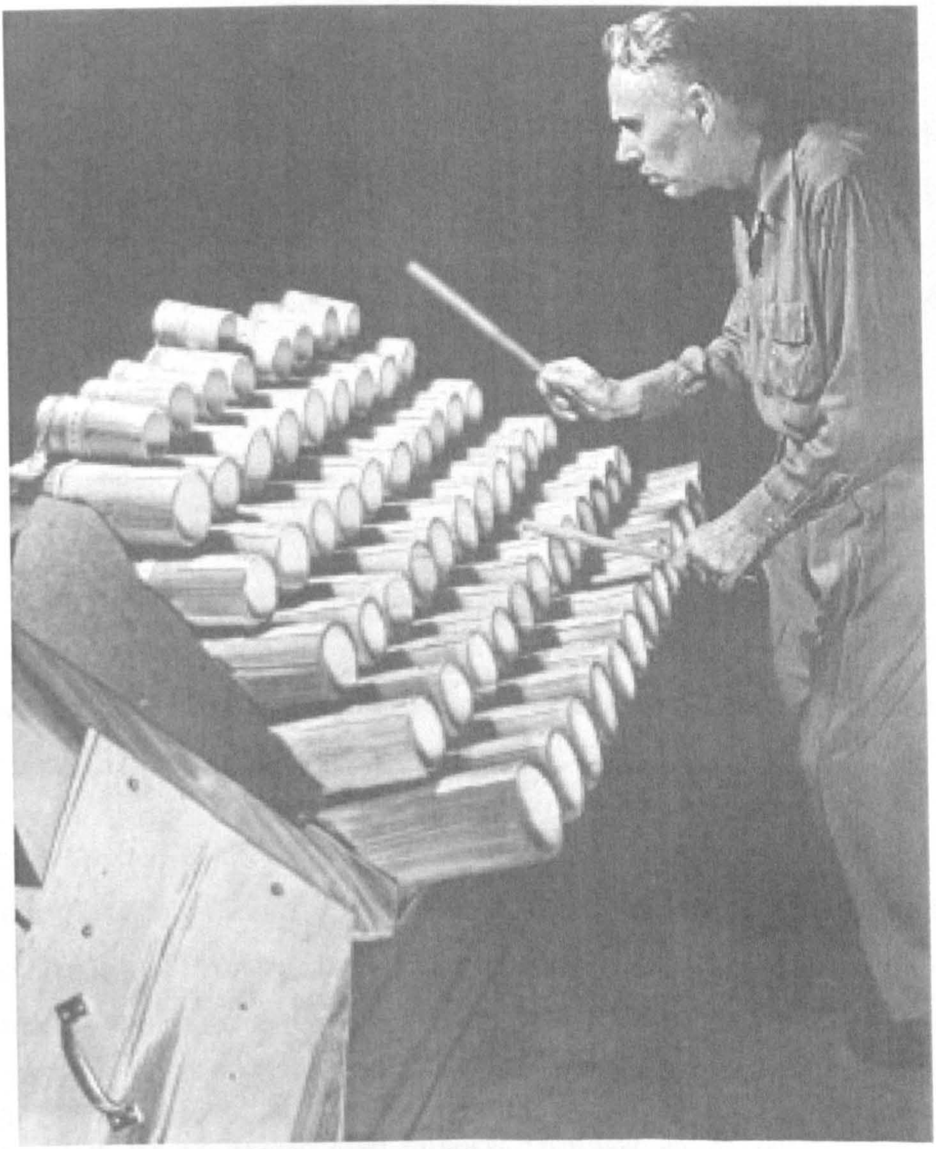

Fig. A2.19. Boo I (photo by Fred Lyon, Sausalito, 1954) (Courtesy of HPSA).

In 1990, Danlee Mitchell, who performed for Partch and became the keeper of the only set of Partch's instruments after his death, and who led an ensemble hosting Partch's instruments, mentioned in a radio program:[55]

"...we don't use bamboo anymore, we use synthetic tubing , bamboo just cracks all the time."

1955: *Ulysses at the Edge* (P16) – for alto saxophone or trumpet, baritone saxophone, Diamond Marimba, Boo, Cloud Chamber Bowls and speaking rhythmic voice.

1955: *U.S. Highball* (P4d') – for subjective voice (tenor-baritone), several objective voices (mostly baritones), Kithara II, Surrogate Kithara II, Harmonic Canon II, Chromelodeon I, Diamond Marimba, Boo, Spoils of War, Cloud-Chamber Bowls and Bass Marimba.

1952-55: *The Bewitched* (P17) – for solo soprano (the Witch), piccolo, clarinet, bass clarinet, cello, Kithara II (players on both sides), two Harmonic Canons II (two players), koto, Surrogate Kithara, Chromelodeon I, Cloud Chamber Bowls, Spoils of War, Diamond Marimba, Boo, Bass Marimba, Marimba Eroica, chorus of musicians and approximately ten dancers.

1958: Bloboy was invented (Evanston).

1958: *Windsong* (P18) (for a film by Madeline Tourtelot) – for harmonic canon II, Kithara II, Adapted Viola, Surrogate Kithara, Chromelodeon, Boo, Diamond Marimba, Cloud-Chamber Bowls, Spoils of War and Bass Marimba.

Rewritten as Daphne of the Dunes (1967) (P18') – for dance, for Kithara II, Surrogate Kithara, four Harmonic Canons, Chromelodeon, Diamond Marimba, Boo, Spoils of War, Bass Marimba, Cloud Chamber Bowls, Adapted Viola, Gourd Tree and Cone Gongs, plus pre-recorded tape of Harmonic Canons, Kithara, Diamond Marimba and Boo.

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[55] Mitchell, D. 1990. Vaults: Harry Partch Instruments. *New Sounds*, ed. No 427. Interview radio broadcasted on 23 August 2006 (original recording on 23 January 1990). WNYC homepage: www.wnyc.org/shows/newsounds/episodes/2006/08/23. Consulted on 30 August 2007.

1959-60: Crychord was invented (Champaign-Urbana). Standard added in 1961.

1960 *Revelations in the Courthouse Park* (P19) (after *The Bacchae* of Euripides). A "double-tale" which alternates between *The Bacchae* and a modern parallel, set in the "Courthouse Park" with text by Harry Partch. The cast doubles between parallel characters.

Other instrumental parts: two Kitharas (I and II), three Harmonic Canons (I and II), double bass, Crychord, two Adapted Guitars (I and II), Adapted Viola, two Chromelodeons (I and II), Bloboy, Spoils of War, Diamond Marimba, Boo, Marimba Eroica (two players), Cloud Chamber Bowls and Cone Gongs (two players), Bass Marimba (two players), Drone Devils (jaw harps) and pre-recorded tape.

1961: *Rotate the Body in All Its Planes* (P20) (music for an exhibition of gymnasts) – for soprano solo, women's voices, men's voices, piccolos, trumpets, trombones, tuba, drums, harmonic canon II, Adapted Guitar I, Chromelodeon I, Chromelodeon II, Cloud-Chamber Bowls, Spoils of War, Diamond Marimba, Marimba Eroica, Lyndel Davis, Crychord, string bass. Almost the same instrumentation than for *Revelations in the Courthouse Park.*

1961: *Bless This Home* (P21) (text by Vincenzo Prockelo) – for intoning voice, oboe, Adapted Viola, Kithara, Harmonic Canon II and Mazda Marimba.

1961: *Water! Water!* (P22) (text by Harry Partch) – for bass clarinet, trumpet, violins, viola, cello, string bass, Chromelodeon II, jazz percussion, Surrogate Kithara, Kithara II, Spoils of War, Diamond Marimba, Bass Marimba, Marimba Eroica, soprano saxophone, tuba and trombone. Although this large music theatre work was performed three times during 1962, Partch considered it an unfinished work.

1963: Zymo-xyl was invented (Petaluma).

1963: Mazda Marimba was invented (Petaluma).

1964: Gourd tree with Cone Gongs was invented (Del Mar) (Fig. A2.20). The two conical shape large gongs were not added until 1965 in Venice.

Fig. A2.20. Gourd Tree and Cone Gongs (photo by Don Hunstein, New York, 1968) (Courtesy of HPSA).

1963-66: *And on the Seventh Day Petals Fell in Petaluma* (P23) – for Adapted Guitar, two Kitharas, Surrogate Kithara, five Harmonic Canons, two Chromelodeons, Bloboy, Koto, Crychord, Diamond Marimba, Bass Marimba, Marimba Eroica, Boo, Cloud Chamber Bowls, Spoils of War, Gourd Tree, Cone Gongs, Mazda Marimba, Zymo-xyl, Drone Devils and Gubagubi.

1964-67: Eucal blossom was invented (started in Del Mar and completed in San Diego) (Fig. A2.21).

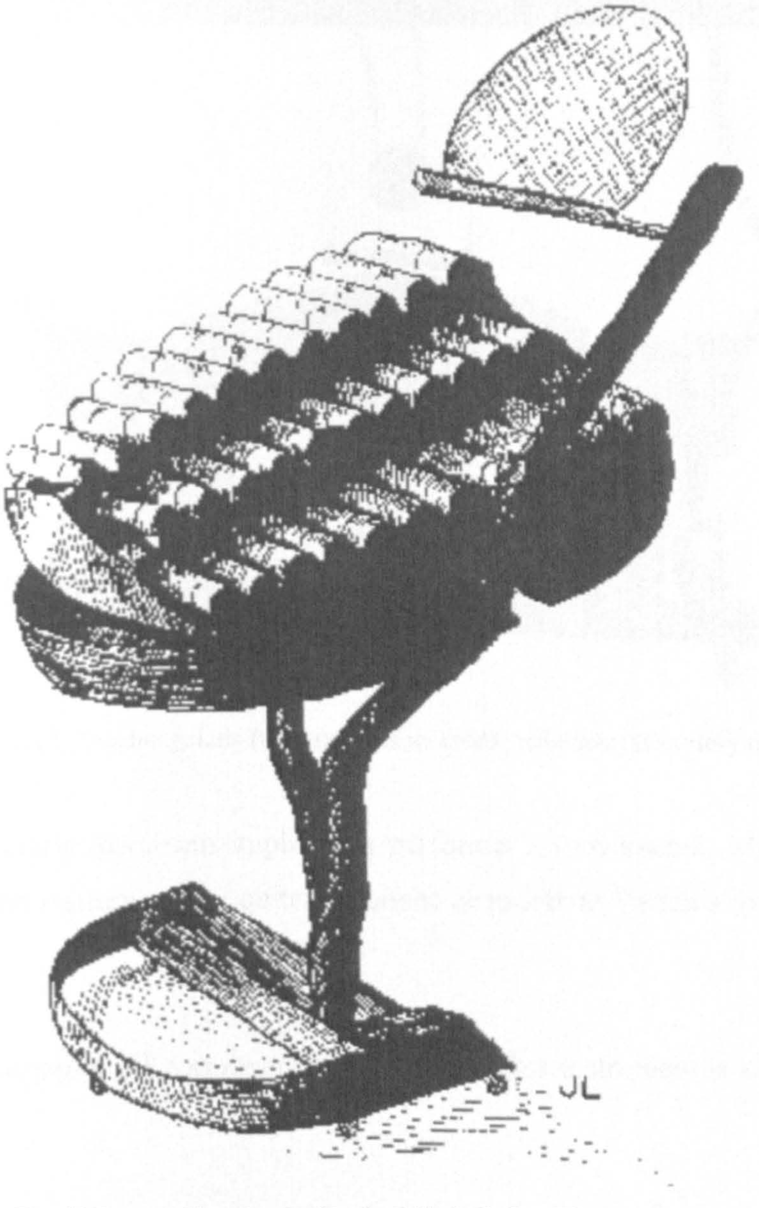

Fig. A2.21. Eucal Blossom (drawing by Danlee Mitchell, San Diego, 1969) (Courtesy of HPSA).

These bamboo claves are not of definite pitch nature but the chromatic layout in a comfortable position for the player to slide the mallets is unique, and also the sound effect that this action produces.

1965: Quadrangularis Reversum was invented in Van Nuys (Fig. A2.22). The blocks of this marimba were originally made with Hormigo wood from Guatemala, and later on replaced by African Padouk in order to increase the ringing time (Encinitas, 1971).

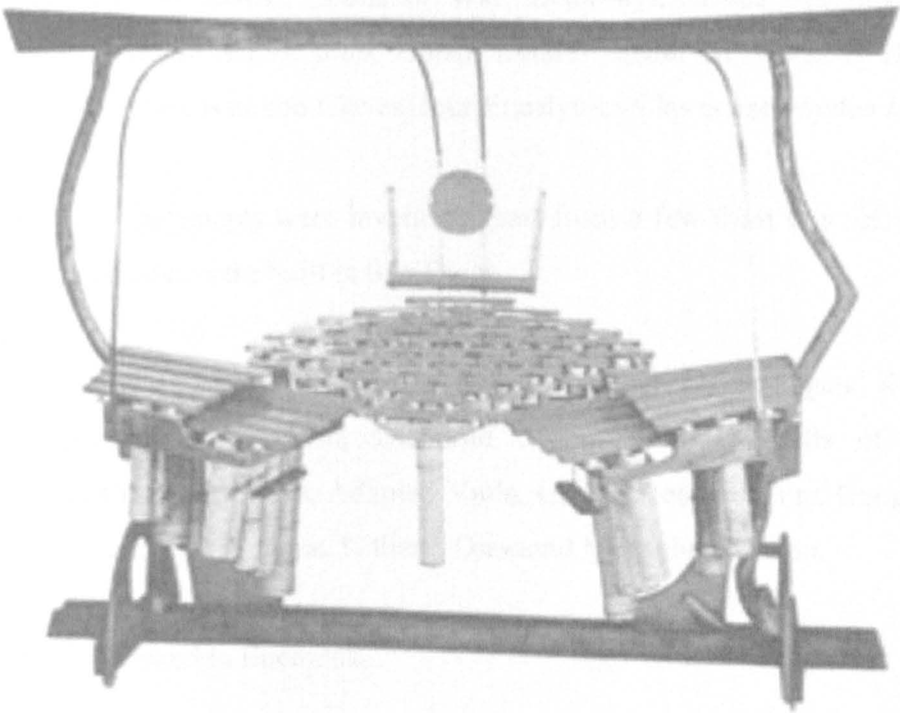

Fig. A2.22. Quadrangularis Reversum (photo credit: unknown) (Courtesy of HPSA).

The Quadrangularis Reversum implies the performer's movements, which together with the shape of the instrument are quite important elements to Partch's visual aspect of the performance.

1965: Harmonic canon III was invented in Venice. This instrument is also called the Blue Rainbow.

1966: Surrogate Kithara was retuned. These two canons were rearranged for the tuning used for *Petals* (P23) and *Delusion* (P24).

1966: Koto was an adaptation of a traditional Japanese zither with the same name.

1966-67: Ektaras. Two of them were built in San Diego (models A and B; A not used). A third Ektara (model C) was also built (before 1972, which is the year it was used).

1965-66: *Delusion of the Fury* (P24) – *A Ritual of Dream and Delusion*, for Adapted Guitar II, two Chromelodeons (I and II), two Kitharas (I and II), Surrogate Kithara, five Harmonic Canons (I, II and III), Bloboy, Koto, Crychord, Diamond Marimba, Quadrangularis Reversum, Bass Marimba, Marimba Eroica, Boo, Eucal Blossom, Gourd Tree, Cone

Gongs, Cloud Chamber Bowls, Spoils of War, Zymo-xyl, Mazda Marimba, Ugumbo, Waving Drums, *Bolivian double flute*, *mbira*, Ektara (model B), Rotating Drum, Belly Drums, Gourd Drum, six Bamboo Claves, four Eucalyptus Claves and *rhythm boat*.

1967: Small hand instruments were invented, apart from a few from this set, which were gifts. The invented ones were built in San Diego.

1967: *Daphne of the Dunes* (P25) – for dance; for Kithara, Surrogate Kithara, four Harmonic Canons, Chromelodeon, Diamond Marimba, Boo, Spoils of War, Bass Marimba, Cloud Chamber Bowls, Adapted Viola, Gourd Tree and Cone Gongs, plus pre-recorded tape of Harmonic Canons, Kithara, Diamond Marimba and Boo.

1971: Boo II was created in Encinitas.

1972: Kithara I was revised resulting in the New Kithara I (Encinitas)

1972: New Harmonic Canon I was developed in Encinitas with a blue-tinted plexiglass base.

1972: Mbira Bass Dyad was built in Encinitas. An instrument that Partch considered incomplete, due to its lack of resonance.

1972 *The Dreamer That Remains, a Study in Loving* (P26) – text by Harry Partch; for narrating (intoning) voice, chorus, and fifteen instruments: Gourd Tree, Adapted Viola, Harmonic Canon I, New Harmonic Canon I, Quadrangularis Reversum, Eucal Blossom, Mbira Bass Dyad, New Kithara I, Adapted Guitar II, Cloud-Chamber Bowls, Ektaras (B and C), Bamboo Marimba II, Mbira Bass Dyad, Harmonic Canon III and Chromelodeon II.

From 1949 until 1972, Partch's output pointed towards ritualistic musical theatre and his orchestrations became large and while still experimental. Since Partch was unable to get funds, he worked with students at various universities to realise these works. There was a consequent change in musical style which brought back the incorporation of the voice but with a different approach than in his early works, and instead of focusing on the developing of a refined speech, the main aim was the integration of the performer's movement into the ritualistic performance to enhance the overall dramatic effect on the audience. This visual aspect of this idea has been adopted by the creative-comparative development approach adopted in the thesis (see Appx 3, pp. 372-460), without necessarily thinking of theatrical performance, but simply in terms of instrumental performance. For this purpose the term corporeal expression (see Glossary) of a musical instrument is used to define the capability that an instrument has to allow expression through movement during the performance, and when considering a mechanised instrument the expression applies to the movement of the sound producing mechanisms that can be visualised. This term has also been expanded to include to the spatial projection capability of the instrument's sound, which is something that was noticed by Henry Brant while collaborating with Partch and then taken to an extreme in his late work for large combined orchestras. Electro-acoustic music offers many possibilities towards the exploration of spatial music. However, the late work of Henry Brant is enough evidence standing for the dramatic impact that spatial music with acoustic instruments has on the audience.

The term *corporeality* was initially used by Partch to define the integration of speech to music, and later on it also embraced the integration of music and movement through musical functionality (rituals), choreography and theatre.[56] A lot has been learnt from Partch and his conception of *corporealism*. However, this conception is here considered an interdisciplinary choice (among many others) for the composer who wants to explore beyond the boundaries of the musical art (not to be re-defined but enriched by possibilities). Consequently, what has been defined as the instrument's corporeal expression attempts to incorporate ideas derived from Partch's interdisciplinary *corporealism* strictly to the music discipline and specifically to a category of the music discipline that has the potential to deal with this concept in depth: instrument-development-led composition.

To conclude this later theatrical period of Partch's music, it is important to state the impact that the conception of ritualistic musical theatre had on instrument development in the adoption of ethnic instruments (19 out of the 29 musical instruments invented in his career were invented, adapted or adopted during this period).

A chronological reference chart of Partch's instruments and compositions, which was prepared to guide this appendix, is shown in Fig. A2.23, as follows:

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[56] Johnston, B. 1975. The Corporealism of Harry Partch. *Perspectives of New Music.* vol. 13, no. 2 (Spring-Summer). pp. 85-97.

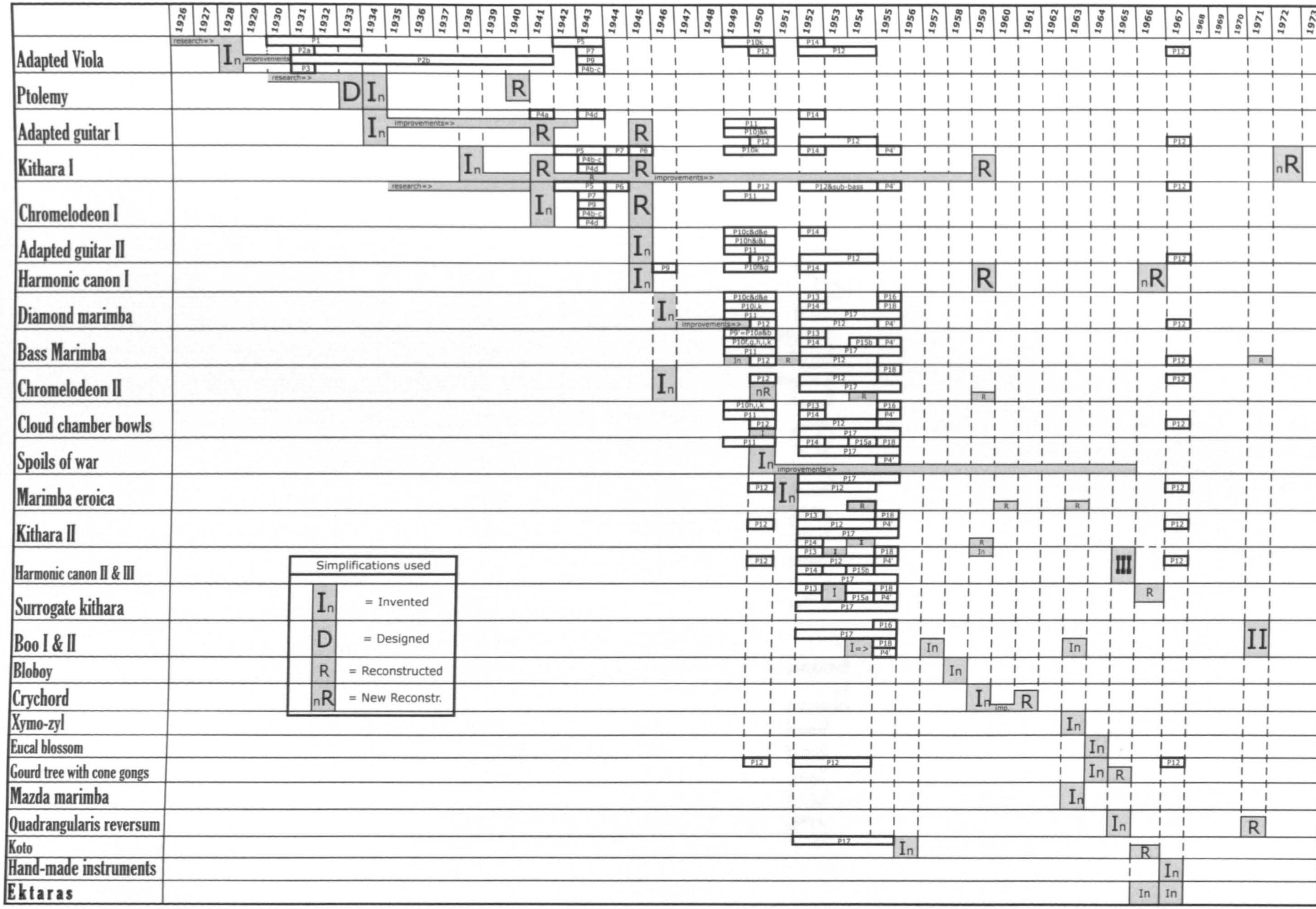

Fig. A2.23. Parch's compositions by codes (in chronological order) and instrumentaria.

Appendix Three

Appendix Three: Criteria, designs and evaluation

Appendix 3.1: A pitch-based classification of the instruments of Carrillo and Partch.

This Appendix explains the pitch-based classification criteria used for the study of pitch capabilities intrinsic to the instruments used by Carrillo and Partch. A classification code is proposed for each group of microtonal and sliding pitch capabilities considered, which additionally incorporates a symbol referring to the origin of the instrument. This appendix concludes listing all the instruments used by Carrillo and Partch with classification details (and additional annotations to the ones found in Appx 1 and Appx 2), classified under the K-H-S classification system devised by Toshie Kakinuma,[1] and incorporating the previously proposed code to the right-hand side of the K-H-S code so it is easy to sight-read the instrument's pitch capabilities by looking at classification codes, for the study that takes place in Chapter 1 (§1.3, pp. 58-71).

The pitch criteria are represented with two digits. The first subindex used for 'P' (standing for the pitch capability) has a value from 0 to 4 and is in some cases followed by 'r' to indicate 'restricted'. The subindexes represent the following criteria:

(P_4) *Sliding-pitch instruments.* Those suited to sound pitch slides throughout most of the instrument's range (e.g. trombone and violin).

(P_{4r}) *Restricted sliding-pitch instrument.* Those suited to sound pitch slides, but only in very few areas of the pitch range (e.g. clarinet) or throughout most of the range but covering a very limited range per slide (mainly the orchestral blown instruments which allow short pitch slides by means of lip techniques, excluding the trombone).

(P_3) *Microdiscrete-sliding-pitch instruments.* Those suited to sound microdiscrete pitch slides (with an average contiguous interval smaller than 100 cents, and the

[1] Kakinuma, T. 1989. *The Musical Instruments of Harry Partch as an apparatus of production in musical theater.* PhD dissertation. University of California, San Diego. pp. 12-16.

playing surface in an appropriate layout to allow fast multiple fixed-pitch ornamentation, and smooth sliding-pitch simulations) throughout the full range or most of it.

(P_{3r}) *Restricted microdiscrete-sliding-pitch instruments.* Those suited to sound discrete or microdiscrete-sliding-pitch effects, but only in very restricted areas of the range or covering a very short range.

(P_2) *Discrete-sliding-pitch instruments.* Those suited to sound discrete pitch slides while using an average contiguous interval of 100 cents, and the playing surface in an appropriate layout to allow fast multi-fixed-pitch ornaments and smooth sliding-pitch simulations) throughout the full range.[2]

(P_{2r}) *Restricted discrete-sliding-pitch instruments.* Those suited to sound discrete or micro-discrete sliding-pitch effects, but only in very restricted areas of the range or covering a range shorter than an octave.

(P_1) *Macrodiscrete-sliding-pitch instruments.* Those suited to sound macro-discrete pitch slides with an average contiguous interval larger than 100 cents, and using an appropriate layout and size to allow fast multi-fixed-pitch ornaments and smooth sliding-pitch simulations.

(P_{1r}) *Restricted macrodiscrete-sliding-pitch instruments.* Instruments or set of instruments for one or several players (in the case of fixed pitch instruments with one single pitch), which allow fast multi-fixed-pitch ornaments and smooth sliding-pitch simulations, but only in very restricted area(s) of the instrument's range.

(P_0) *Non-dynamic-pitch instruments.* Those not suited for dynamic pitch. To this group belong indefinite-pitch instruments and single-pitch instruments with stable pitch (unless they are part of a set with different pitches and multi-fixed-pitch ornaments can be achieved by one or several coordinated performers).

This coding system requires indicating the major subindex applicable and if several subindexes apply and need to be indicated, then forward slashes (/) are introduced.

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[2] This implies to 12-et and other 12-note-per-octave tunings.

In order to explain the second number that is placed as subindex for the letter 'P', an 'x' will substitute the first subindex (explained above), to indicate that the value has either been left open (but can be used too when is unknown).

The average contiguous interval size[3] (ACIS hereafter) for a pitch range considered (octave or simply for the pitch range of the instrument), determines the groupings of the second subindex, since this is chosen according to the amount of digits required for a decimal numerical notation when using an equal temperament (-et)[4] with that interval (or the closest to that interval) as the basic chromatic step (-cs). An exception must be observed for instruments using a macro-interval (an interval larger than 100 cents, excluding those built with 100 cent steps) as ACIS, in which case those instruments incorporate the code P_{X1}. The properties for each subindex are explained below:

(P_{X0}) *12-et instruments*: Exclusively those tuned to the 12-et (or a subset of the 12-et), which cannot be retuned without physically changing the instrument and whose pitch cannot be finely adjusted before or during performance.

(P_{X1}) *Macro-intervallic instruments*: At least one of the contiguous intervals has to be larger than 100 cents, and not an interval from the 12-et. Since instruments with macro-intervals among themselves, or combined with 12-et instruments, can produce micro-intervals, the instrument-development-led composer can strategically achieve micro-intervals by means of developing instruments with macro-intervals.

Before moving to the next group it is necessary to understand that intervals of 12 cents, 1.2 cents and 0.12 cents are used to fix the limits of the three groups to follow (P_{X2}-P_{X4}), since they are the sizes of the intervals used for the 100, 1000 and 10000 equal temperaments. Each of these equal temperaments represent the last '-et' of a group that uses two, three and four digits respectively (in the decimal system) to notate pitch number, and consequently for numerical notation. These limits do not have a precise acoustical significance, since not all types of tunings are necessarily equal, but it has significance when dealing with instruments with an extensive number of tuned sounding bodies. The decimal system is simply the common system of counting, and therefore ideal when using numerical notation or graphs. The octave has been chosen

[3] Large gaps within the range are not counted for the average.
[4] In this case the number has to be a natural number or rounded to the closest natural.

as the basic interval in this case, but the criteria can be reconsidered and utilised for the range of the instrument, or simply when dealing with a tuning based on an interval different than the octave.

(P_{X2}) *Micro-intervallic instruments*: The ACIS for the range of the instrument (or section of the range considered for restricted type, see below), has to be 12 cents or larger, and smaller than 100 cents. The *koto*, for example, is traditionally tuned to a pentatonic Pythagorean scale and therefore it can play fast macro-intervallic passages. Tuning takes place before the performance, although bridges can also be changed during the performance. The 13 strings of the *koto* can also be tuned to 13 different tones within an octave and allow for fast microtonal passages. Also, regardless of the chosen tuning for the open strings, a *koto* performer, by pressing and holding the strings, can achieve microtones (but in this case at a restricted speed) using scales from 13 to approximately 100 notes within an octave (provided an appropriate training).[5] Consequently, the *koto* is considered to have macro-intervallic capabilities, micro-intervallic capabilities (employing more than 12 notes per octave), and restricted micro-intervallic capabilities, and all this can be reflected in the extended K-H-S classification code using the following micro-intervallic pitch code: $P_{x,1/2r/2}$. However, for this general study of the instruments considered by Partch and Carrillo, the micro-intervallic instruments are assumed to also have macro-intervallic capabilities and therefore only the code for the micro-intervallic capability is considered necessary, (P_{X2r} or P_{X2r}).[6]

(P_{X3}) *Fine micro-intervallic instruments*: The ACIS for the range of the instrument (or section of the range considered for restricted type, see below), has to be 1.2 cents or larger, and smaller than 12 cents. It is assumed herewith that, with the appropriate training, the instruments that have a clear and long sustained pitch, and which need to

---

[5] It is not exactly 100 the limit considered and this might substantially vary according to the performer's training. The notes per octave that can be pitched on plucked strings which are adjusted by ear (e.g. *koto*), is restricted due to the short sustain of these instruments, which does not allow enough time to adjust the pitch with fine accuracy. Therefore, the limit of notes that could be pitched within an octave is more likely to have two rather than three digits. Carrillo's numerical notation principle of using two digits to notate the notes contained in one octave has been adopted to define the smaller interval of this group. Since 100 notes per octave is the maximum that can be achieved with two digits (00-99), the 12 cents step of the 100-et is the smallest interval of the group.

[6] In this case the x is placed in the code in order to say that this time we do not want to show the value since we are not referring to it.

be finely adjusted during the performance, can play from 101 up to approximately 1000 different pitches within an octave.[7]

(P_{X4}) *Ultrafine micro-intervallic instruments*: The ACIS, or smallest contiguous interval (for restricted type, adding 'r' to code), is 0.12 cents or larger, and smaller than 1.2 cents. An instrument that has to be finely adjusted during the performance by the player is unlikely to belong to this group since it would require delivering a chromatic scale of more than 1000 notes per octave increasing the pitch for each step.

An 'r' might be placed after the second subindex number to indicate significant irregularities in the distribution of the notes throughout the pitch range, that might consequently leaving noticeable gaps in relation to the size of the average contiguous interval. In most of the cases the first subindex number will also have the 'r' so this is placed only once c both numbers. If there was a case in which the restriction applies only to one number, then the numbers need to be separated by commas and the 'r' placed after the corresponding number.

Although neither Carrillo nor Partch made ultra-fine micro-intervallic instruments, this research initially considers the possibility, and discusses the requirements of an ultra-fine micro-intervallic instrument as part of the thinking process behind the instrument development Study Case (Chapter 2). This research also, as part of the creative-comparative strategy, proposes variant conceptual instruments with ultra-fine micro-intervallic characteristics (e.g. *Lucent tree,* pp. 413-434).

The additional information about the origin of the instruments (enclosed in parentheses), is represented after 'P' code and a dash under the following symbols:

[7] This limit might vary from instrument to instrument according to the sustain length and the pitch stability that can be achieved on the instrument once the right pitch has been spotted. There is no doubt that the training of the performer would also count for this capability. In this case, the line at 1000 notes per octave has also been defined in order to use three digits to indicate pitch number, when using numerical notation, since this limitation also is in the transition area. 1200 notes per octave is slight above the octave but in the very limit of what can be humanly achieved according to the American Festival of Microtonal Music ensemble, which is trained to play to the closest cent.

-(O) = Western Orchestra Instruments used with provisional alternative tunings or extended techniques to reach microtones or new sliding techniques (WOI).[8]

-(●) = Adapted Western Orchestra Instruments (AWOI).

-(□) = Western Non-Orchestra Instruments (WNOI).

-(■) = Adapted Non-Orchestra Western Instruments (AWNOI).

-(△) = New Western Non-Orchestra Instruments (NWNOI). Including any new Western musical instrument that has not been generally accepted by the Western orchestra.

-(▲) = Adapted New Western Non-Orchestra Instruments (ANWNOI).

-(◇) = Non-Western instruments (NWI).

-(◆) = Adapted non-Western instruments (ANWI)

The last section of the code indicates the composer(s) that used the instrument in chronological order from left to right, and separated by a forward slash as follows:

-C = Original instrument by Julián Carrillo.

-P = Original Instrument by Harry Partch.

-/C/P = Instrument used first by Carrillo and then by Partch (but not developed by any of them)

-H/P = Instrument developed by Lou Harrison and used by Partch.

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[8] Notice that a retuned piano is notated with the symbol '-(O)', since the tuning can be easily changed back to the original tuning, while a retuned orchestral marimba is notated with the symbol '-(●)' since the change is physical sand it cannot be tuned back to the original tuning without making another physical change, which makes it an adapted Western Orchestral instrument.

Notice that the openness of this system requires annotations every time that is used to accommodate new composers being compared. In this case: 'C' for Julián Carrillo, 'P' for Harry Partch, and 'H' for Lou Harrison.

Most of the information required was available for Partch's instruments (mainly from Toshie Kakinuma's thesis and Partch's *Genesis of a Music*, see Bibliography), but the limited amount of information published on Carrillo's instruments led this research to retrieve information from the original scores. An example about how this was achieved is followed by the extended K-H-S codes of the instruments used by Carrillo and Partch with an explanation of what each code means. Kakinuma's classification code is a slight variation of the Hornbostel-Sachs system.[9]

Carrillo combined the use of the 12-et parts with quartertone, eighthtone and sixteenthtone parts. It is easy to locate intervals and consequently for which division of the tone Carrillo writes a passage by following the following steps:

(1) A passage is written in sixteenthtones if it has an odd number. If not then:

(2) A passage is written in eighthtones if it uses one of the following numbers: 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 70, 74, 78, 82, 86, 90 and(or) 94. If not then:

(3) A passage is written in quartertones if it uses one of the following numbers 4, 12, 20, 28, 36, 44, 52, 60, 68, 76, 84 and(or) 92 (multiples of 4 from 4 to 92). If not:

(4) The passage is written in semitones, or in other words it only uses multiples of 8 apart from 0.

Fig. A3.1 shows an example of Carrillo's handwriting in sixteenthtones, where the solo Horn part is written in sixteenthtones and supported by sixteenthtone parts for the *'Carrillo' harp*, and the timpani.

[9] Hornbostel, Erich M. von, and Curt Sachs. 1961. Classification of Musical Instruments. Translated by Anthony Baines and Klaus P. Wachsmann. *The Galpin Society Journal.* vol. 14 (March). pp. 3-29.

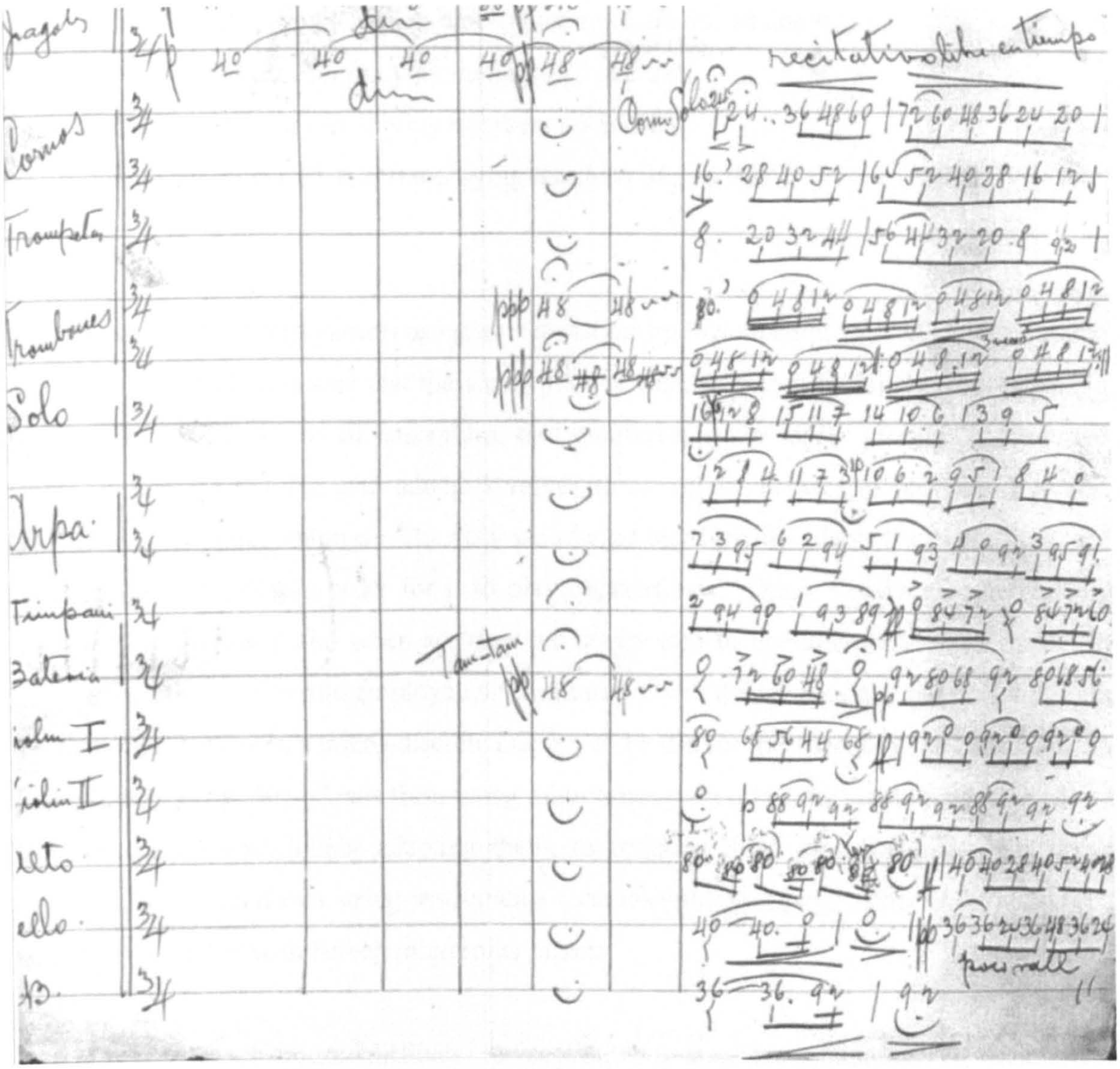

Fig. A3.1. Horn Caprice (Carrillo, 1929) excerpt: orchestra without most woodwinds (bars1-7) (CA).

In the extract above (Fig. A3.1) the following instruments and tunings employed can be observed:

> Bassoon: 12-et (The parts missing above the bassoon part are the rest of the woodwinds playing from bars 1 to 6 too, also using 12-et).
>
> French horn (I and II): quartertones (employing numbers 60 and 52)
>
> Trumpet: quartertones (employing numbers 20 and 44)
>
> Trombones (I and II): quartertones (chromatic passage: 0-4-8-12)
>
> Solo French horn: sixteenthtones (employing numbers 15, 11 and 7)
>
> '*Carrillo' (zither) harp*: sixteenthtones (employing numbers 3, 7 and 11)
>
> Timpani: sixteenthtones (employing numbers 1, 93 and 89)

Tam-tam: quartertones (employing numbers 56, 68 and 92)

Violin (I and II): quartertones (employing numbers 68, 44 and 92)

Viola: quartertones (employing numbers 80 and 28)

Cello: quartertones (employing numbers 36 and 20)

Double bass: quartertones (employing numbers 36 and 92)

Carrillo wrote two string quartets using tone divisions up to sixteenthtones: in 1926 (C10) and 1933 (C35),[10] which indicates that the string players were expected to develop techniques to play sixteenthtones for small ensembles, and quartertones for larger groups (as observed above in Fig. A3.1). He also added 3 valves to all of the brasses to play quartertones, eighthtones and sixteenthtones. The only woodwind that Carrillo adapted was the flute (see Appx 1, pp. 243-244), in order for it to play quartertones. Other woodwinds were rarely used with quartertones and when so, they were expected to use alternative fingerings. In terms of percussion, Carrillo employed sixteenthtones with the timpani and quartertones with the Tam-tam, but not in a micro-discrete manner as he did for the *sixteenthtone piano* (see an example Fig. 11, p. 50). Apart from using microtones with all of the stable pitch symphony orchestra instruments (either adapting them, or retuning them or using new fingerings), Carrillo also invented two string instruments (one resembling a large zither and the other, a large lute), together with fifteen microtonal pianos.

Partch's scores are more difficult to access, but his documentation of instrument development is very clear and supported by the work of several researchers. He used around 40 microtonal instruments, which he either adapted or developed fully. If we add the Western instruments that he incorporated to his large performances (requiring pitch adjustments through fingerings or adjustments) then the number is slightly above eighty.

The instruments used by Partch and Carrillo have been classified into the 4 main categories of the Hornbostel-Sachs system to ease the access to details, as follows:[11]

[10] See chart on Fig. A1.107. p. 295.

[11] So as to assist the interpretation of the code, the figure indicating the materials are in **bold** style, and in most of the cases come from the K-H-S system.

A3.1.1 Idiophones

Eucalyptus Claves: 111.111-P_{11r}-(●)-P. Idiophone struck directly; concussion sticks; wood.

Bamboo Claves: 111.152.5-P_{11r}-(△)-P. Idiophone struck directly; concussion tubes with idioglot lamella; bamboo.

High Redwood Blocks A, B (Spoils of War): 1112. .11.11-4-$P_{0,1r}$-(△)-P. Idiophone struck directly; individual percussion of wood; without slit; without resonator; sounded with mallet.

Low Wood Block (Spoils of War): 1112. .11.121-4-$P_{0,1r}$-(△)-P. Idiophone struck directly; individual percussion of wood; without slit; with resonator of wood; sounded with mallet.

Chinese Wood Block (Spoils of War): 1112. .11.21-4-$P_{0,1r}$-(◆)-P. Idiophone struck directly; individual percussion of wood; with slit; without resonator; sounded with mallet.

Bass Marimba: 1112. .21.122.211-4-5-P_{12r}-(△)-P. Idiophone struck directly; table xylophone; with resonators of wood suspended singly; sounded with mallets and bare hands. The playing speed limitation rather than the tuning, makes this instrument slightly restricted to achieve fast ***multi-fixed-pitch ornaments*** and/or smooth sliding-pitch simulations. The presence of only two micro-intervals (of around 53 ¢ and 63 ¢) makes the availability of macro-intervallic scales within the range very restricted.

Diamond Marimba: 1112. .21.122.215-4-5-P_{12}-(△)-P. Idiophone struck directly; table xylophone; with resonators of bamboo suspended singly; sounded with mallets and bare hands.

The Quadrangularis Reversum: 1112. .21.122.215-4-P_{12}-(△)-P. Idiophone struck directly; table xylophone; with resonators of bamboo suspended singly; sounded with mallets.

The Marimba Eroica: 1112. .21.142.1-4-5-P_{11r}-(△)-P. Idiophone struck directly; bedded trough xylophone; with individual resonators of wood for each sounding body; sounded with mallets or bare hands.

Xyl (The Zymo-xyl):[12] 1112. .21.221.1-4-P_{11}-(△)-/P. Idiophone struck directly; suspension through xylophone (with sounding bodies of wood); with a trough resonator for all sounding bodies; resonator of wood; sounded with mallets.

Mbira Bass Dyad: 1112. .21.322.21-4-P_{11r}-(△)-P. Idiophone struck directly; tongue xylophone (wood); with individual double-resonator for each sounding body; resonator of wood; sounded with mallets. It's based on same principle than Emil Richard's *flapamba.*[13]

Whang Guns (Spoils of War): 111.222.231.2-4-$P_{4r,2}$-(△)-P. Idiophone struck directly; set of percussion plaques of metal; tongue with resonator; with vibration mechanism; sounded with mallets (Three large *flex-a-tones* controlled with pedals and hammered with wooden mallets).

The Boo II (Bamboo Marimba): 111.232.125-4-P_{32}-(△)-P. Idiophone struck directly; set of percussion tubes; both ends open; with idioglot lamella; tubes of bamboo; sounded with sticks.

The Boo I (Bamboo Marimba): 111.232.225-4-P_{32}-(△)-P. Idiophone struck directly; set of percussion tubes; one end open; with idioglot lamella; tubes of bamboo; sounded with sticks.

Bamboo Blocks (Spoils of War): 111.232.225-4-P_{11r}-(△)-P. Idiophone struck directly; set of percussion tubes; one end open; with idioglot lamella; tubes of bamboo; sounded with rubber mallets.

Bamboo Slit Drums (The Maramboo): All made by Bill Loughborough in collaboration with Partch based on the log based Aztec slit drum named *teponatzli.*[14]

> 111.232.225-4-$P_{1r,1}$-(◆)-/P. Idiophone struck directly; a set of percussion tubes; one end open; with idioglot lamella; tubes of bamboo; sounded with mallets.

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12 Design in collaboration with an Industrial Design student at the University of Illinois (the blocks and resonators were designed by the student in 1959).

13 Richards, E. 1972. *World of percussion: a catalogue of 300 standard, ethnic, and special musical instruments and effects.* Sherman Oaks, CA: Gwyn Publishing. p. 55.

14 Castañeda, D. and Mendoza, V. 1933. Los Teponaztlis en las civilizaciones precortesianas. *Anales del Museo Nacional de Arqueología, Historia y Etnografía.* 4a época. vol. 8, no.2 (April-June). Mexico City: Talleres Gráficos del Museo Nacional. pp. 5-80.

111.232.32**5**-4-P$_{1r,1}$-(◆)-/P. Idiophone struck directly; a set percussion tubes; both ends closed; with idioglot lamella; tubes of bamboo; sounded with mallets.

111.232.12**5**-4-P$_{1r,1}$-(◆)-/P. Idiophone struck directly; a set percussion tubes; both ends open; with idioglot lamella; tubes of bamboo; sounded with felted sticks. Bill Loughborough's version of the Aztec instrument called *teponatzli.*

<u>The Eucal Blossom</u>: 111.232.31**5**-4-P$_{32}$-(△)-P. Idiophone struck directly; a set of percussion tubes; both ends closed; without lamella; tubes of bamboo; sounded with mallets.

<u>Gong</u>: 111.241.1-P$_{01}$-(○)-/P. Individual Gong.

<u>Gourd Tree</u>: 111.24**2**.222.2**6**-4-P$_{32r}$-(△)-P. Idiophone struck directly; a set of percussion vessels of metal; suspended bells with resonator or gourd; sounded with sticks. The first '2' figure in **bold** style indicates that "a striker (clapper) is attached inside the bell", in the H-S system. [15] In the K-H-S system refers to the material of the bell (metal), With only two micro-intervallic intervals (70 ¢ and 48 ¢), which happen to be continuous, there is a one single micro-discrete sliding effect possible, but very effective due to its sustain.

<u>Cone Gongs</u>: 111.24**2**.223-4-P$_{11r}$-(△)-P. Idiophone struck directly; a set of bells (percussion vessel with vibration weaker near the vertex) of metal, attached to a stand at the vertex; sounded with mallets.

<u>Auto hubcaps and aluminium kettle top (Zymo-Xyl)</u>: 111.242.**2**32-4-P$_{11r}$-(△)-P. Idiophone struck directly; a set of bells (percussion vessel with vibration weaker near the vertex) of metal; cymbals attached to stand at the vertex; sounded with mallets.

<u>Brass Shell Casings (Spoils of War)</u>: 111.242.**2**42-4-P$_{32r}$-(△)-P. Idiophone struck directly; a set of percussion vessels of metal; cylindrical; suspended; sounded with mallets. The following consecutive intervals (in cents) were employed in the last tuning used: 31.2 - 35 - 31.2 - 31.7 - 21.5 - 27.3. An ACIS of 29.6 ¢, with maximum deviations of +5.3 ¢ and -8.1 ¢, produces an even microdiscrete glissando. The microdiscrete glissando used for the seven Brass Shell Casings is restricted to 178 ¢ of range (so an 'r' is used although the scale seems

[15] Hornbostel, Erich M. von, and Curt Sachs. 1961. Classification of Musical Instruments. Translated by Anthony Baines and Klaus P. Wachsmann. *The Galpin Society Journal.* vol. 14 (March). p. 15.

to have even steps. The micro-intervallic scale used is also considered restricted for the same reason, the 178 ¢ range.

Zymo (The Zymo-Xyl): 111.242.441.2-4-P_{32}-(△)-P. Idiophone struck directly; set of percussion vessels of glass; whole bottles; placed upside down on stand; sounded with mallets. With a range of 17 micro-intervallic pitches within a range of an approximate major sixth (exactly an interval with ratio 15/9 or 884.35 ¢), the instrument is here considered to have non-restricted regular microdiscrete-dynamic pitch (subindex 3), and in this case with an ACIS (Average continuous size interval) of 55.3 ¢ (slightly over a quartertone). The contiguous intervals in cents are: 31.8 - 38.9 - 117.7 - 84.5 - 35 - 84.5 - 80.5 - 31.2 - 70.7 - 21.5 - 27.3 - 63 - 38.9 - 14.4 - 66.2 - 84.5). In this tuning used there is a maximum deviation from the ACIS of +62.4/-40.9 ¢ (values have been underlined above). If we make the average between the deviation above the ACIS and the deviation below there is a maximum average deviation (MAD from now onwards) of 51.65 ¢, which is 3.65 ¢ below the ACIS. From now onwards if the MAD value is higher than the ACIS value then the tuning will be considered restricted in the code due to undesired unevenness. This time it is not considered restricted, although it was at the limit.

Cloud-Chamber Bowls: 111.242.442.2-4-P_{32r}-(△)-P. Idiophone struck directly; a set of percussion vessels of glass; cut bottles; suspended; sounded with mallets. Pitches changes every time a bowl breaks, but in the version described at Partch's *Genesis of a Music*, there are 6 clear pitch areas where 4 pitches are found within a semitone, or in other words, micro-intervallic (second subindex of value 2), but restricted a specific area of the range. The sliding capabilities are microdiscrete (first subindex of value 3) for that restricted area already mentioned, and it is also restricted by the speed at which the performer can strike consecutive bowls without breaking them.

Cloud-Chamber Bowls (Spoils of War): 111.242.442.2-4-P_{32r}-(△)-P. Idiophone struck directly; a set of percussion vessels of glass; cut bottles; suspended; sounded with mallets. A very few chords or arpeggios can be played with the four pitches available. Those four pitches have the following continuous intervals (in cents): 333 - 466.3 - 53.3 (two macro-intervals and one micro-interval). Since the interval of 53.3 ¢ can be used for a trill, and then the microdiscrete-sliding pitch capability is there, although restricted to this trill. This would produce a quartertone-like vibrato illusion which here is considered sliding pitch property of subindex 3. The static pitch properties are micro-intervallic and macro-intervallic, so the first one includes the second one and the subindex 2 is used, but with the 'r' for restriction for the same reason than before.

The Mazda Marimba: 111.242.451.2**8**-4-P_{32r}-(△)-P. Idiophone struck directly; a set of percussion vessels of glass; light globes; placed on a stand; with resonator of plastic; sounded with mallets. The first two top rows are separated from the two lower rows by and interval of 813.7 ¢ (interval between the lowest note of the 2nd row and the highest of the 3rd), which divides the dynamics of the instrument into two sections. By checking the ACIS separately for each section, a value of 144.2 ¢ for the two top rows and of 98.9 ¢ for the two lower rows is obtained. Therefore the lower half of the instrument could be considered to have microdiscrete-sliding properties, while the upper half of the instrument is having macrodiscrete sliding properties. Given the fact, that the instrument has to be classified considering its entire range and it has partial microdiscrete-sliding properties, it is therefore herewith classified as an instrument with restricted microdiscrete-sliding properties (first subindex is 3 and the 'r' indication applies). The instrument has a section in the upper half with three consecutive micro-intervals (54.5 ¢, 27.3 ¢ and 53.3 ¢), which qualifies it for a short microdiscrete-sliding pitch effect in the upper section with an ACIS of 55 ¢ and a MAD of 28 ¢.

Bamboo Ceremonial Poles: 111.3**5**-P_{11r}-(◆)-P. Idiophone struck directly; stamping idiophone of bamboo. They are bounced on rocks or concrete floors, which is why they were not used (since that type of floor was not available). Similar to the ones found in the South Pacific. Three are available around a semitone, and a tone apart respectively.

Flex-a-tone: 112.14**2**-P_{42r}-(□)-P. Indirectly struck idiophone; shaken plaque of metal.

Drone Devil: 121.221.**2**-$P_{3r/4,2}$-(□)-P. Plucked idiophone; heteroglot guimbarde of metal. An ordinary American jaw harp. An ordinary American jaw harp.

Mbira: 122.122.**1**-P_{11}-(◆)-H/P. Plucked idiophone; in board-form; with laced on lamellae of metal; with resonator of wood. Designed by Lou Harrison (H) based on the Cuban *marimbula* (which belongs to the African *mbira* family). This instrument was only used once and according to Partch, 'its tuning was quite irrational'.[16] Since the instrument is not

[16] Partch, H. 1949. *Genesis of a Music*. Second edition (1974). New York: Da Capo Press. p. 315.

presumably tuned to 12-et and semitones or smaller intervals are not normally used, the instrument is classified as macro-intervallic.

A3.1.2 Membranophones

Timpani: 211.12-$P_{4r,2}$-(O)-/C. Set of kettle drums. Played using up to sixteenthtones.

Gourd Drum: 211.122.26-4-5-7-P_{01}-P. Membranophone struck directly; (separate) kettle drum; with additional resonator; with sound hole at the bottom; body of gourd; sounded by mallet; with membrane nailed to the drum.

Concert toms: 211.211.12-$P_{3r,2}$-(O)-/C. Membranophones struck directly. Set of open cylindrical drums. Tuned in quartertones.[17] The restriction indicated in the code refers to the speed at which a micro-discrete glissando could be simulated with a quartertone set.

Boobams: 211.211.15-92-4-5-$P_{1r,1}$-(▲)-P, 211.211.11-92-4-5- $P_{1r,1}$-(▲)-P, 211.211.12-92-4-5-$P_{1r,1}$-(▲)-P. Membranophone struck directly; single-skin cylindrical drums, open; resonator of bamboo (or wood, or metal); with membrane lapped on by a hoop; sounded by mallet and bare fingers. Build by William Loughborough. Tuned in just intonation, resembling a diatonic scale.

Tom-tom: 211.212.1-P_{01}-(O)-/P. Membranophone struck directly; Double-skin cylindrical drum (individual). Tuned to a note in the just-intonation scale used.

Bass Drum: 211.212.1-P_{01}-(O)-/P. Membranophone struck directly; Double-skin cylindrical drum (individual). Tuned to a note in the just-intonation scale used.

Waving Drum B: 211.321.5-01-91-5-P_{01r}-(◆)-/P. Drum struck directly; single-skin frame drum with handle; body of wood; waved after the strike; membrane lapped on a ring of cord; sounded with bare fingers. The skin is nailed and therefore not adjustable. The instrument is restricted to one-single pitch. Tuning is also unstable. Presented by E. Richards. Here it is assumed that the instrument was based on a non-Western instrument.

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[17] See Fig. A3.1 (above) where Carrillo calls them 'tam-tam' (SP).

Belly drums: 211.321.**5**-02-7-5-P_{41r}-(△)-P. Drum struck directly; single-skin frame drum with handle; body of bamboo; bared belly as part of resonator; with membrane nailed to drum; sounded with bare fingers.

Waving Drum A: 211.322.**5**-01-7-5-P_{01r}-(◆)-P. Drum struck directly; double-skin drum with handle; body of bamboo; waved after the strike; with membrane nailed to drum; sounded with bare fingers. Harry Partch's version of the Japanese *Uchiwa Daiko* (frame drum).

Rotating Drum: 212.3**5**-7-P_{01r}-(◆)-P. Drum struck indirectly; frame-rattle drum; body of bamboo; with membrane nailed to drum. Based on a Chinese *rotating drum.*

A3.1.3 Chordophones

Ugumbos: 311.121.223.**6**-P_{41r}-(◆)-P / 322.111-5-P_{41r}-(◆)-P. Mono-heterochord musical bow/arched harp; with double resonator; with tuning peg; resonator of gourd; sounded with bare finger and beater. Partch's version of an *Ugumbu, Ugubo, Ugubu, or Ugumbu.*

Koto A: 312.22**1**-6-P_{42r}-(◆)-P. Heterochord half-tube zither; resonator of wood; sounded with plectra. The sliding effect is restricted to approximately a semitone upwards for each string and although the bridges can be changed to achieve a micro-intervallic, this would be limited to 13 notes, since the instrument has 13 strings (same applies to Koto B)

Koto B: 312.22**1**-4-6-P_{42r}-(◆)-P. Heterochord half-tube zither; resonator of wood; placed on a specially built low stand, played by a performer sitting on an attached low chair; sounded with plectra. See Koto A (above) for more details.

Crychord: 314.122.1**1**-02-4-5-6-71-P_{42r}-(△)-P. True board zither; monochord with resonator box of wood; with pitch control handle; sounded with beater, bare fingers, plectrum, or bow. Built in cooperation with an Industrial Design student at the University of Illinois (1959). Pitch glides can be achieved after plucking the string but since the decay is faster when gliding, its effect is rather restricted. Micro-intervals can be achieved but not with much precision.

Harmonic Canon III (Blue Rainbow): 314.122.211.1-4-6-$P_{3/4r,2}$-(△)-P. True board zither; with resonator box; polychord box zither; with single set of strings on one plane; with single resonator of wood; sounded with beater and plectrum. It consists of three 22-string cannons out of which two can be incorporated into the stand to be played at the same time. These three cannons are interchangeable with the two of the Harmonic Canon II and vice versa. With 44 strings Partch's basic 43-note just intonation scale can be achieved.

Harmonic Canon II (Castor and Pollux): 314.122.211.1-01-4-6-$P_{3/4r,2}$-(△)-P. True board zither; with resonator box; polychord box zither; with single set of strings on one plane; with single resonator of wood; with pitch control bar; sounded with beater and plectrum. With 2 cannons of the same dimensions than Harmonic Canon III, a total of 44 strings are used. Counting the three cannons from the Harmonic Canon III, a range of 3 octaves and a just fifth range is covered from the lowest note, which is a major tone below the G at 98 cps (ratio 1/1), which is represented by the ratio 19/6 (vibrating at 87.11 cps).

Surrogate Kitharas: Although Partch named them all 'Surrogate Kithara', here they are treated separately under model A and B as Toshie Kakinuma suggests in her thesis,[18] since they have a slight different stand containing the two canons, and particularly in the area where the mandolin tuning pegs are fitted. The Surrogate Kithara A (Fig. A3.2), is used with two different tunings. Kakinuma uses model A2 to relate to the model A when the open tuning employs strictly consecutive macro-intervals between the strings, and model A1 to relate to the model A when the open tuning employs one micro-interval between two strings, and macro-intervals between the others. This is also adopted by the code used in the extended K-H-S system.

Fig. A3.2. Surrogate Kithara A (Photo by Fred Lyon, Sausalito, 1954).

[18] Kakinuma, T. 1989. *The Musical Instruments of Harry Partch as an apparatus of production in musical theater.* PhD dissertation. University of California, San Diego. p. 103.

The need for different tunings within the same performance made Partch develop a new model of Surrogate Kithara, the model B (Fig. A3.3), using the occasion to also improve on the design of the instrument.

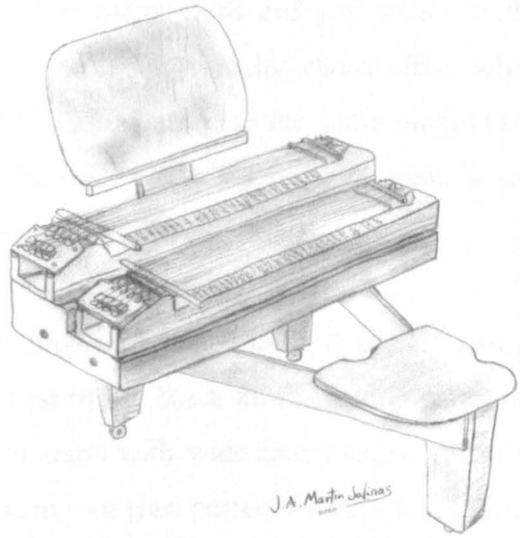

Fig. A3.3. Surrogate Kithara B (1966) (sketch by author).

The three models have the same K-H-S code: 314.122.212.1-4-6. True board zither; with resonator box; polychord box zither; with single set of strings on one plane; with additional resonator of wood; with pitch control bar; sounded with felted sticks (also fingers and mallets) and plectrum. Each of three models considered have two canons with 8 strings, and they all have two different indications for the sliding pitch capability separated by a forward slash, so the first one relates to the fix tuning between the strings and the second one to the pure sliding capability when using the Pyrex rod (which Partch also uses for percussion purposes). Both capabilities can be combined which is why they need to be indicated in the classification code.

Here are the codes for the extended K-H-S system considered, explaining the pitch capabilities of each of the models:

> <u>Surrogate Kithara A1 (1956)</u>; 314.122.212.1-4-6-P$_{(1/4,2)r}$-(△)-P. For the upper canon (green), starting from 84 cps (1st string), it uses the following contiguous interval sizes (in cents from lowest to highest): 498 - 386.3 - 1017.6 - 182.4 - 165 - 0 - 150.6. For the lower canon (orange), the following interval sizes: 498 - 498 - 1017.6 - 386.3 - 231.2 - 0 - (-)48.8. This tuning is used for the following works: *The Bewitched, Barstow, Castor and Pollux, Daphne and the Dunes, The Mock Turtle Song* and *Two Settings from Louis Carroll.*

The tuning used for the upper canon (green) is macro-intervallic and it has a very interesting chord effect when playing all the strings in a fast sequence (in ascending pitch order, and/or vice versa). It has wide intervals between the first four strings (just perfect fourth, just major third and just major sixth respectively) producing almost a drone-like effect, followed by chord effect which emphasises a note by having the 6th and 7th strings tuned to the same pitch (11/7). This repetition of the note 11/7 can also be used as a pivot point to create a smooth change of direction (from increasing pitch to decreasing).

The lower canon (orange), starting from 73.5 cps (1st string), at 231 cents lower than the upper canon's first string, has a similar tuning pattern but with a slight variation. The interval pattern starts with wide intervals, so it can produce drone-like effects between strings one to four (just perfect fourth - 4/3, followed by another just perfect fourth - 4/3, and just major sixth - 5/3). This is also followed by reasonably small macro-intervals (between a semitone and a tone) and the sixth and seventh strings tuned to the same pitch (12/7). The unique issue about the tuning of this canon is that the pitch of the 8th string is lower (by 48.8 ¢) than the pitch of the 6th and 7th strings, which makes more interesting the pivoting effect in this specific string rather than on the 7th, since it creates a quartertone vibrato-like effect that defines the inflection area for the pitch contour.

Considering that there is only one micro-interval in this instrument, it is considered hereby to have restricted microdiscrete-sliding-pitch capabilities, which is what differentiates its classification code from the next model (A2).

<u>Surrogate Kithara A2 (1955)</u>, 314.122.212.1-4-6-$P_{(3/4,2)r}$ -(△)-P. This model is used for the following works: *U.S. Highball* (1955) and *The Letter*. The date placed next to the instrument name simply represents the date in which the first work using the corresponding new tuning was composed. This is exactly the same Kithara as in model A1 but with the following tuning: the upper canon (green), starting also from 84 cps (1st string), is tuned using the following contiguous interval sizes: 498 - 386.3 - 1017.6 - 182.4 - 165 - 0 - 150.6; which is the same tuning used for the upper canon for the model A1. All macro-intervals and pivoting effect (already explained for model A1) are possible. The lower canon (orange), starting from 74.6 cps (1st string), at 435 ¢ lower than the upper canon's first string, is tuned using the following

continuous interval sizes: 702 - 498 - 1017.6 - 386.3 - 182.4 - 0 - 0, which means that a less acute curve can be sounded as part of the pitch contour produced by playing a fast sequence from string one to eight and coming back to the first string.

This instrument (being the same as the previous) is classified differently since, unlike the previous model (and due to the use of a slightly different tuning), it has restricted micro-intervallic capabilities and restricted microdiscrete-sliding-pitch capabilities.

Surrogate Kithara B (1963); 314.122.212.1-4-6-$P_{(1/4,2)r}$-(△)-P (Fig. A3.3). The code is the same than the one of the Surrogate Kithara A1, observing Fig. A3.2 and Fig.A3.3 one can observe that they are not the same instrument.

The upper canon (green) is tuned starting from 74.6 cps (1st string), using the following contiguous interval sizes: 702 - 0 - 498 - 702 - 0 - 582.5 - 301.8. This tuning uses a drone effect with the just perfect fifth (3/2) reinforced and then it adds an unusual interval named the minor septimal tritone (ratio 7/5 or 582.5 ¢ above the reinforced fifth of the drone), followed by a ratio 25/21, which is almost the tempered major third (+1.8 ¢). The last two intervals together makes an interval of ratio 5/3, which is a pure major sixth sounded above the reinforced fifth of the drone and a pure sub-major second (10/9, or 182.4 ¢) above the drone, and making a perfect balance for the dissonance of the minor septimal tritone. This is a very unique tetrachord, since its continuous intervals are all larger than a 12-et tone in the way that it has been rendered. The macro-intervallic nature of these intervals balance the dissonant nature of the chosen intervals.

The lower canon (orange), starting from 74.6 cps (1st string), at 27.3 cents lower than the upper canon's first string, is tuned using the following continuous interval sizes: 702 - 0 - 498 - 702 - 0 - 315.6 - 386.3. This tuning, in terms of just intonation consists of a perfect fifth (3/2), unison (1/1), perfect fourth (4/3), unison (1/1), minor third (6/5) and major third (5/4), which is nothing else than a drone lower sound followed by the major triad made with the drone.

In a similar way than the Adapted Guitars (A and C, see below) and the Kitharas, the Surrogate Kitharas in general can produce arpeggiated chords using macro-intervals and in some cases micro-intervals too, which can also slide with a Pyrex rod. By having the position in horizontal (unlike the Kitharas) and with more strings than the Adapted Guitars, this arpeggio capability can be used to draw pitch contours contained within the intervallic relation between strings. This bi-dimensionality of the sliding pitch capabilities is also shared with the Harmonic Canons and with the Adapted Guitars A and C, when using Pyrex rod.

('Carrillo') Thirdtone (ground) *piano*: 314.122-4-8-P_{32}-(●)-C. Box zither with resonator made from slats; with keyboard; with hammer playing action. Originally a Steinway ground piano, then adapted by Buschmann following Carrillo's instructions to have thirdtones.

('Carrillo') Metamorphosing (upright) *pianos* (15): *Tone metamorphosing piano*, 314.122-4-8-P_{10}-(△)-C and other 14 pianos covering, with an extended piano keyboard of 97 notes, one or several octaves range, each one tuned using a different equal step: thirdtones, quartertones, fifthtones, etc., up to sixthtones. All these fourteen pianos share the same classification code: 314.122-4-8-P_{32}-(△)-C. The fifteen *metamorphosing pianos* share the same K-H-S code and therefore they all can be said to be: Box zither with resonator made from slats; with keyboard; with hammer playing action.

Harmonic Canon I: 314.122.221.1-01-6-P_{32}-(△)-P. True board zither; with resonator box; polychord box zither; with another set of strings crossed with the original set; with single resonator of wood; with pitch control bar; sounded with plectrum.

New Harmonic Canon I: 314.122.221.1-01-6-P_{32}-(△)-P. True board zither; with resonator box; polychord box zither; with another set of strings crossed with the original set; with single resonator of wood; with pitch control bar; sounded with plectrum. Made to provide alternative tuning to Harmonic Canon (which was also getting old).

Zither (SP. cítara) harp: 314.122.211.1-6-P_{32}-(△)-C. True board zither; with resonator box; polychord box zither; with single set of strings on one plane; with single resonator of wood; sounded with plectrum. This instrument is tuned to sixteenthtones. Several models have been observed, but neither the pictures nor the documentation was clear enough to define each model as a separate instrument. This instrument could simply be the portable version of the *'Carrillo' harps* covering only one octave range (Fig. A1.11, pp. 244).

'Carrillo' (zither) harps: 314.122.231.1-6-P_{32}-(△)-C. True board zither; with resonator box; polychord box zither; with two sets of strings on two parallel planes (this expressed with 3 which is a category added to the K-H-S system); with single resonator of wood; sounded with plectrum. This instrument is tuned to sixteenthtones, and the strings have several bridges to get different notes so with two rows of 97 strings more than 5 octaves range can be covered.

('Carrillo') Quartertone (zither) harps: 314.122.231.1-6-P_{32}-(△)-C. First of the zither-harps built. In the beginning was used to train singers to perform quartertones.

Kithara I: 321.222.111-01-5-6-$P_{(1/4,2)r}$-(△)-P. Box lyres, a set; with single resonator for each set of strings; with strings secured inside resonators; with resonator box of wood; with pitch-control bar; sounded with plectrum and bare fingers.

New Kithara I: 321.222.121(+8)-01-5-6-$P_{(1/4,2)r}$-(△)-P. Box lyres, a set; with single resonator for each set of strings; with strings secured inside resonators; with resonator box of wood (and plastic); with pitch-control bar; sounded with plectrum and bare fingers.

Kithara II: 321.222.221-01-5-6-$P_{(1/4,2)r}$-(△)-P. Box lyres, a set; with single resonator; with strings secured outside of resonators; with resonator box of wood; with pitch-control bar; sounded with plectrum and bare fingers.

Violin: 321.322-11-P_{43}-(○)-/C/P. Up to sixteenthtones in the case of Carrillo.

3-Strings Violin: 321.322-11-P_{43}-(●)-C. Carrillo wrote in quartertones for this violin.

Viola: 321.322-11-P_{43}-(○)-/C/P. Up to sixteenthtones in the case of Carrillo.

Violoncello: 321.322-71-P_{43}-(○)-/C/P. Up to sixteenthtones in the case of Carrillo.

Adapted Viola: 321.322.12-71-P_{43}-(●)-P. Necked box lute; with electronic pick up; held upright between knees; sounded with a bow.

Guitar: 421.121.12-P_{20}-(○)-/C/P.

Appendix Three (1): A pitch-based classification of the instruments of Carrillo and Partch

Quartertone Mandola: 421.121.12-P_{32}-(●)-C.

Quartertone Mandolin: 421.121.12-P_{32}-(●)-C.

Acoustic guitar: 421.121.12-P_{20}-(□)-/P.

Quartertone guitar: 421.121.12-P_{32}-(●)-/C (Made by Baudelio García).

Thirdtone Guitar (7-strings): 421.121.12-P_{32}-(●)-C.

Adapted Guitar A: 321.322.13-01-5-6-$P_{(3/4,2)r}$-(■)-P. Necked guitar; without electronic pick up; placed on the lap; with pitch-control bar; sounded with bare fingers or plectrum.

Adapted Guitar C: 321.322.13-01-5-6-$P_{(3/4,2)r}$-(■)-P. Necked guitar; without electronic pick up; placed on the lap; with pitch-control bar; sounded with bare fingers or plectrum.

Adapted Guitar B: 321.322.24-5-6-P_{32}-(■)-P. Necked guitar; with electronic pick up; held on a side of player; sounded with bare fingers or plectrum.

Double Bass: 321.322-16-P_{43}-(O)-/C/P. Held upright and played standing up. Up to sixteenthtones in the case of Carrillo.

Octavina: 321.322-16-P_{32}-(△)-C. Held upright and played standing up. Fretted in eighthtones.

Gubagubi (Ubagubi): 324.111.16-6-P_{42r}-(◆)-P. Monochord plucked drum; open; with single resonator; string end attached to stick; body of gourd; sounded with plectrum.

Ektara B:[19] 324.126-5-P_{42r}-(◆)-P. Monochord plucked drum; with frame; body of gourd; sounded with bare fingers.

Ektara C: 324.226-5-P_{42r}-(◆)-P. Polychord plucked drum; with (double) frame; body of gourd; sounded with bare fingers.

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[19] Ektara A was never used in performance therefore it is not mentioned.

A3.1.4 Aerophones

Chromelodeon I: 412.132-61-8-P_{32}-(■)-P. Free aerophone; idiophonic interruptive free reeds, a set; with rigid air reservoir; with keyboard.

New Chromelodeon II: 412.132-61-8-P_{32}-(■)-P. Free aerophone; idiophonic interruptive free reeds, a set; with rigid air reservoir; with keyboard.

Mama Cry: 412.221.112-P_{41r}-(□)-P. Open flute with internal duct; without fingerholes; metal. Notice that timbre can be dynamically changed palming the opened end, but not the pitch. Instrument introduced to Partch by Emil Richards.

Tin Whistle: 412.221.112-$P_{2/4r,3}$-(□)-P. Open flute with internal duct; with fingerholes; metal. Commercial tin whistle with six fingerholes. Pure pitch slides can be performed sliding the fingertips on top of the holes, but it is a very difficult technique and the range is very limited (according to the performer's capabilities). Special fingering for micro-intervals and partial covering of holes can be used to achieve micro-intervals.

Piccolo: 421.121.12-$P_{2/4r,3}$-(○)-C/P (cylindrical bore).

Flute: 421.121.12-$P_{2/4r,3}$-(○)-C/P (cylindrical bore).

Quartertone Flute: 421.121.12-P_{32}-(●)-C (conical bore). Pre-Boehm flute with quartertone tone-hole in the mouthpiece. Developed in cooperation with Manuel Asencio for Carrillo.

Bloboy: 4212. .231.2+1]1+2-61-$P_{0,1r}$-(△)-P. Edge instrument with duct, a set, stopped; without fingerholes; composed partly of pipes of metal with external duct and partly of pipes of wood with internal duct; with rigid air reservoir.

Double Flageolet: 421.222.121-71-P_{13}-(□)-P. Double-duct flute with inverse conical bores; with fingerholes; wood.

Bolivian double flute (Ugumbu): 421.222.121-P_{33}-(◆)-P. Open end-blown flutes, a set; with fingerholes; wood. The fingerholes must have been transformed in order to achieve the just intonation tuning and therefore is considered an adapted instrument. The macro-intervallic properties of this instrument can be considered a study the different pure thirds, since each double hole has two notes a third apart, covering six different sizes of just intonation thirds: 144/121 (301.3 ¢, almost a 12-et third but using ratios with primes up to 11), 6/5 (315.6 ¢, a pure minor third), 11/9 (347.4, a just neutral third), 27/22 (354.5 ¢, or a more dissonant version of a just neutral third also using a ratio with primes up to 11), 5/4 (386.3 ¢, a just major third), and 96/77 (381.8 ¢, which is almost 5 ¢ below the pure major third). This flute has five double-holes at the front and one at the back (which is normally covered by the left thumb). Partch used the traditional fingering in which the left hand uses fingers I (thumb), II, and III to cover back, 5th (top) and 4th double-holes, and the right hand uses fingers II (index), III and IV to cover 3rd, 2nd and 1st (bottom) double-holes. However, the instrument has the potential to sound individual notes. A suggestion to explore the microdiscrete-sliding-pitch potential of this instruments would be to cover the fifth pair of holes (the closest to the mouth from the five frontal pairs) with the right thumb (and the back double-hole with the left thumb), leaving four fingers from each hand to cover separately the left and the right hole of each 4 pairs. This is not how is traditionally played (neither how Partch suggested), and it is difficult to cover the sound holes with precision separately with different fingers, but with a bit of training is a potential capability reflected in the classification code. Here are the intervals in cents for the chromatic scale: 165 - 150.6 - 0 - 150 - 31.7 - 133.2 - 31.8 - 150.6 - 84.5 - 119.4 - 84.4 - 80.5 - 97.4 - 53.3 - 150.6 - 165 - 182.4. Also notice that the interval with value zero cents represents a note that is repeated (ratio 3/2), which can be used for a tremolo effect.

Tin Oboe: 422.111.22-$P_{4r,3}$-(●)-P. Oboe with cylindrical bore; with fingerholes; metal. Commercial tin whistle flute supplied with an oboe reed on its top. Although this is a hybrid instrument between an orchestral oboe and a folk tin whistle, and considering that such classification has not been defined, the original instrument that has the closest sound to the hybrid instrument, is represented in the classification code, and in this case (closer to the sound of the oboe), an adapted orchestral instrument. Sliding pitch is possible and it is restricted to particular areas of the pitch range and the skills of the performer. There are micro-intervals available through alternative fingering and extended techniques, and the fine pitch adjustments are as precise as the performer's ears.

Oboe: 422.112.21-$P_{4r,3}$-(O)-C/P (with conical bore).

English horn: 422.112.21-$P_{4r,3}$-(O)-C (with conical bore).

Bb clarinet: 422.112.21-$P_{4r,3}$-(○)-C/P (with cylindrical bore).

Bass clarinet: 422.112.21-$P_{4r,3}$-(○)-P (with cylindrical bore).

Bassoon: 422.112.2-$P_{4r,3}$-(○)-C (with conical bore).

Saxophones (4; SATB): 422.212-$P_{4r,3}$-(□)-P (with conical bore).

Cornet: 422.121.12-$P_{4r,3}$-(□)-C (with conical bore).

Flugelhorn: 421.121.12-$P_{4r,3}$-(○)-P (with conical bore).

French horn: 423.211-$P_{4r,3}$-(○)-C/P (with cylindrical bore).

Sixteenthtone French Horn: 423.211-$P_{3/4r,3}$-(●)-C (with cylindrical bore).

Trombone: 423.221-P_{43}-(○)-C/P (with cylindrical bore).

Sixteenthtone Trombone: 423.221-$P_{3/4,3}$-(●)-C (with cylindrical bore).

Bass trombone: 423.221-P_{43}-(O)-P (with cylindrical bore).

Tuba: 423.231-$P_{4r,3}$-(○)-C/P (with conical bore).

Sixteenthtone Tuba: 423.231-$P_{3/4r,3}$-(●)-C (with conical bore).

Trumpet: 423.233-$P_{4r,3}$-(○)-C/P (with cylindrical bore).

Voice: 424-P_{43}-(○)-C/P. Carrillo using up to eighthtones (48-et), while Partch used up to 43-notes-to-the-octave scale (just intonation).

A3.2 Creative-comparative evaluation criteria

The criteria previously explained in this appendix, was used to classify Carrillo's and Partch's musical instruments. The classification was laid out for the analysis and comparison of the instruments produced by both composers. From here onwards, the original designs to this research are dealt with. In this section, evaluation criteria is proposed In order to evaluate each considered set of Musical Instrument Characteristics (MIC), an evaluation system considering a creative and comparative approach is adopted and applied. Glissando and microtonal capabilities added to timbre and corporeal expression are the main aspects to be evaluated for the considered set of MIC.

The main aspects initially considered for this evaluation are the form and sound of the instrument, which are explained in detail below:

Form. Does not simply refer to the shape of the instrument, since here the performer-instrument as a whole body and the movements of the performer are both taken into consideration. Spatial projection is a characteristic shared with sound, the other main aspect.

I attach herewith the utmost importance to the dramatic effect of a high degree of expression in the performance (as opposed to mechanised reproduction), which also has an impact on how the compositions for such an instrument can be perceived. Therefore, the body expressiveness of the performer while playing the instrument was also thoroughly considered, and the term *corporeal expression* is defined to encompass these elements.

Sound. With regards to the sound aspect of the MIC, one of the main issues to consider is that whilst the shape of the sounding bodies can define the way in which formants are perceived, either in isolation, or in groups when sustained or when changing in time,[1] several issues may arise from this early decision when it comes to the actual performance of the instrument. Two capabilities of the instrument in direct relation to the sound it can produce are considered: glissando capabilities, microtonal capabilities. The two are the two aspects of pitch encompassed by this research. The timbre properties of the sound

[1] Sliding pitch and microdiscrete-sliding pitch can be major contributors to gradual changes of timbre.

produced will make the instrument perceptively from typical western instruments. By providing a distinctive tone, the instrument aims to be used as a guideline for other instruments that do not have stable-fix-microtonal and sliding pitch or microdiscrete-sliding-pitch properties (e.g. violinist playing with a quartertone piano would rely on the piano at particular points to adjust its pitch, as the piano has fixed and stable pitch).

The evaluation system is defined herewith as the decision-making process of the instrument development-led method exploring pitch resources. It basically consists of a series of percentages comparing 'ideal' situations with factual capabilities. A total value has also been calculated as an average of the four main aspects considered.

Hence, the main elements considered for the analysis of the capabilities of each prototype of the *conic bellophone* and their corresponding conceptual instruments are: microtonality, sliding pitch, timbre, and corporeal expression.

They are evaluated separately and then an average of the four values is calculated so that it can be used for general conclusions. Each aspect is structured into subcategories, which are given a value between 0 and 3, rather than in percentages, in order to ease the evaluation process. Half steps between the four possible values are accepted to place a value that is considered to be between two already used values, and 3.5 can be used in exceptional cases when the value is above others that already reach an ideal value. The values are added, then multiplied by one hundred and divided by the maximal possible value (3) to obtain percentages values, which is how the final results are presented for posterior analysis. Although this evaluation system is created for the comparison and analysis of instruments to be conceived rather than for existent instruments, examples evaluating existent instruments are included to illustrate the criteria. Therefore, these examples are considered reference points for the evaluation of new designs.

The four main capabilities are evaluated separately, although some of the subcategories may directly influence more than one main capability under consideration.

As for the alternative instruments proposed, they are only some of the infinite possibilities for the specifications represented. These instruments have only been sketched and in some cases graphically simulated in 3-D for future possible transformation of the 3-D model into a virtual MIDI instrument (MAVMI as defined on page 40). At the same time, 3-D models allow the designer to easily produce views from any desired angle and help the composer to orchestrate by providing a comprehensible view of the instrument layout.

The most important aspects considered here are: (1) The evaluation process was initiated through practice and turned into method afterwards; (2) personal perception has been used as a valuable tool for the full development of the instrument.

The four main aspects and their subcategories are explained as follows:

(1) Glissando (including pitch-gliding properties). As part of this research on pitch resources, and as part of the dynamic pitch resources, a wide range of glissando characteristics are desired and analysed separately under the different subcategories:

Maximum speed. Sliding-pitch instruments such as the violin produce faster glissandi that what is considered ideal in this thesis and are valuated with a score of 3.5. As for fixed pitched instruments, the speed of the ideal microdiscrete-sliding pitch (see Glossary) is considered around 16 notes per second (see *Glissando study*, Sc. 4), although instruments with sounding bodies very close to each other, such as the *'Carrillo' harps*, can achieve higher speeds and have a score of 3.5.

Range in octaves. The range covered by the instrument in octaves rounding to the closest value with a value of 3.5 for any ranges above 3 octaves.

Evenness. This glissando subcategory refers to the smoothness with which a glissando is perceived to be played with microdiscrete-sliding pitch instruments. Pure sliding instruments have a 3.5 score while fixed pitch instruments receive scores depending on how the sound of one note joins to the sound of the next one, ideally sounding as an even sliding effect (score 3, as in the case of the *'Carrillo' sixteenthtone harp* played at high speed). Carrillo's *sixteenthtone piano*, for instance, would almost have a value of 2.5 due to the softness of the hammers (and consequent attack in comparison with a dulcimer for example), an in the case of his *sixteenthtone harps* when playing microdiscrete-sliding pitch at moderately fast speed the value would be 3.

Continuity throughout the range. The lack of a breaking point in the glissando is here considered with a score of 3, as in the case of a chromatic harp, while a violin has slight breaking points when changing strings, which places it just under at 2.5. A score of 2 is considered for the trombone, 1.5 for timpani and 1 for flute and similar instruments requiring different sound quality for quartertone positions (since the semitones are not considered here smooth for chromatic glissando unless they are played very fast).

Simultaneous glissandi-playability. Instruments that cannot sound more than one note at a time automatically get a score of 0. The breaking points of the violin become an obstacle when sliding two notes on two strings, bringing its value slightly down to 2, while Carrillo's *sixteenthtone piano* goes up to 3 since the evenness does not interfere with this subcategory, and the glissandi position is very easy to control with great precision.

(2) Microtones (and in general fixed pitches outside the 12-equal temperament). Microtonality is one of the main targets of this research and is considered separately from timbre.

Semitone subdivision (or average amount of notes contained within a tempered semitone). Although the denomination of 'semitone subdivision' might be inconvenient to use other tunings that do not subdivide the semitone, it is useful for creating values between 0 and 3, as they exactly represent the tunings most commonly considered in this research. Based on that principle, the following criteria has been adopted:

The value is 0 when the smallest interval is exactly 100 cents (a tempered semitone). The value is 1 when the smallest interval is 50 cents or between 50 and 100 cents. The value is 2 when the smallest interval is 25 cents or between 25 and 50 cents. The value is 3 when the smallest interval is 12.5 cents or between 12.5 and 25 cents. The value is 3.5 when the smallest interval is smaller than 12.5 cents.

Chords playability. This value refers to the instrument's capability to play chords and chord changes at different speeds. The value 3.5 refers to keyboards and mechanised instruments for which the speed at which they can be achieved is exceptional.

Scales playability. This value refers to the instrument's capability to play scales and the maximum speed at which scales can be played.

(3) Timbre. A rich and clear harmonic component helps performers to recognise the instrument's timbre in a group and consequently makes the instrument ideal to provide microtonal sustain pitches or gliding tones for reference to other players. Many subcategories of timbre are here considered separately and with equal weight for the calculation of how ideal the timbre is, expressed in a percentage. These subcategories are:

Maximum sustained volume of pitched spectra. This value reflects how the creator of a new instrument envisages the instrument's maximum amplitude and how long the sustained pitch spectra will be. Therefore, the typical envelope of a plucked string or of a snare drum hit by a stick (a loud and short attack and a very fast release, with almost no sustain) would get the lowest evaluation and a long and loud sustained spectrum the highest.

Sustained inharmonicity. Inharmonicity here refers to a rich harmonic content that makes the sound quality of the instrument easily distinguishable from other instruments.

Sustained compactness. Refers to the stability and regularity of the sustained pitch spectra, which makes it easier for the ear to recognise the pitch with accuracy. For example, a wide-vibrato formant in the area of the spectra where the pitch is recognised would receive a low value since the pitch stability is slightly variable, while an organ would produce a spectra that hardly changes in time when a note is sustained.

Attack's sharpness. The sharpness of the attack can help the listener to easily recognise the beginning of a section and therefore give clues to other performers that need to refer to the pitch that will be exposed after the attack.

Acuteness (intensity of attack). This refers to the intensity of the attack, since the attack of a sound can be sharp but not intense enough to be appreciated by the listener in an ensemble or orchestral context.

Duration of sustain. Instruments that can be sustained without limits (friction) receive a value of 3.5; otherwise the values are kept between 1 and 3, with 0 reserved for highly percussive and pitch-less sounds and 0.5 for highly percussive pitched sounds without sustain.

Thinness. One instrument can produce a rich harmonic spectrum and therefore sound distinctive from the regular orchestra instruments, but its density can still be perceived as thin, as in the exceptional case of the triangle that here takes the value 3.5. A highly dense sound (especially in the low register of the spectra) would have value 0.

Metallicness.[2] Sounds with a metallic quality are preferred to others in this research since it is already quite distinctive from most of the Western orchestra instruments. This property is related in most of the cases to the hardness of the material. This is a highly subjective category when evaluating materials that are not metallic.

Brightness. The higher the register, the brighter the sound.

(4) *Corporeal expression*

One quarter of the value is refers to the elements that make the difference between watching and listening to the performance of an instrument and listening to a recording. It involves physical presence, sound quality and sound projection.

Three main subcategories have been considered as follows:

Maximum number of players per instrument. An instrument moderately played by several players can gain as much corporeal expression during performance as an instrument played by one single player using a wide range of techniques, movements, speeds, etc. Therefore this value reflects the number of players, keeping 0 for mechanised instruments and 3.5 for instruments that can be played by more than 3 players.

Performer's movement (instrument layout's dimension). This value refers to the performer's maximum possible movement required, which is in most of the cases related to the dimensionality of the instrument's sounding bodies and size of the instrument,[3] especially when considering tuned percussion. The layout of the instrument has been a

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[2] The term 'metallicness' was invented for the purpose of this research to represent a type of hard sound that has a particularly metallic ring.
[3] At least in the case of standing instruments.

major element in the design process of this thesis, and we can find precedents in the work of Partch. Ben Johnston clearly defines Partch's phenomenon:[4]

> The design of Partch's remarkable instruments is an achievement of great scope and subtlety. Many of them call for a three-dimensional performing technique, as contrasted with the predominantly two-dimensional techniques of most common instruments. This is not a new idea. It is a basic feature of percussion technique when a mixed set of instruments is used. But Partch designed such setups into his instruments.

This is a subjective evaluation of the maximum physical involvement that can be potentially perceived by the audience, but one could simply use the value number to describe the highest dimension employed to describe all the possible movements.

Possible sound-initiation processes. A change of sound activation actions (process) not only influences the sound but also the movement executed by the performer, and therefore it anticipates a change in the sound, preparing the audience to perceive a substantial sound, as well as breaking the monotony of the action to be changed. A change of sound-initiation process also brings a strong change of expression capabilities for the performer and consequently, the more variety an instrument has in its sound initiation processes, the wider the range of *corporeal expression* available to a performer during a performance of a work.

Some possible sound-initiation actions (processes) are: striking, blowing, string friction (longitudinal and transversal), scraping, plucking, plosive tapping, etc. The value reflects the number of possible sound-initiation processes that are substantially different from each other. The value 0 is kept a soundtrack coming out from one single speaker, since it cannot create visual impact neither create the sensation of moving around the space.

In order to evaluate the number of different sound-initiation processes that can be produced by the instrument, a comprehensive list by Lysloff and Matson is provided for reference as follows:[5]

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[4] Johnston, B. 1975. The Corporealism of Harry Partch. *Perspectives of New Music*. vol. 13, no. 2 (Spring-Summer). p. 95.
[5] Lysloff, R. T. A. and Matson, J. 1985. A New Approach to the Classification of Sound-Producing Instruments. *Ethnomusicology*. vol. 29, no. 2 (Spring-Summer). p. 222.

air passes against non-vibrating edge(s)
air passes against single vibrating edge
air passes against multiple vibrating edges
air passes against both vibrating edge and non-vibrating edge
plosive
struck
plucked
scraped (slow/crude strigilation)
rubbed (fast/fine strigilation)
shaken/spun (indirect initiation)
electronic

In the global evaluation process described above, subjective evaluative data might seem to bring confusing data to the reader, but one must realise that the person evaluating is the composer that is going to orchestrate with those instruments, and therefore evaluating is part of the composition process (specially during orchestrating process). Therefore it is advisable that the reader who is interested in experimenting with this evaluation for compositional practice will attempt to produce a personal evaluation. Otherwise it would be comparable to composing a tune and using Bach's rules (for chorales) to produce an original choral work. These are simply possible guidelines for the development of a personal method, here utilised for the Case Study to illustrate the process.

A3.3 Variant conceptual instruments for feedback. Prototype groups 1-3

In this section, a sample of detailed documentation of the creative-comparative process is provided for the group corresponding to the first prototype of the *conic bellophone*. Then two more examples (groups corresponding to prototypes two and three) are documented in a more basic format showing how ideas can be sketched to inform the evaluation without having to delay the composition process, and still providing a brief description towards future implementation. Although groups four to fourteen were also sketched, they are not documented here since showing a few samples of how the variant conceptual instruments considered for the creative-comparative process provides enough to see how the evaluation process can be approached and documented.

A3.3.1 Prototype group 1: Non-cylindrical helix layouts

The main idea behind this shape is to achieve continuity in sequential microdiscrete pitch layouts while the performer rotates, to make possible a wide range of speeds of rotational movement of the mallets. A helix in conical rather than cylindrical form was the first form of frame considered. The performer was initially considered as being placed inside the helix. A 180 degrees range of rotation can be achieved, keeping the feet in the same place so that the mallets can slide smoothly. This would normally be achieved by a twist and rotation of the chest (combined with a rotation of the head to visualise the notes when required). It is still easy to achieve smooth slides by slightly twisting the whole torso (or adding rotation of the pelvis) to achieve around 270 degrees of rotation range (half to each side), but in order to achieve 360 degrees, a rotation of the whole torso as a unit might not be the ideal, in which case a smooth relocation of feet provides more stability to the performer, consequently allowing a smooth continuation of the mallet slide movement. When using rotation combined with foot relocation the ratio of the helix has to be designed so this movement does not imply the performer's foot touching the ground with less than, 1/8 ball (1/8 toe, ¼ foot),[1] since less foot contact with the ground is not likely to provide

[1] Guest, Hutchinson. 2005. *Labanotation, the system for analysing and recording movement.* Fourth edition. Routledge, Oxon, UK. p. 180.

stability to the torso and consequently to the arms holding the mallets. A zigzag glissando exercise exploring different angles has been thought of at this point.

The helix can also be considered externally, and in this case, several players can be added. This way of conceiving the helix involves walking around the helix and playing laterally when moving around, although this cannot be achieved at high speed since the feet are not stable on the ground while sliding the mallets, especially when a large sounding body for a possible lower range is considered. However, this layout can be used in addition to the previous and since more space is available for the sounding bodies in the outside of the helix, lower ranges could also be achieved within the same instrument by using the external layout as an variant or even as an extension. This idea applies directly to instruments requiring a sounding body per pitch, which excludes most winds (although a similar idea can be used for the layout used for the holes and the keys.

A3.3.1.1 The *spiral conic bellophone* (I_a)

The *spiral conic bellophone* is the result of placing a microdiscrete-sliding pitch (see Glossary) sequence of *conic bells* around the performer following a conical helix (Fig. A3.4). This makes an ideal instrument for the realisation of microdiscrete-sliding pitch with a high corporeal expression capability.

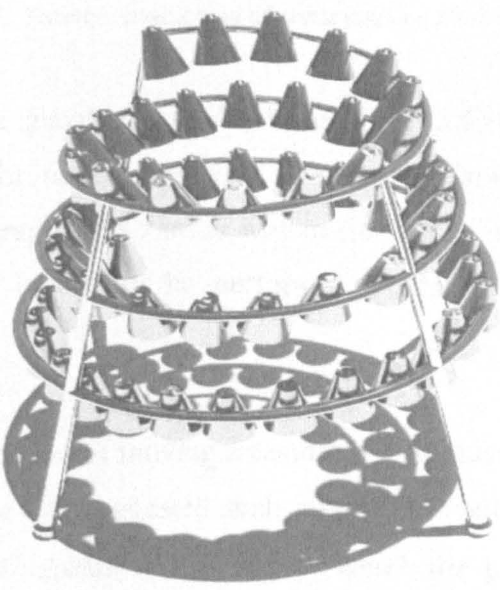

Fig. A3.4. Internal positioning of *conic bells* on a spiral frame.

The movements involved in zigzag pattern were considered during the development of this instrument group. The composition-pattern consists of microdiscrete-sliding pitch in ascending and descending order, starting with a trill, and following a zigzag pattern that starts with two notes and increases up to 16 notes, and then reducing amplitude and coming back to two notes and trill. This pattern can also be applied the other way around to move from 16 notes span to one note and then back to 16. The exercise is so simple that it was not documented as a compositional sketch, but only here as a guideline towards the designs of this group's instruments and specially the *spiral conic bellophone*.

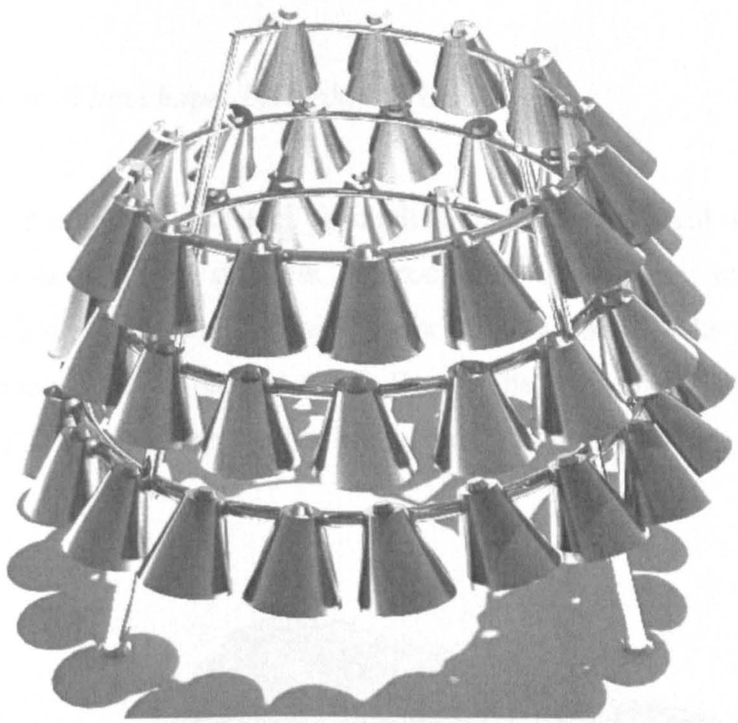

Fig. A3.5. External positioning of *conic bells* on a spiral frame.

The external layout of the *spiral conic bellophone* (Fig. A3.5) can take larger size bells, and comfortably allow for up to 4 players, who move around the instrument using welcoming group-choreography in a similar way to that which is done with Japanese *taiko* drums, and in this case involving the performer moving around the outside of the instrument.

This choreographed conception of moving around the instrument has awakened interest in a Japanese nursery school that suggested such instrument could be used for their yearly gymnastics festival (JP. *Undokkai* – 運動会), in which the group choreography as the main performance element could be used to play instruments this way, bringing more excitement to the performance. Promoting this idea at very early ages is very relevant since it generates a new taste for group corporeal expression in musical performance among youngsters, leading to more appreciation of such elements in the future contemporary music scene. There is no doubt that radical changes have to target kids, since they are the ones who will decide the fashions and interests to come. For this reason, this idea is utilised for several other projects, in order to allow for the development of kids' choreographed music ensembles in a near future, as an expansion of what is here postulated.

A3.3.1.2 The *cyclic-Whitechapel bellophone* (I_b)

The clarity of sound of the Whitechapel handbell (Fig. A3.7) combined with the curiosity to experience glissando with different microdiscrete-pitch steps in a mechanised instrument, led to a design placing a conical helix of Whitechapel bells around a conical frame with the rotating axis in parallel to the floor. The performer controls the rotation speed by means of a foot pedalling mechanism as shown in Fig. A3.6.

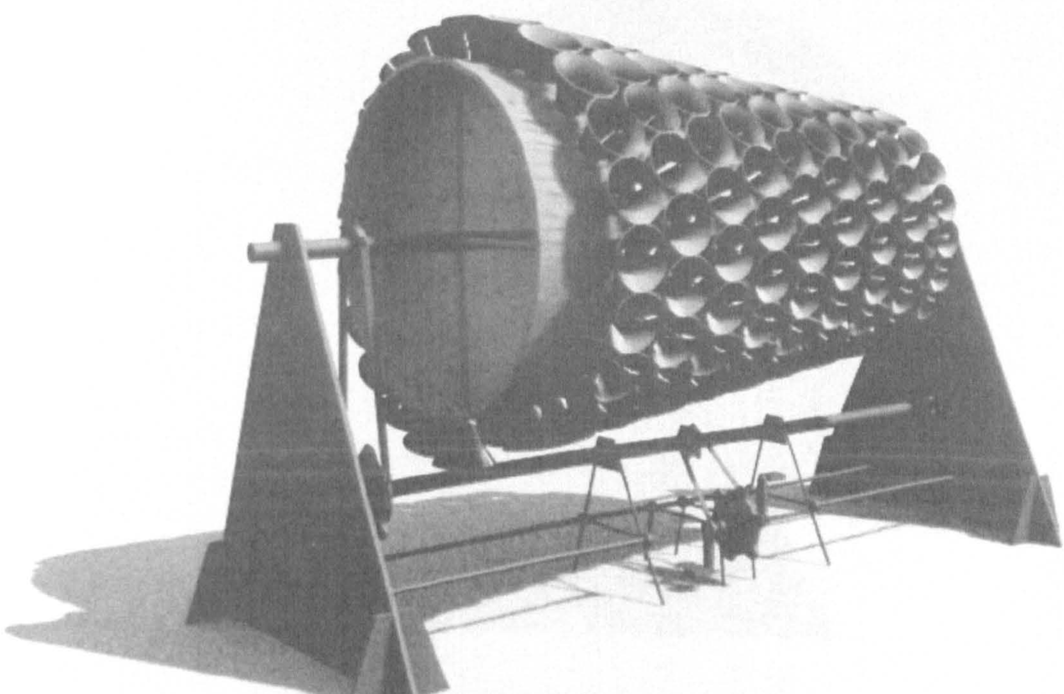

Fig. A3.6. *Cyclic-Whitechapel bellophone.*

The initiation of the rotation process could be aided with four levers placed around the large mouth of the conical frame so the player can use the left hand for sudden initiations of rotation, or even sudden stops, although a braking pedal can be incorporated to produce smooth decelerations and stops.

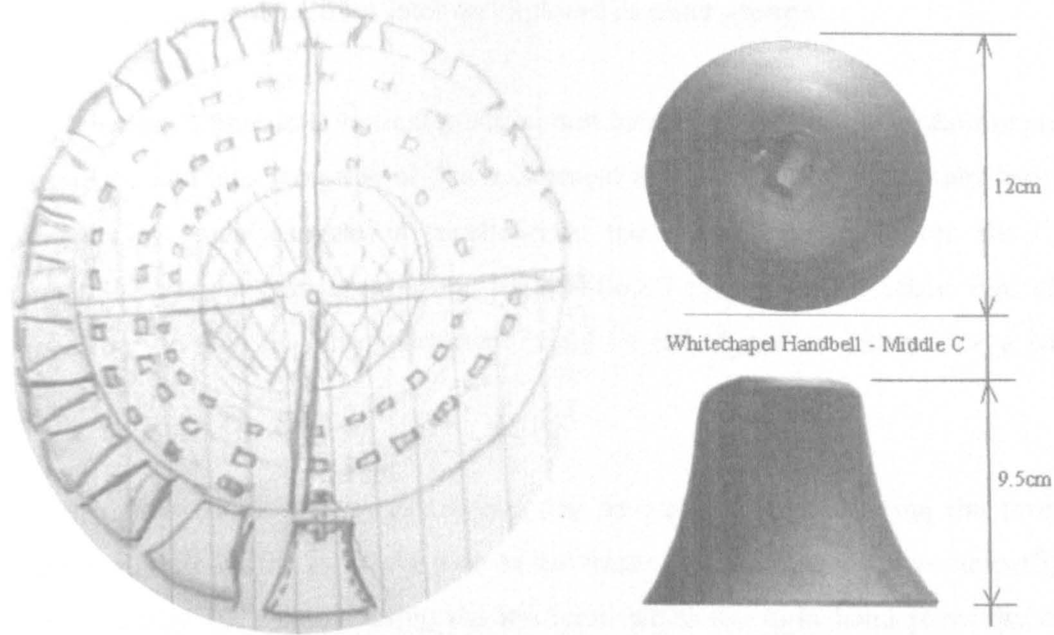

Fig. A3.7. *Cyclic-Whitechapel bellophone*'s inner view sketch and Whitechapel handbell.

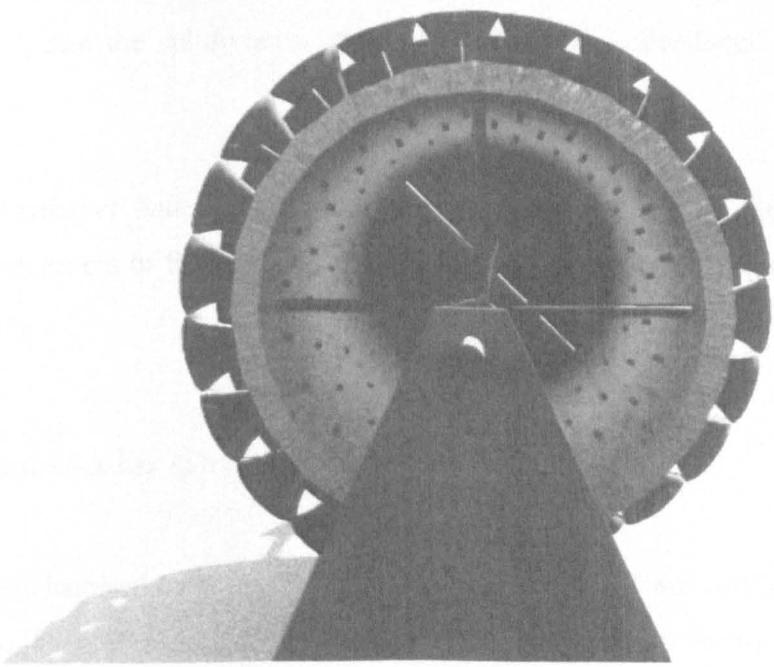

Fig. A3.8. *Cyclic-Whitechapel bellophone*'s inner view.

A wooden conical structure as a frame to support the bells would be ideal if carved in one piece, since this structure (in which all bells are fixed or screwed) effectively acts as a soundboard.

The concept of an instrument involving pedalling rotation and subsequently the rotation of a frame opens up new perspectives later on explored in other groups.

Placing the conical frame in a vertical position and having a few players pedalling around the instrument could be a variation of this instrument involving more players and therefore increasing the corporeal expression capability of the instrument. However, the *Cyclic Whitechapel bellophone* can incorporate an additional player at the other side of the instrument comfortably, and the instrument could be redesigned to incorporate a second pedal system.

The zigzag pattern proposed for this group can be easily achieved using the proposed levers that would go on the left-hand side of the frame. These levers allow the performer to suddenly change the rotation using the left hand while the right hand plays the zigzag pattern. This pattern can be done using two different chromatic steps on this instrument, the one used for the tuning of this instrument that follows the spiral pattern (around 100 notes per octave), and the subdivision of this tuning which is produced when choosing diagonal patterns.

The *cyclic Whitechapel bellophone* prototype suggested the use of diagonal patterns towards the achievement of faster glissando, which is used in succeeding prototypes of the *conic bellophone*.

A3.3.1.3 The *stand-a-key spiral-bass marimba* (I_c)

This instrument is inspired by Harry Partch's bass marimbas and was initially thought of as an ergonomic solution if a large set of these marimba keys was to be used. It consists of individual keys, named *stand-a-key* (Fig. A3.9), placed in a vertical position in parallel with the resonator and with a heavy weight at the bottom to stop the device from falling.

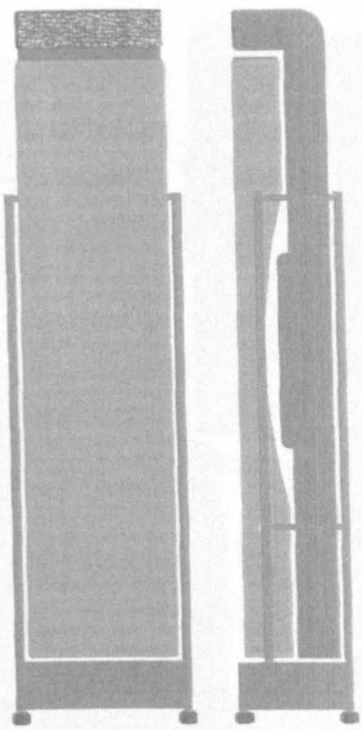

Fig. A3.9. *Stand-a-key*'s inner view and side view.

A concrete block, or a solid metal block, supports the metal structure holding the bars crossing the marimba bars inside the nodal area, and the resonator. The resonator is open at the top end. That ending section of the resonator is flexible, so the mouth's orientation can be adjusted 180°, although pointing to the striking side is the normal position (Fig. A3.9). If it points to the other side, and a sequence of *stand-a-key* is placed forming a spiral, with the striking area pointing inside the spiral, the sound of the resonators is projected outside the spiral towards the audience. In fact this inner layout of the *stand-a-key spiral bass marimba* is ideal if only one percussionist is available or simply if the glissandi are meant to be played fast. The inner layout though has a limited number of stand-a keys that it can use, since more than three *stand-a-key* in front of each other can make it difficult for the performer to hit the one farther away, which would be blocking the sound of the smaller ones closer to the performer. The outer layout of the *stand-a-key spiral bass marimba* has been represented approximately using a quartertones step sequence (Fig. A3.10). Eighthtones and sixteenthtones keys can be incorporated in this spiral layout by making a larger spiral and using up to three layers of *stand-a-key* in front of each other. This prototype could accommodate a largest bar of over 1.50 m, and ideally not any taller than the shoulders of the average player considered, so the top end of the bar can be comfortably reached.

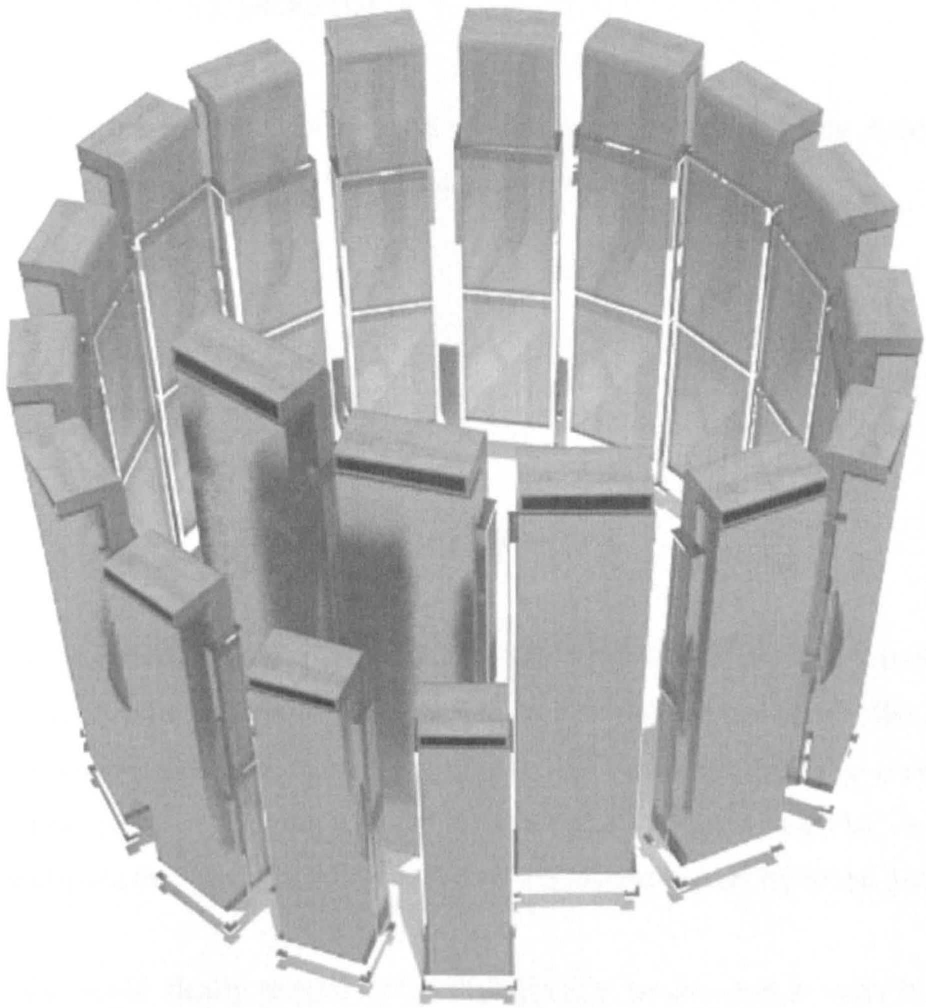

Fig. A3.10. *Stand-a-key spiral-bass marimba* (outer layout).

The zigzag exercises have to be achieved by sliding mallets and running around the instrument, and for this reason special mallets have to be tested, although padded gloves can also be employed. With several players around the instrument, parallel glissando can be easily achieved and choreographed at the same time. To get a louder sound doing glissando, striking techniques are advisable, which means that the tempo used to play the sequence (ascending or descending) cannot be fast, since the performer cannot be expected to keep a good balance while running at fast speeds around the instrument.

The independence of the *stand-a-key* unit has inspired other similar percussive units to follow, and specially the *16-stand conic bellophone*, while it also suggested the usage of an outer layout in the *spiral conic bellophone*.

A3.3.1.4 The *spiral t'rungophone* (I_d)

A *t'rung* is a Vietnamese tuned percussion instrument in which a frame holds a net supporting tuned sections of bamboo with a cut as indicated in Fig. A3.11.

Fig. A3.11. *T'rung*'s bamboo bar.

The *spiral t'rurungophone* employs the same key, and it has been conceived with the same frame as the *spiral conic bellophone* using the internal layout of the keys. The bamboo section's lower node is not held, allowing the bar to vibrate more while also producing a visual interaction between the player and the instrument. Considering that the player cannot be seen inside the spiral, this adds corporeal expression capability to the instrument.

An outer layout would ideally require the conical spiral to be inverted in order to prevent the stand bars getting in the way of the mallets when sliding around the layout. This layout also requires all the lower node of the bamboo keys to be tight with one string following the spiral so the bars do not rotate and hit each other. This layout increases corporeal expression and the amount of players that can be involved in a performance. If a wide ratio for the frame is considered, another frame with the inner layout can be placed inside too.

Other possibilities are using individual stands following a spiral-shaped sequence, or even a two cylindrical spirals (inner and outer) sharing the same stands, if both nodes of the *t'rung* key are held to avoid rotation and concussion between keys.

The inner layout (Fig. A3.12) has been adopted here for the comparative process. In this design each *t'rung* key resonates rotates around the node it hangs from when struck, unlike the bells of the main bellophone project. However, this inspired a succeeding bellophone prototype in which the stands that holds the *conic bells* are not fixed so they slightly shake when the bells are hit.

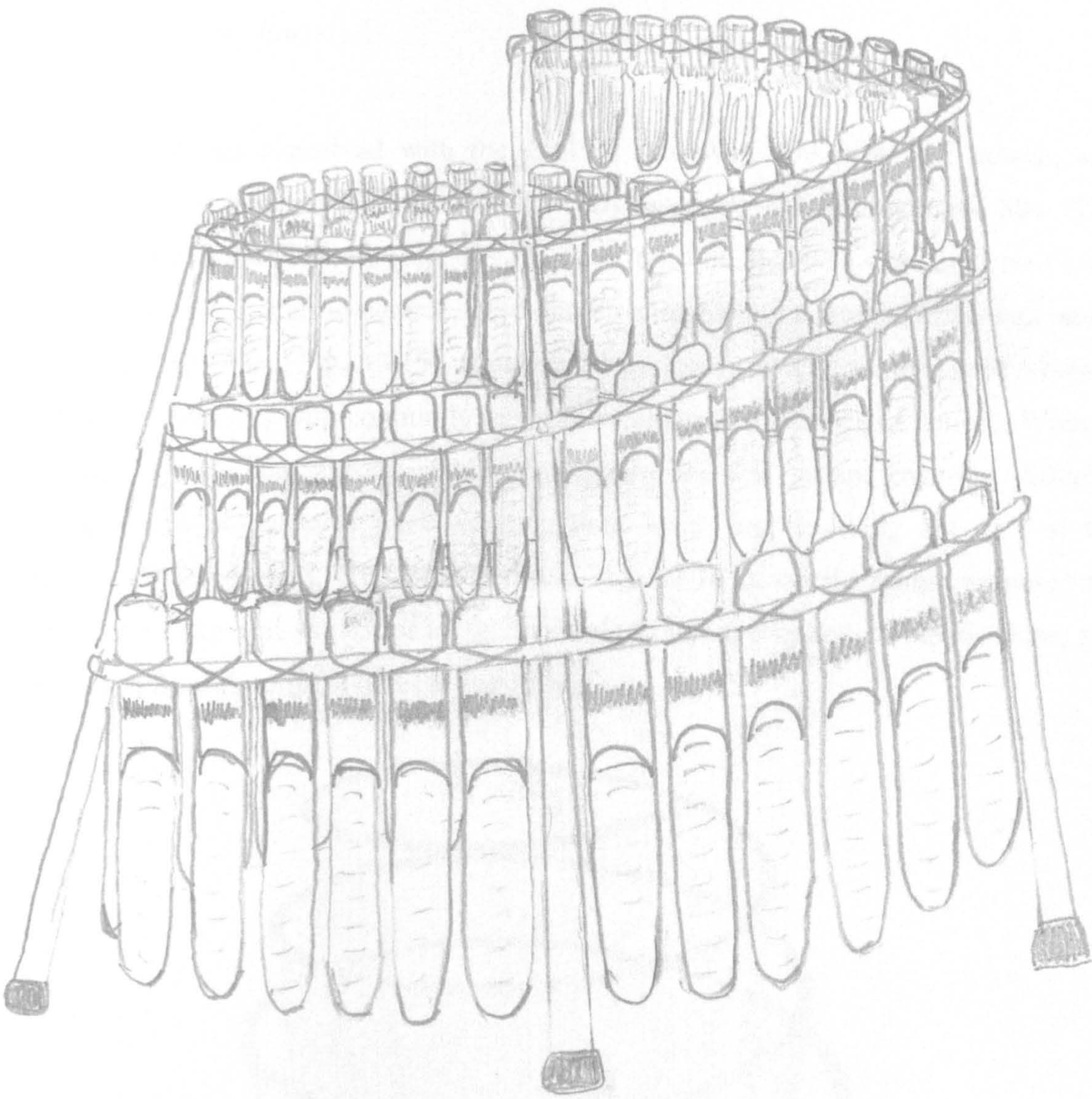

Fig. A3.12. *Spiral t'rungophone.*

This instrument is designed to use quartertones. With a smaller chromatic step (e.g. sixteenthtones), it could lose the crispness of the peculiar sliding sound quality expected. However, experimentation is required and if sixteenthtones, or eighthtones happened to be of interest.

The zigzag ascending and descending passages are easily achieve on this instrument with one hand while the other can be used to mute the required keys or at least stop them from moving if this gets in the way of the performer's movements.

A3.3.1.5 The *spiral harp* (I_e)

This instrument was conceived with the goal of achieving 400 notes per octave, and particularly the harmonic series contained between harmonic 400 and harmonic 800. The original idea was a fixed frame (Fig. A3.13) Later on, this idea was also conceived on a rotation system with pedals to control speed and direction, using a motor mechanism under the table (Fig. A3.14 and Fig. A3.15), allowing the performer to achieve the speed required to glide larger intervals with continuity or even using gradual changes of tempo. Without pedal-motor system, the zigzag exercises proposed for this group, covering different ranges, can still be achieved by combining both hands and covering one half of the instrument with each hand. The table in figure Fig. A3.16 shows the tuning proposed for this instrument, the cent values for all the intervals from the root and chromatic steps, and the deviation from the closest notes to the 12-et.

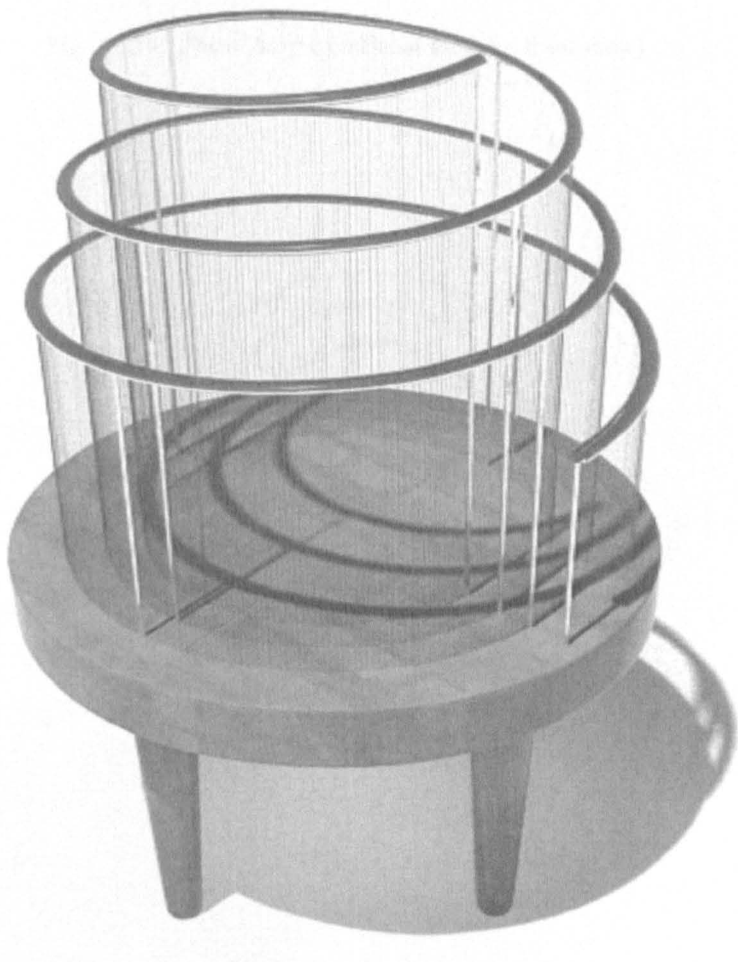

Fig. A3.13. *Spiral harp*'s (fixed model).

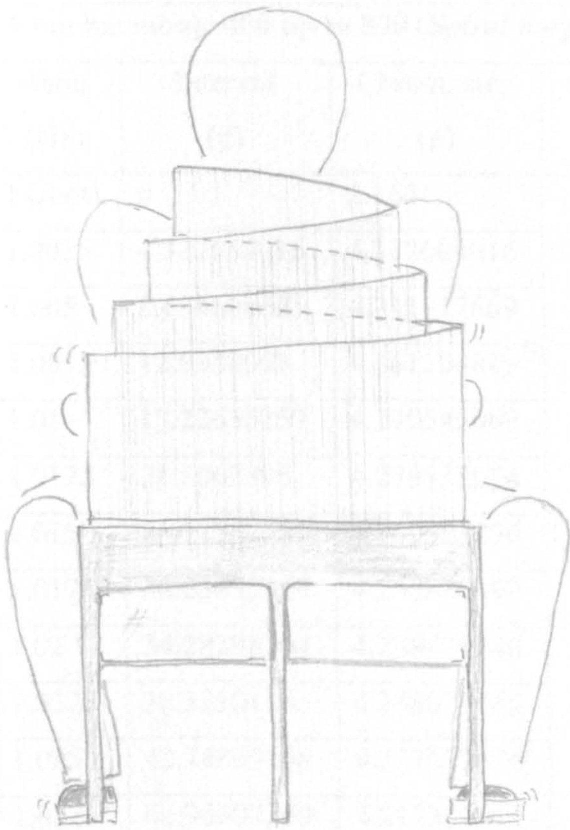

Fig. A3.14. *Spiral harp* (rotational model – front view).

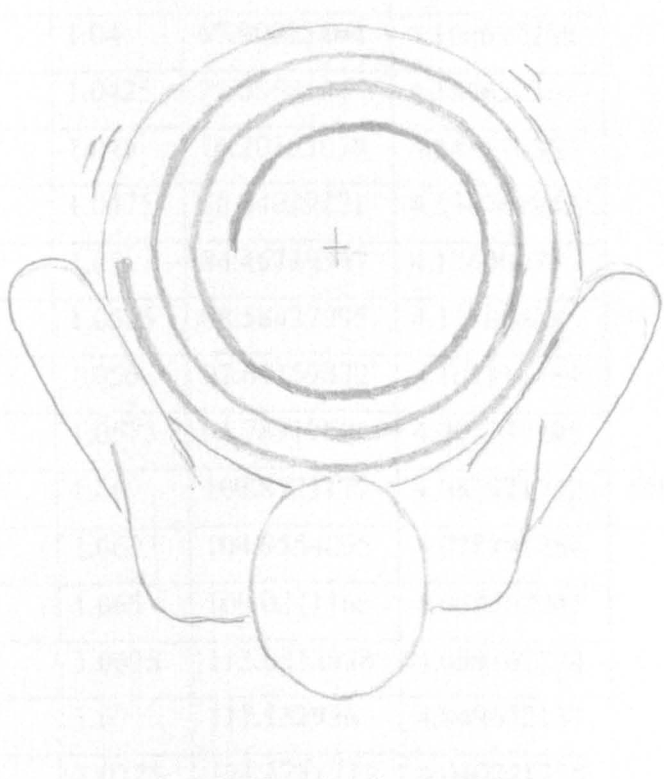

Fig. A3.15. *Spiral harp* (rotational model – top view).

Harmonic series from harmonic 400 up to 800 (*Spiral harp*'s tuning)					
String No.	Harmonic No.	Ratio (Hz)	Interval (¢)	Chrom. step (¢)	Cents deviation from 12-et
0	400	1 (root)	0	2.165	C
1	401	1.0025	4.322684016	4.322684016	
2	402	1.005	8.634601685	4.311917669	
3	403	1.0075	12.9358065	4.301204819	
4	404	1.01	**17.22635157**	4.290545069	
5	405	1.0125	21.5062896	4.279938024	
6	406	1.015	25.77567289	4.269383296	
7	407	1.0175	30.03455339	4.258880497	
8	408	1.02	**34.28298264**	4.248429246	
9	409	1.0225	38.5210118	4.238029164	
10	410	1.025	42.74869168	4.227679876	
11	411	1.0275	46.96607269	4.217381011	
12	412	1.03	**51.17320489**	4.207132202	
13	413	1.0325	55.37013797	4.196933083	
14	414	1.035	59.55692127	4.186783296	
15	415	1.0375	63.73360375	4.176682482	
16	416	1.04	**67.90023404**	4.166630288	
17	417	1.0425	72.0568604	4.156626364	
18	418	1.045	76.20353077	4.146670363	
19	419	1.0475	80.34029271	4.136761942	
20	420	1.05	**84.46719347**	4.12690076	
21	421	1.0525	88.58427995	4.11708648	
22	422	1.055	92.69159872	4.107318769	
23	423	1.0575	96.78919601	4.097597295	
24	424	1.06	**100.8771177**	4.087921732	C#+0.87711775
25	425	1.0625	104.9554095	4.078291754	
26	426	1.065	109.0241165	4.068707041	
27	427	1.0675	113.0832838	4.059167274	
28	428	1.07	**117.132956**	4.049672137	
29	429	1.0725	121.1731773	4.040221318	

30	430	1.075	125.2039918	4.030814508	
31	431	1.0775	129.2254432	4.0214514	
32	432	1.08	**133.2375749**	4.012131689	
33	433	1.0825	137.2404299	4.002855076	
34	434	1.085	141.2340512	3.993621261	
35	435	1.0875	145.2184812	3.98442995	
36	436	1.09	**149.193762**	3.975280849	
37	437	1.0925	153.1599357	3.966173668	
38	438	1.095	157.1170438	3.957108121	
39	439	1.0975	161.0651277	3.948083921	
40	440	1.1	**165.0042285**	3.939100787	
41	441	1.1025	168.9343869	3.930158439	
42	442	1.105	172.8556435	3.921256601	
43	443	1.1075	176.7680385	3.912394996	
44	444	1.11	**180.6716119**	3.903573354	
45	445	1.1125	184.5664033	3.894791404	
46	446	1.115	188.4524522	3.88604888	
47	447	1.1175	192.3297977	3.877345516	
48	448	1.12	**196.1984787**	3.868681049	
49	449	1.1225	200.058534	3.86005522	D+0.05853396
50	450	1.125	203.9100017	3.851467771	
51	451	1.1275	207.7529202	3.842918446	
52	452	1.13	**211.5873272**	3.834406992	
53	453	1.1325	215.4132603	3.825933157	
54	454	1.135	219.230757	3.817496694	
55	455	1.1375	223.0398544	3.809097354	
56	456	1.14	**226.8405893**	3.800734894	
57	457	1.1425	230.6329983	3.792409072	
58	458	1.145	234.417118	3.784119647	
59	459	1.1475	238.1929844	3.77586638	
60	460	1.15	**241.9606334**	3.767649037	
61	461	1.1525	245.7201008	3.759467382	
62	462	1.155	249.471422	3.751321184	

63	463	1.1575	253.2146322	3.743210213	
64	464	1.16	**256.9497664**	3.735134241	
65	465	1.1625	260.6768595	3.727093041	
66	466	1.165	264.3959459	3.719086391	
67	467	1.1675	268.1070599	3.711114066	
68	468	1.17	**271.8102358**	3.703175848	
69	469	1.1725	275.5055073	3.695271518	
70	470	1.175	279.1929081	3.68740086	
71	471	1.1775	282.8724718	3.679563657	
72	472	1.18	**286.5442315**	3.671759699	
73	473	1.1825	290.2082203	3.663988773	
74	474	1.185	293.8644709	3.656250671	
75	475	1.1875	297.5130161	3.648545184	
76	476	1.19	**301.1538882**	3.640872108	D#+1.15388824
77	477	1.1925	304.7871195	3.633231237	
78	478	1.195	308.4127418	3.62562237	
79	479	1.1975	312.0307872	3.618045307	
80	480	1.2	**315.641287**	3.610499847	
81	481	1.2025	319.2442728	3.602985794	
82	482	1.205	322.8397757	3.595502952	
83	483	1.2075	326.4278269	3.588051127	
84	484	1.21	**330.008457**	3.580630127	
85	485	1.2125	333.5816968	3.57323976	
86	486	1.215	337.1475766	3.565879838	
87	487	1.2175	340.7061268	3.558550172	
88	488	1.22	**344.2573773**	3.551250577	
89	489	1.2225	347.8013582	3.543980867	
90	490	1.225	351.3380991	3.53674086	
91	491	1.2275	354.8676294	3.529530375	
92	492	1.23	**358.3899787**	3.522349229	
93	493	1.2325	361.9051759	3.515197246	
94	494	1.235	365.4132502	3.508074248	
95	495	1.2375	368.9142302	3.500980059	

96	496	1.24	**372.4081447**	3.493914504	
97	497	1.2425	375.8950221	3.48687741	
98	498	1.245	379.3748908	3.479868607	
99	499	1.2475	382.8477787	3.472887923	
100	500	1.25	**386.3137139**	3.46593519	
101	501	1.2525	389.7727241	3.45901024	
102	502	1.255	393.224837	3.452112907	
103	503	1.2575	396.67008	3.445243026	
104	504	1.26	**400.1084805**	3.438400433	E+0.10848047
105	505	1.2625	403.5400654	3.431584967	
106	506	1.265	406.9648619	3.424796466	
107	507	1.2675	410.3828967	3.418034771	
108	508	1.27	**413.7941964**	3.411299723	
109	509	1.2725	417.1987876	3.404591164	
110	510	1.275	420.5966965	3.39790894	
111	511	1.2775	423.9879494	3.391252895	
112	512	1.28	**427.3725723**	3.384622875	
113	513	1.2825	430.750591	3.378018728	
114	514	1.285	434.1220313	3.371440304	
115	515	1.2875	437.4869188	3.364887452	
116	516	1.29	**440.8452788**	3.358360023	
117	517	1.2925	444.1971366	3.35185787	
118	518	1.295	447.5425175	3.345380846	
119	519	1.2975	450.8814463	3.338928806	
120	520	1.3	**454.2139479**	3.332501605	
121	521	1.3025	457.540047	3.3260991	
122	522	1.305	460.8597682	3.31972115	
123	523	1.3075	464.1731358	3.313367612	
124	524	1.31	**467.4801741**	3.307038349	
125	525	1.3125	470.7809073	3.300733219	
126	526	1.315	474.0753594	3.294452087	
127	527	1.3175	477.3635542	3.288194814	
128	528	1.32	**480.6455155**	3.281961265	

129	529	1.3225	483.9212668	3.275751307	
130	530	1.325	487.1908316	3.269564804	
131	531	1.3275	490.4542332	3.263401624	
132	532	1.33	**493.7114949**	3.257261636	
133	533	1.3325	496.9626396	3.25114471	
134	534	1.335	500.2076903	3.245050714	F+0.207690295
135	535	1.3375	503.4466698	3.238979521	
136	536	1.34	**506.6796008**	3.232931003	
137	537	1.3425	509.9065059	3.226905033	
138	538	1.345	513.1274073	3.220901485	
139	539	1.3475	516.3423276	3.214920235	
140	540	1.35	**519.5512887**	3.208961158	
141	541	1.3525	522.7543129	3.203024131	
142	542	1.355	525.9514219	3.197109032	
143	543	1.3575	529.1426376	3.191215741	
144	544	1.36	**532.3279818**	3.185344135	
145	545	1.3625	535.5074759	3.179494097	
146	546	1.365	538.6811414	3.173665507	
147	547	1.3675	541.8489996	3.167858247	
148	548	1.37	**545.0110718**	3.162072202	
149	549	1.3725	548.1673791	3.156307254	
150	550	1.375	551.3179424	3.150563288	
151	551	1.3775	554.4627826	3.144840191	
152	552	1.38	**557.6019204**	3.139137848	
153	553	1.3825	560.7353766	3.133456148	
154	554	1.385	563.8631715	3.127794977	
155	555	1.3875	566.9853258	3.122154226	
156	556	1.39	**570.1018595**	3.116533783	
157	557	1.3925	573.2127931	3.11093354	
158	558	1.395	576.3181465	3.105353387	
159	559	1.3975	579.4179397	3.099793217	
160	560	1.4	**582.5121926**	3.094252922	
161	561	1.4025	585.600925	3.088732397	

162	562	1.405	588.6841565	3.083231535	
163	563	1.4075	591.7619068	3.077750231	
164	564	1.41	**594.8341951**	3.072288382	
165	565	1.4125	597.901041	3.066845885	
166	566	1.415	600.9624637	3.061422635	F#+0.96246367
167	567	1.4175	604.0184822	3.056018532	
168	568	1.42	**607.0691157**	3.050633475	
169	569	1.4225	610.114383	3.045267362	
170	570	1.425	613.1543031	3.039920095	
171	571	1.4275	616.1888947	3.034591573	
172	572	1.43	**619.2181764**	3.029281699	
173	573	1.4325	622.2421668	3.023990374	
174	574	1.435	625.2608843	3.018717503	
175	575	1.4375	628.2743473	3.013462987	
176	576	1.44	**631.282574**	3.008226733	
177	577	1.4425	634.2855826	3.003008644	
178	578	1.445	637.2833913	2.997808626	
179	579	1.4475	640.2760179	2.992626586	
180	580	1.45	**643.2634803**	2.987462431	
181	581	1.4525	646.2457964	2.982316068	
182	582	1.455	649.2229838	2.977187405	
183	583	1.4575	652.1950601	2.972076351	
184	584	1.46	**655.1620429**	2.966982815	
185	585	1.4625	658.1239496	2.961906709	
186	586	1.465	661.0807976	2.956847942	
187	587	1.4675	664.032604	2.951806425	
188	588	1.47	**666.9793861**	2.946782072	
189	589	1.4725	669.9211609	2.941774793	
190	590	1.475	672.8579454	2.936784502	
191	591	1.4775	675.7897565	2.931811114	
192	592	1.48	**678.716611**	2.926854542	
193	593	1.4825	681.6385257	2.9219147	
194	594	1.485	684.5555172	2.916991506	

195	595	1.4875	687.4676021	2.912084873	
196	596	1.49	**690.3747968**	2.90719472	
197	597	1.4925	693.2771178	2.902320963	
198	598	1.495	696.1745813	2.89746352	
199	599	1.4975	699.0672036	2.892622309	G-0.9327964
200	600	1.5	**701.9550009**	2.887797249	
201	601	1.5025	704.8379891	2.882988258	
202	602	1.505	707.7161844	2.878195258	
203	603	1.5075	710.5896026	2.873418168	
204	604	1.51	**713.4582595**	2.86865691	
205	605	1.5125	716.3221709	2.863911404	
206	606	1.515	719.1813524	2.859181573	
207	607	1.5175	722.0358198	2.854467339	
208	608	1.52	**724.8855884**	2.849768625	
209	609	1.5225	727.7306738	2.845085355	
210	610	1.525	730.5710912	2.840417453	
211	611	1.5275	733.4068561	2.835764842	
212	612	1.53	**736.2379835**	2.831127449	
213	613	1.5325	739.0644887	2.826505198	
214	614	1.535	741.8863867	2.821898015	
215	615	1.5375	744.7036925	2.817305828	
216	616	1.54	**747.5164211**	2.812728562	
217	617	1.5425	750.3245872	2.808166145	
218	618	1.545	753.1282058	2.803618506	
219	619	1.5475	755.9272913	2.799085572	
220	620	1.55	**758.7218586**	2.794567272	
221	621	1.5525	761.5119221	2.790063535	
222	622	1.555	764.2974964	2.785574292	
223	623	1.5575	767.0785959	2.781099472	
224	624	1.56	**769.8552349**	2.776639006	
225	625	1.5625	772.6274277	2.772192825	
226	626	1.565	775.3951886	2.76776086	
227	627	1.5675	778.1585316	2.763343043	

228	628	1.57	**780.9174709**	2.758939308	
229	629	1.5725	783.6720205	2.754549585	
230	630	1.575	786.4221943	2.75017381	
231	631	1.5775	789.1680062	2.745811914	
232	632	1.58	**791.9094701**	2.741463833	
233	633	1.5825	794.6465996	2.737129501	
234	634	1.585	797.3794084	2.732808853	
235	635	1.5875	800.1079103	2.728501824	G#+0.10791026
236	636	1.59	**802.8321186**	2.72420835	
237	637	1.5925	805.552047	2.719928366	
238	638	1.595	808.2677088	2.71566181	
239	639	1.5975	810.9791174	2.711408619	
240	640	1.6	**813.6862861**	2.707168728	
241	641	1.6025	816.3892282	2.702942078	
242	642	1.605	819.0879568	2.698728604	
243	643	1.6075	821.7824851	2.694528247	
244	644	1.61	**824.472826**	2.690340944	
245	645	1.6125	827.1589926	2.686166635	
246	646	1.615	829.8409979	2.68200526	
247	647	1.6175	832.5188547	2.677856758	
248	648	1.62	**835.1925757**	2.673721071	
249	649	1.6225	837.8621739	2.669598137	
250	650	1.625	840.5276618	2.6654879	
251	651	1.6275	843.1890521	2.6613903	
252	652	1.63	**845.8463573**	2.657305279	
253	653	1.6325	848.4995901	2.653232778	
254	654	1.635	851.1487629	2.649172742	
255	655	1.6375	853.793888	2.645125112	
256	656	1.64	**856.4349778**	2.641089832	
257	657	1.6425	859.0720447	2.637066845	
258	658	1.645	861.7051008	2.633056095	
259	659	1.6475	864.3341583	2.629057527	
260	660	1.65	**866.9592294**	2.625071085	

261	661	1.6525	869.5803261	2.621096714	
262	662	1.655	872.1974604	2.617134359	
263	663	1.6575	874.8106444	2.613183966	
264	664	1.66	**877.4198899**	2.609245481	
265	665	1.6625	880.0252087	2.60531885	
266	666	1.665	882.6266128	2.601404019	
267	667	1.6675	885.2241137	2.597500936	
268	668	1.67	**887.8177232**	2.593609547	
269	669	1.6725	890.407453	2.589729801	
270	670	1.675	892.9933147	2.585861644	
271	671	1.6775	895.5753197	2.582005026	
272	672	1.68	**898.1534796**	2.578159894	
273	673	1.6825	900.7278058	2.574326198	A+0.727805803
274	674	1.685	903.2983097	2.570503886	
275	675	1.6875	905.8650026	2.566692908	
276	676	1.69	**908.4278958**	2.562893213	
277	677	1.6925	910.9870006	2.559104751	
278	678	1.695	913.542328	2.555327474	
279	679	1.6975	916.0938894	2.55156133	
280	680	1.7	**918.6416956**	2.547806272	
281	681	1.7025	921.1857579	2.544062249	
282	682	1.705	923.7260871	2.540329215	
283	683	1.7075	926.2626942	2.536607119	
284	684	1.71	**928.7955901**	2.532895915	
285	685	1.7125	931.3247857	2.529195554	
286	686	1.715	933.8502917	2.52550599	
287	687	1.7175	936.3721189	2.521827174	
288	688	1.72	**938.8902779**	2.518159061	
289	689	1.7225	941.4047795	2.514501603	
290	690	1.725	943.9156343	2.510854753	
291	691	1.7275	946.4228527	2.507218467	
292	692	1.73	**948.9264454**	2.503592698	
293	693	1.7325	951.4264228	2.499977401	

294	694	1.735	953.9227954	2.496372529	
295	695	1.7375	956.4155734	2.492778039	
296	696	1.74	**958.9047673**	2.489193885	
297	697	1.7425	961.3903873	2.485620024	
298	698	1.745	963.8724437	2.482056409	
299	699	1.7475	966.3509467	2.478502999	
300	700	1.75	**968.8259065**	2.474959748	
301	701	1.7525	971.2973331	2.471426614	
302	702	1.755	973.7652366	2.467903553	
303	703	1.7575	976.2296272	2.464390522	
304	704	1.76	**978.6905146**	2.460887478	
305	705	1.7625	981.147909	2.457394379	
306	706	1.765	983.6018202	2.453911182	
307	707	1.7675	986.052258	2.450437846	
308	708	1.77	**988.4992324**	2.446974328	
309	709	1.7725	990.942753	2.443520588	
310	710	1.775	993.3828295	2.440076583	
311	711	1.7775	995.8194718	2.436642273	
312	712	1.78	**998.2526894**	2.433217616	
313	713	1.7825	1000.682492	2.429802573	A#+0.682492
314	714	1.785	1003.108889	2.426397102	
315	715	1.7875	1005.53189	2.423001164	
316	716	1.79	**1007.951505**	2.419614718	
317	717	1.7925	1010.367743	2.416237725	
318	718	1.795	1012.780613	2.412870145	
319	719	1.7975	1015.190125	2.409511939	
320	720	1.8	**1017.596288**	2.406163068	
321	721	1.8025	1019.999111	2.402823493	
322	722	1.805	1022.398605	2.399493176	
323	723	1.8075	1024.794777	2.396172077	
324	724	1.81	**1027.187637**	2.392860159	
325	725	1.8125	1029.577194	2.389557383	
326	726	1.815	1031.963458	2.386263712	

327	727	1.8175	1034.346437	2.382979109	
328	728	1.82	**1036.726141**	2.379703535	
329	729	1.8225	1039.102577	2.376436954	
330	730	1.825	1041.475757	2.373179329	
331	731	1.8275	1043.845687	2.369930622	
332	732	1.83	**1046.212378**	2.366690798	
333	733	1.8325	1048.575838	2.36345982	
334	734	1.835	1050.936076	2.360237651	
335	735	1.8375	1053.2931	2.357024257	
336	736	1.84	**1055.64692**	2.3538196	
337	737	1.8425	1057.997543	2.350623646	
338	738	1.845	1060.34498	2.347436358	
339	739	1.8475	1062.689237	2.344257703	
340	740	1.85	**1065.030325**	2.341087644	
341	741	1.8525	1067.368251	2.337926147	
342	742	1.855	1069.703024	2.334773178	
343	743	1.8575	1072.034653	2.331628701	
344	744	1.86	**1074.363146**	2.328492683	
345	745	1.8625	1076.688511	2.32536509	
346	746	1.865	1079.010757	2.322245887	
347	747	1.8675	1081.329892	2.319135041	
348	748	1.87	**1083.645924**	2.316032518	
349	749	1.8725	1085.958862	2.312938285	
350	750	1.875	1088.268715	2.309852309	
351	751	1.8775	1090.575489	2.306774557	
352	752	1.88	**1092.879194**	2.303704996	
353	753	1.8825	1095.179838	2.300643593	
354	754	1.885	1097.477428	2.297590316	
355	755	1.8875	1099.771973	2.294545133	B-0.228026675
356	756	1.89	**1102.063481**	2.29150801	
357	757	1.8925	1104.35196	2.288478918	
358	758	1.895	1106.637418	2.285457822	
359	759	1.8975	1108.919863	2.282444693	

360	760	1.9	**1111.199302**	2.279439499	
361	761	1.9025	1113.475744	2.276442207	
362	762	1.905	1115.749197	2.273452788	
363	763	1.9075	1118.019668	2.270471209	
364	764	1.91	**1120.287166**	2.267497441	
365	765	1.9125	1122.551697	2.264531453	
366	766	1.915	1124.813271	2.261573214	
367	767	1.9175	1127.071893	2.258622694	
368	768	1.92	**1129.327573**	2.255679862	
369	769	1.9225	1131.580318	2.252744689	
370	770	1.925	1133.830135	2.249817145	
371	771	1.9275	1136.077032	2.246897199	
372	772	1.93	**1138.321017**	2.243984824	
373	773	1.9325	1140.562097	2.241079988	
374	774	1.935	1142.80028	2.238182663	
375	775	1.9375	1145.035572	2.235292821	
376	776	1.94	**1147.267983**	2.232410431	
377	777	1.9425	1149.497518	2.229535465	
378	778	1.945	1151.724186	2.226667894	
379	779	1.9475	1153.947994	2.223807691	
380	780	1.95	**1156.168949**	2.220954826	
381	781	1.9525	1158.387058	2.218109271	
382	782	1.955	1160.602329	2.215270998	
383	783	1.9575	1162.814769	2.21243998	
384	784	1.96	**1165.024385**	2.209616189	
385	785	1.9625	1167.231185	2.206799597	
386	786	1.965	1169.435175	2.203990176	
387	787	1.9675	1171.636363	2.201187899	
388	788	1.97	**1173.834756**	2.198392739	
389	789	1.9725	1176.03036	2.195604668	
390	790	1.975	1178.223184	2.192823661	
391	791	1.9775	1180.413234	2.19004969	
392	792	1.98	**1182.600516**	2.187282728	

393	793	1.9825	1184.785039	2.184522749	
394	794	1.985	1186.966809	2.181769727	
395	795	1.9875	1189.145832	2.179023635	
396	796	1.99	**1191.322117**	2.176284446	
397	797	1.9925	1193.495669	2.173552136	
398	798	1.995	1195.666496	2.170826678	
399	799	1.9975	1197.834604	2.168108047	
400	800	2	**1200**	2.165396216	C

Fig. A3.16. Harmonic series from harmonic 400 up to harmonic 800 (the string values of the *spiral harp*).

The idea behind devising this tuning (in parallel with a gliding harp) was to use a continuous section of the harmonic series containing very close approximations to the 12-et intervals, and chromatic steps small enough to simulate tones gliding at very low speed.[2] The interval chosen is the octave between harmonic 400 and harmonic 800. The harmonic 400, located in the 8th octave of the series, is taken as the root for this system (in C), and harmonic 800 in the 9th octave, is the octave where the pattern ends. A larger version of this instrument is postulated later on covering several octaves, the *mechanic-spiral-rotary harp* (XI_e), and in this case the continuity problem is discussed in more detail with one hand on the tuning theory and one hand on the design.

A tuning mechanism fits inside the metal spiral frame to protect the system from getting hit while playing and also to provide a smooth ending to ease the performer's hand movements.

The tuning here, devised in parallel with the instrument, brought back a question for the *spiral conic bellophone* design. Would the use of the harmonic series enhance the timbre of 96 or even a hundred *conic bells*? When using a system from harmonic 100 to harmonic 200 (used by Carrillo's followers, and intervals indicated with bold font in chart Fig. A3.16), the difference from the 96-et was difficult to notice with a retuned sampled version of the original 96 bells played with a MIDI keyboard. Therefore, from this point, it was not considered suitable to use the irregular steps from the harmonic and subharmonic series (as in the case of Partch 43-note just intonation system) to target beat-less intervals, since the timbre of the *conic bells* was proving to be of complex harmonic structure, while some

[2] This allows the rotating version of the instrument to cover a wide range of gliding speeds and dynamics, and what is most important is that when the slow glide is targeted, the strings are not plucked at low speed, which would not allow a smooth pitch-slide simulation (since the attack of the notes would not be masked).

of the irregularities of the metal and construction methods would also make the bell beat within itself. However, the functionality of providing a reference pitch to other instruments of simple harmonic structure can still be provided using 96-et for the instruments to fine tune to the beat-less adjustments.

None of the *spiral harp* models proposed ease the locating of specific strings, and for this reason strings could be coloured and marks placed on the frame. This need to develop an instrument that makes it easy to play specific notes using this tuning is what later on led to the upgrading the *220-bowlophone* (P85 – X_d) into a mechanised *440-stand bowlophone* (P99 – XI_i),[3] in which microtonal and sliding capabilities are fully achieved.

A3.3.1.6 The *spiral waterslapophone* (or *splashophone*) (I_f)

As our bodies are 70% water, it is difficult to escape from sounds produced by liquids in a daily life, regardless of what we are surrounded by. However, there are very few designs of pitched instruments that use liquids as the main vibrating body, and this is due to the fact that liquids can easily evaporate and change pitch, plus they rarely produce a clear tone.

The *waterslap* is a tuned plosive unit that employs water and air as vibrating bodies. The plosive sound is produced by the concussion of a cork convex cavity against water in a similar way that we can slap the water surface in a container with a convex-shaped hand.[4] The plosive action is initiated by pressing the tapping tongue attached on top of the convex cork cavity (see the tapping tongue and internal mechanism in figure Fig. A3.17). Since the pitch is not very clear, it can be reinforced, activating three other sounds (or a combination of them) by setting prior to playing (see Fig. A3.18, Fig. A3.19 and Fig. A3.20 explaining these additional sounds independently). This is done using two valves (bubbling valve and whistle valve), and removing the water whistle lid and fitting a water whistle (Fig. A3.17). Two of these additional sounds are produced by manipulating the air that has been compressed inside a funnel-shaped hole in the centre of the cork cavity. For the other additional pitched sound, a change of water level in the contiguous chamber,[5]

[3] A representation of the 440-bowlophone covering 400 bells is available at the end of this section.
[4] Which is why this unit was initially named *waterslap*.
[5] This air chamber is only created when pressing the tongue, and consequently dividing the inner space into two different ones, the cork cavity and the space behind the cork, which is also communicated with and upper isolated area.

induced by the main plosive action, is employed to recreate the whistling-water-jar effect of pre-Columbian double-chambered whistling water ceramic vessels.

If none of the additional sounds are set, a plosive sound with acute decay is produced by slapping and holding the tongue. Staccato tapping produces an overall sound with more of a splashing quality than plosive and a consequently almost indefinite pitch. Legato slapping action produces a balance between the splashing and the plosive actions.

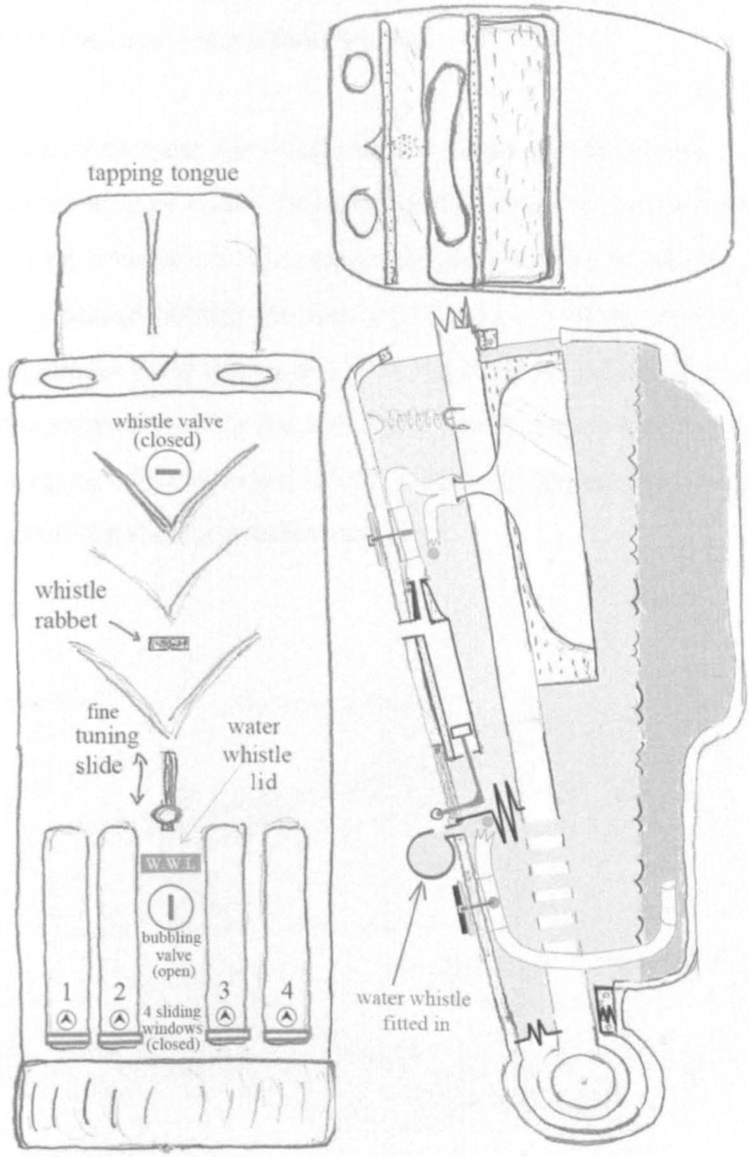

Fig. A3.17. *Waterslap* (top view, front view, and side cut view).

Whether the two sounds that manipulate the compressed air through tubes are used or not, there is an option to open four sliding windows (Fig. A3.17) which brings out of the *waterslap* the internal splashing sounds produced straight after the plosive action. This sound is not pitched, but it can be considered a regulated tone colouring effect that can be indicated with sliding percentages (for example: sliding windows opened a 20%).

Now let us explain first the two additional pitched sounds that make use of the compressed air inside the convex cork cavity that is slapped against the water. This air is conducted through a tube that is bifurcated as soon as it reaches the end of the funnel-shaped area (Fig. A3.18). One of the tubes goes into a small wooden whistle, and the other inside the shallow water area in the back inner vessel section.

When the whistle valve is open, the small size wooden whistle produces a pitched sound several octaves above the main plosive sound, reinforcing in this way its weak pitch clarity when functional. The whistle's pitch can be adjusted to the closest octave with a fine-tuning sliding device placed outside the unit. Stretched or compressed octaves can also be employed with adjustment prior to playing. This process is explained in figure Fig. A3.18 through stages, in combination with the splashing sound, which also is heard if the sliding windows are kept open. The intensity of the splashing sound that is going to be heard depends on how much the sliding windows are open.

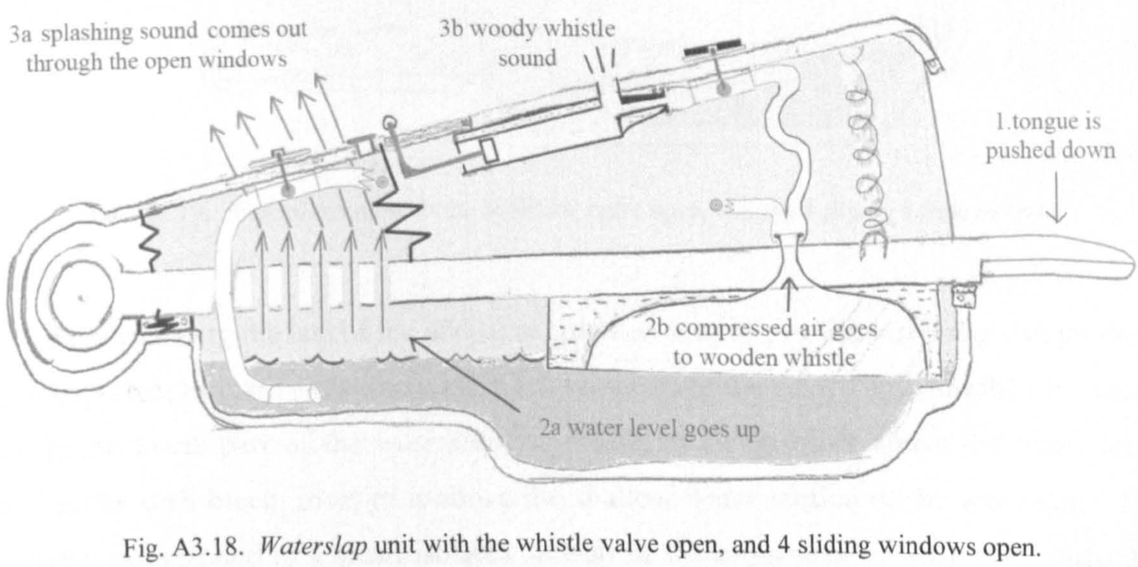

Fig. A3.18. *Waterslap* unit with the whistle valve open, and 4 sliding windows open.

Each conduct has a regulating valve that can either shut it or adjust airflow, so a slight timbre adjustment can be done before playing. For both conducts an elastic plastic tube section can be placed before the regulating valve to reduce the sharpness of the attack, and elongate the sound of the whistle.

When the bubbling valve is open, the air goes inside the rear shallow water area, producing bubbles. These bubbles are splashed by water waves created by the plosive action. The bubbles provide a slight pitched quality, which is distorted by the waves. *Waterslaps* are graded in size, and each size is designed to contain a specific amount of water in a horizontal position.[6] The pitch produced by the bubbles is not very clear and the waves produce oscillations of this already weak pitch, but these elements are contributions towards the beauty of the overall tone colour produced, so here the composer can choose choices concerning pitch clarity and timbre. This process is explained in figure Fig. A3.19 through stages, in combination with the splashing sound, which also is heard. The sliding windows have to be left open to hear the sound, and they can be used to regulate it.

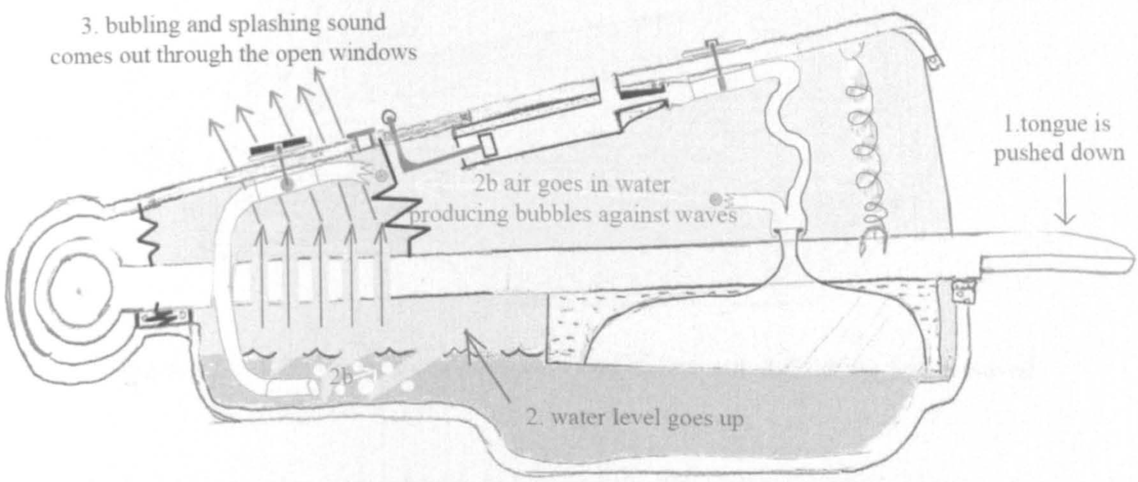

Fig. A3.19. *Waterslap* unit with the bubbling valve open, and the 4 sliding windows open.

Before introducing the last of the additional pitched sounds that the *waterslap* can produce, it is important to clarify that the cork block (containing the cavity underneath) fits exactly inside the lower part of the *waterslap*,[7] to create an air chamber above the water level, behind the cork block, most of it above the shallow water section of the *waterslap*. This chamber is extended to a small isolated section in the upper area of *waterslap*, since it is communicated through vents (Fig. A3.20). A large rectangle cut would have been ideal,

[6] There is a mark zero inside the *waterslap* indicating the water level they have been designed for, so the main pitch of the *waterslap* can be emphasised, and then other numbered lines below and above which the composer can indicate towards experimenting with tone colour.

[7] Isolating the walls of the *waterslap* during the plosive action, and not letting water or air go through.

but the vents do not affect the sound that goes through them much, and they strengthen the structure of the tongue. They have been placed in a perpendicular position to the sliding windows so the air pressure is not directly placed in a parallel position to the sliding windows and does not produce additional undesired vibrations when the tongue is pressed (or make the isolation of the windows more difficult). These vents do not cover the whole span of the sliding windows, so when these windows are open just one centimetre the air going through the vents does not blow directly into the gap left open in the sliding windows. This is an option in which the splashing sound is reduced, which also stops the water from splashing outside.

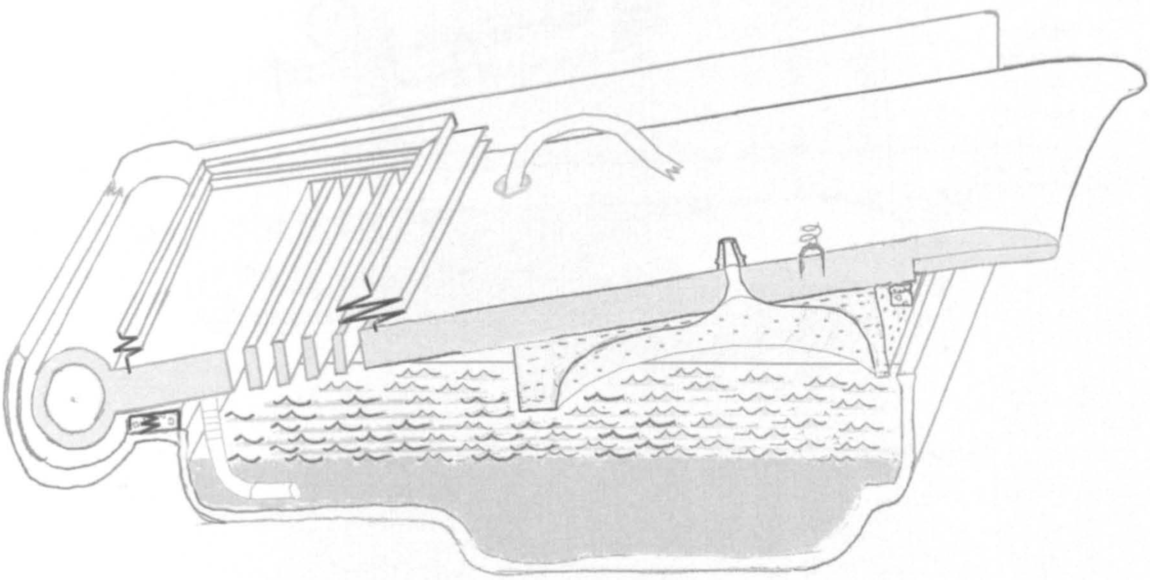

Fig. A3.20. 3-D view of a *waterslap* with longitudinal cut, and the top wall removed.

When the bubbling valve, the whistle valve and the four sliding windows are all closed and the water whistle is placed in its rabbet (after removing the lid), the plosive action is followed by a process that ends up producing the whistle water jar effect.[8] What we here call the water whistle is nothing but a regular pea whistle without the pea that is tuned and fitted in after removing the water whistle lid. The pitch is chosen to match the fundamental of the plosive sound, but this is only a choice since these whistles are made with the same mouth size to fit any size of *waterslaps*, since the hole for all the sizes of *waterslaps* is made the same size. This multiplies the possibilities of experimenting with timbre that this unit offers. The process in which the water whistle produces a sound similar to the pre-Columbian whistle water jars is explained in figure Fig. A3.21. What

[8] Borja, A.J. 1951. *Instrumentos Musicales del Perú*. Lima, Peru: Museo de la Cultura.

this process has to add to the pre-Columbian whistle water jars technique,[9] in the way it is utilised with the *waterslap*, is the fact that the compressed air pumped to the cork cavity elongates the blowing action when the tongue is held or even by slightly pressing after the concussion action. This effect provides the chance to sustain the water whistle sound for a few extra seconds if required. If the bubbling valve is open, the sound can be elongated. This is achieved producing an internal cyclic blowing action, also affecting the tone quality of the bird whistle effect.

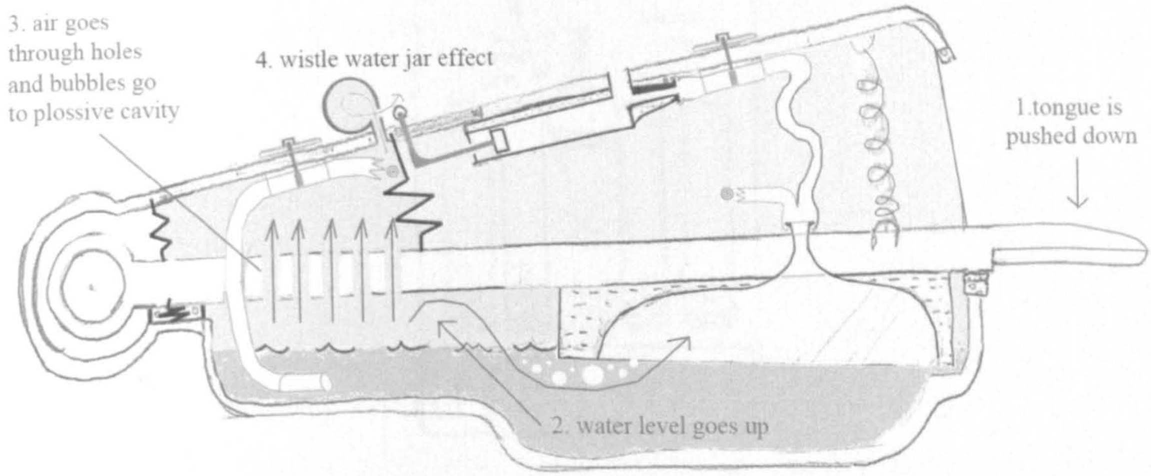

Fig. A3.21. *Waterslap* unit with two valves closed and water whistle inserted.

The sealing of the accordion-like plastic walls (flexible in bents and glued on top and bottom) is important for obtaining good results. For this reason the tube for the bubbling effect can be rearranged as previously shown in figure Fig. A3.20, but this also requires the bubbling valve to be rearranged as shown in figure Fig. A3.22. This avoids the tube going through the accordion-like plastic wall.

[9] Pérez de Arce, J. 2004. Análisis de las cualidades sonoras de las botellas silbadoras prehispánicas de los Andes. *Boletín del Museo Chileno de Arte Precolombino*. No 9. Santiago de Chile. pp. 9-33.

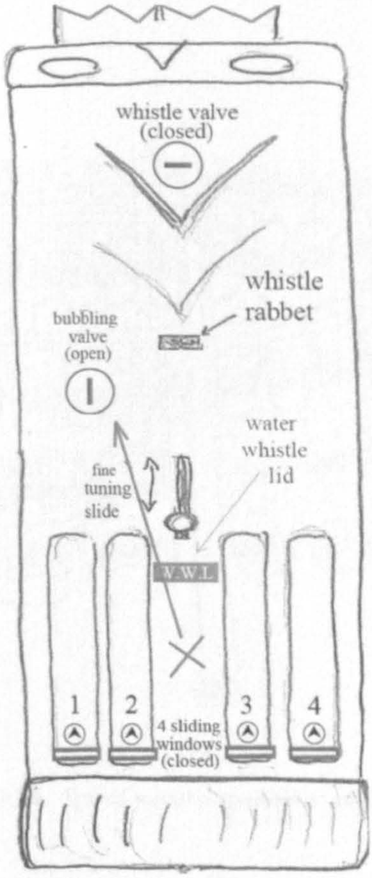

Fig. A3.22. Bubbling valve for the *waterslap*, indicated.

Now that the *waterslap* has been described in detail, let us formulate the concept of a *spiral waterslapophone* (or *splashophone*). A *waterslap* has a stringed support device with a clutch system (Fig. A3.23) which allows it to be hung from a bar, in fact placed below the bar touching it, and this is done on a spiral frame similar to the one used for the *spiral conic bellophone* (Fig. A3.24).

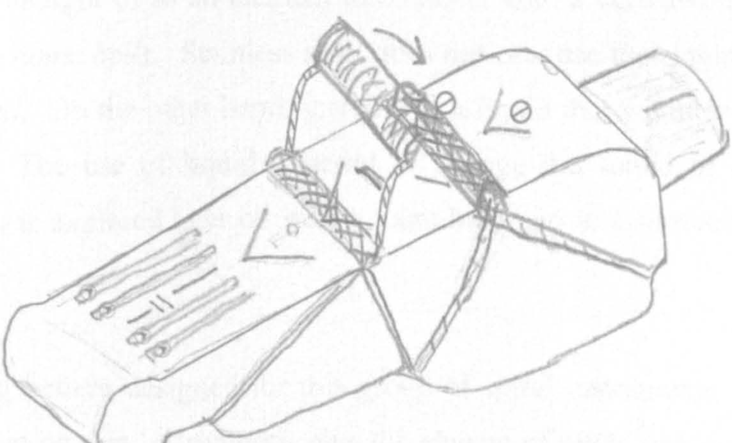

Fig. A3.23. Clutch details for a *waterslap* unit.

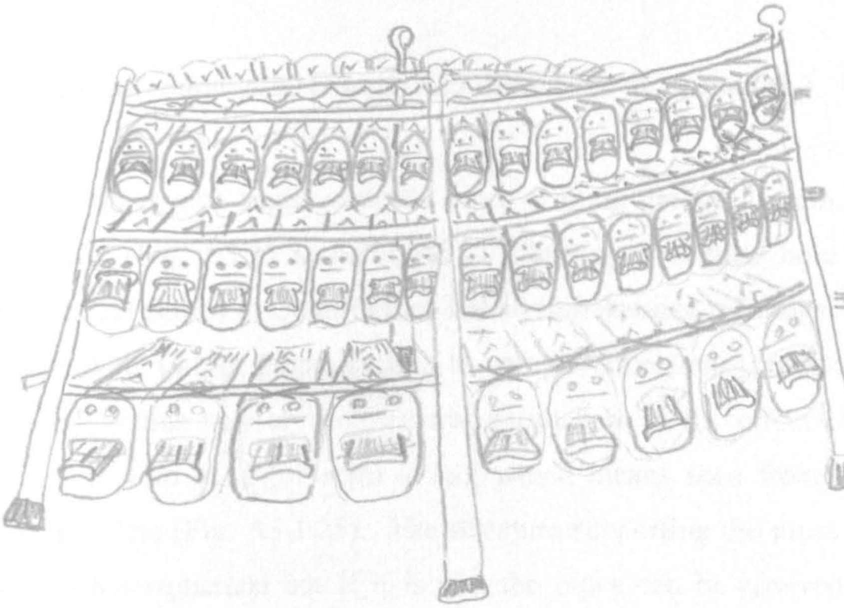

Fig. A3.24. *Spiral waterslapophone*: outer layout.

This *spiral waterslapophone* in outer layout offers a substantial corporeal expression while being performed, and simply for this reason it is preferred here over the internal layout, since the same speed can be achieved with an internal layout, considering that the sound of this instrument cannot be appreciated when played at high speeds. However, a larger frame with the bass range in outer layout can allow space to place a smaller frame with inner layout allowing faster speeds and faster note changing by placing a performer in the inside and covering the higher range.

Water cannot be thought of as an element to combine with a corrosive metal such as the steel used for the *conic bells*. Stainless steel does not produce the ringing quality desired with the *conic bell*. On the other hand, mercury is a liquid that would trouble the steel of the *conic bells*. The use of liquid material to change the sound of *conic bellophone* resonating bodies is explored later on with a giant harp and in a succeeding design of the *conic bellophone*.

As for the zigzag pattern designed for this group of spiral instruments, there is no doubt they can be played on this instruments, plus the change of pitch direction when doing the zigzag glissando can be reinforced by pressing for a bit longer in the pivot note to mask the time that the performer has to take to change direction producing a smooth overall sliding pitch effect.

A3.3.1.7 The *spiral-rotary pipe organ* with *Ahualulco keyboard* (I_g)

This consists of a 96-et pipe organ with the pipes shaping the auditorium, positioned in semi-spherical helix (Fig. A3.25 and Fig. A3.26), leaving a circular hole in the ceiling similar to the ones developed in Quattrocento Italian Renaissance paintings. One option is to cover the hole with a glass sphere section to complete the semi-spherical shape of the space and making in this way an architectural parallelism to the effect of this painting technique called *di sotto in sù* (or *sotto in su*), which means seen from below or from below upward in Italian (Fig. A3.1.25). The structure supporting the pipes does not have to be necessarily hemispherical but if it is not, the pipes can be covered with acoustic isolation if hemispherical acoustics are desired.

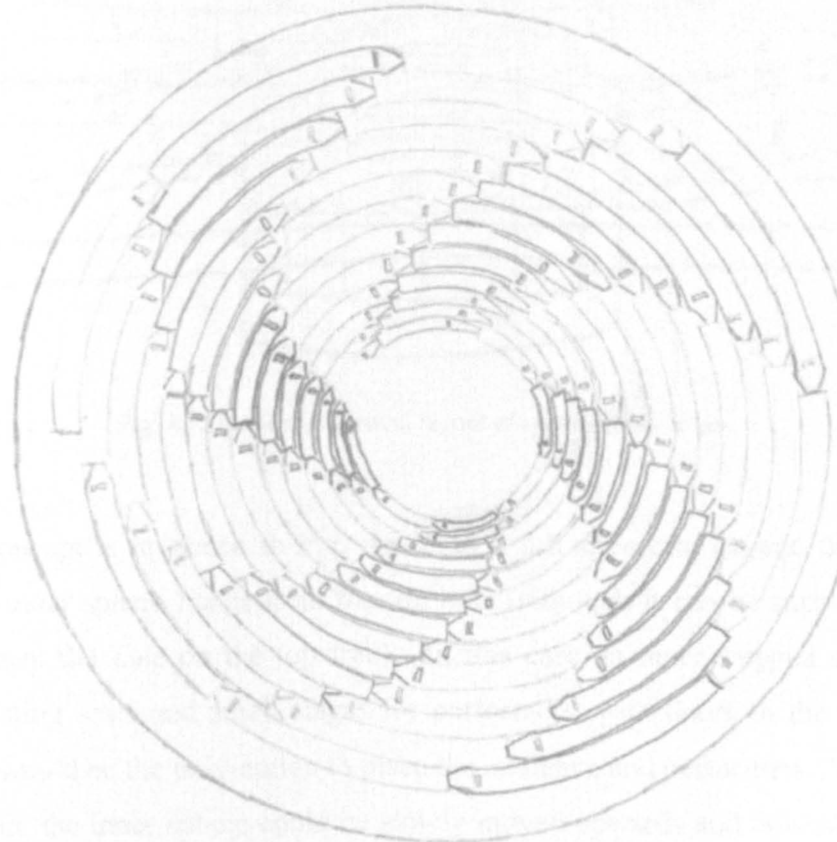

Fig. A3.25. Top pipe layout for the *spiral-rotary organ* from below (Di sotto in sù effect).

This is not a rotating ceiling; what is rotating about this organ is the structure supporting the upper register pipes. These are placed in a small semi-spherical structure that is located concentrically inside the semi-spherical space previously described. The pipes follow a semi-spherical helix outside this inner structure (Fig. A3.26). The inner structure can be either hung up from the ceiling, or if the sky hole is mostly desired, they can be placed on rails on top of the stage where the organist is placed with other possible performers. The dotted lines in figure Fig. A3.26 show a spherical helix next to the pipes as a possible guideline to place a stepped structure to take seats and performers around the space, as a variant to the circular seats and stage at the bottom of the auditorium.

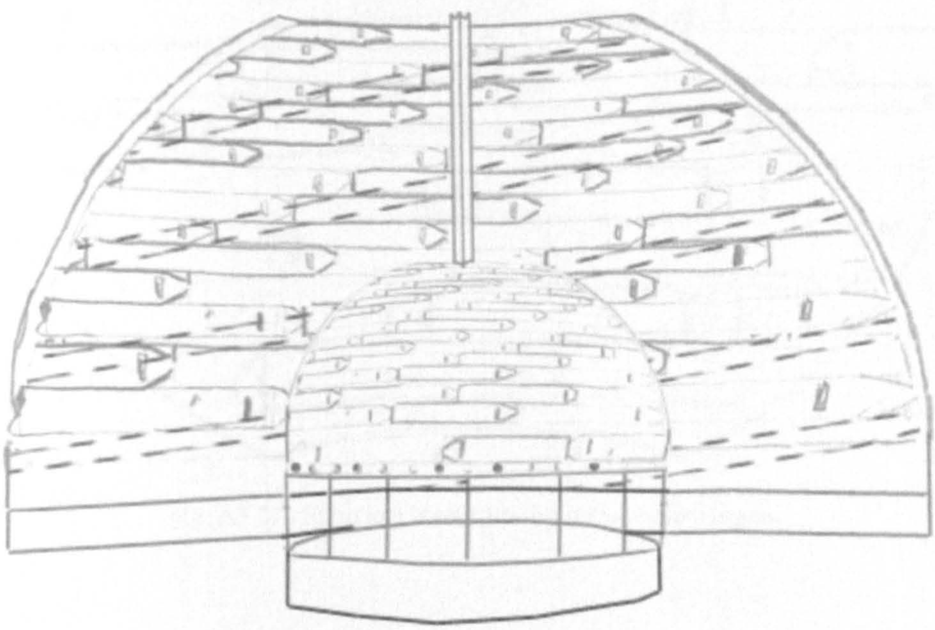

Fig. A3.26. Semi-spherical layout of *spiral-rotary organ.*

The same concept is proposed in Fig. A3.27 to a full sphere to expand the lower pitch range. The inner sphere hangs from the top hole (although it can be supported from the bottom to keep the hole on the top free). In this case an inner stepped spherical helix structure hosting seats and small stages for performers, with doors to the outside of the instrument, would be the only option to place the audience and performers. With a rotating piston system, the inner sphere could be slowly moved upwards and downwards to let the audience see the performers no matter where they are placed. The idea behind the rotation of the inner sphere is to deliver the sound, of the higher register in this case, around the space equally.

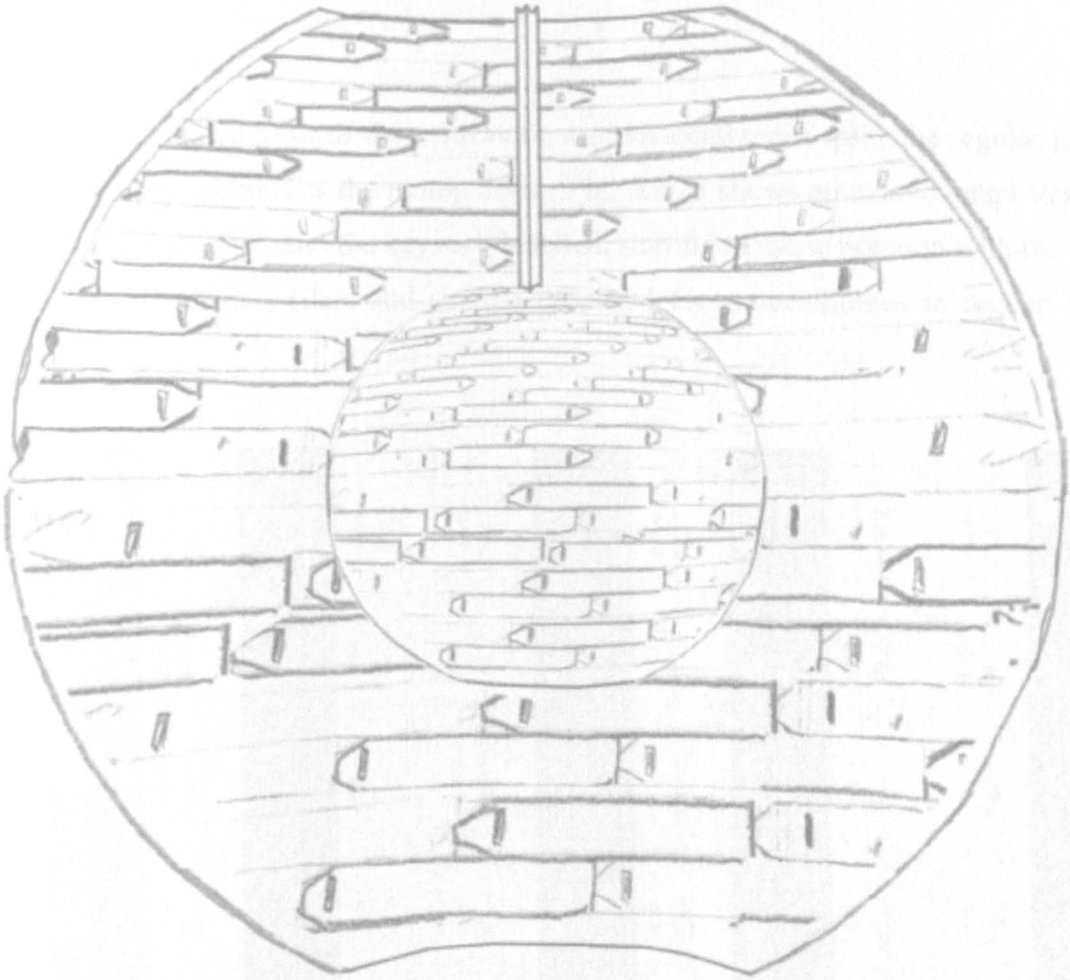

Fig. A3.27. Spherical layout for the *spiral-rotary organ*.

With the spherical layout a full range of nine octaves can be covered using 96-et requiring 865 pipes in total. Since the organ is likely to be the main instrument for a performance that takes place inside this sphere, one option for the solo recital would be to split the nine octaves keyboard into four keyboards with three octaves range each. The keyboards with the lowest and the highest range would have an overlapping octave each, with their respective next-door keyboard in the range. The keyboards covering the middle range would have two overlapping octaves (the lowest with the keyboard below in the overall range and the one above with the keyboard above in the overall range). In this case a transparent ring around the inner sphere could be hung from the ceiling or raised from the bottom to support the four keyboards and keyboard players. If the ring is elevated from below then a slow rotation system could be incorporated so they can all be clearly seen by the audience.[10]

The keyboard designed towards the achievement of sixteenthtones splits the regular piano keys into as many sections as the tuning does. Fig. A3.28 shows an octave range starting from G, as the *conic bells* and the keys are labelled, starting numeric notation with the zero in G and the accidentals (flats and sharps) proposed for sixteenthtones in regular staff notation (Ch. 1).

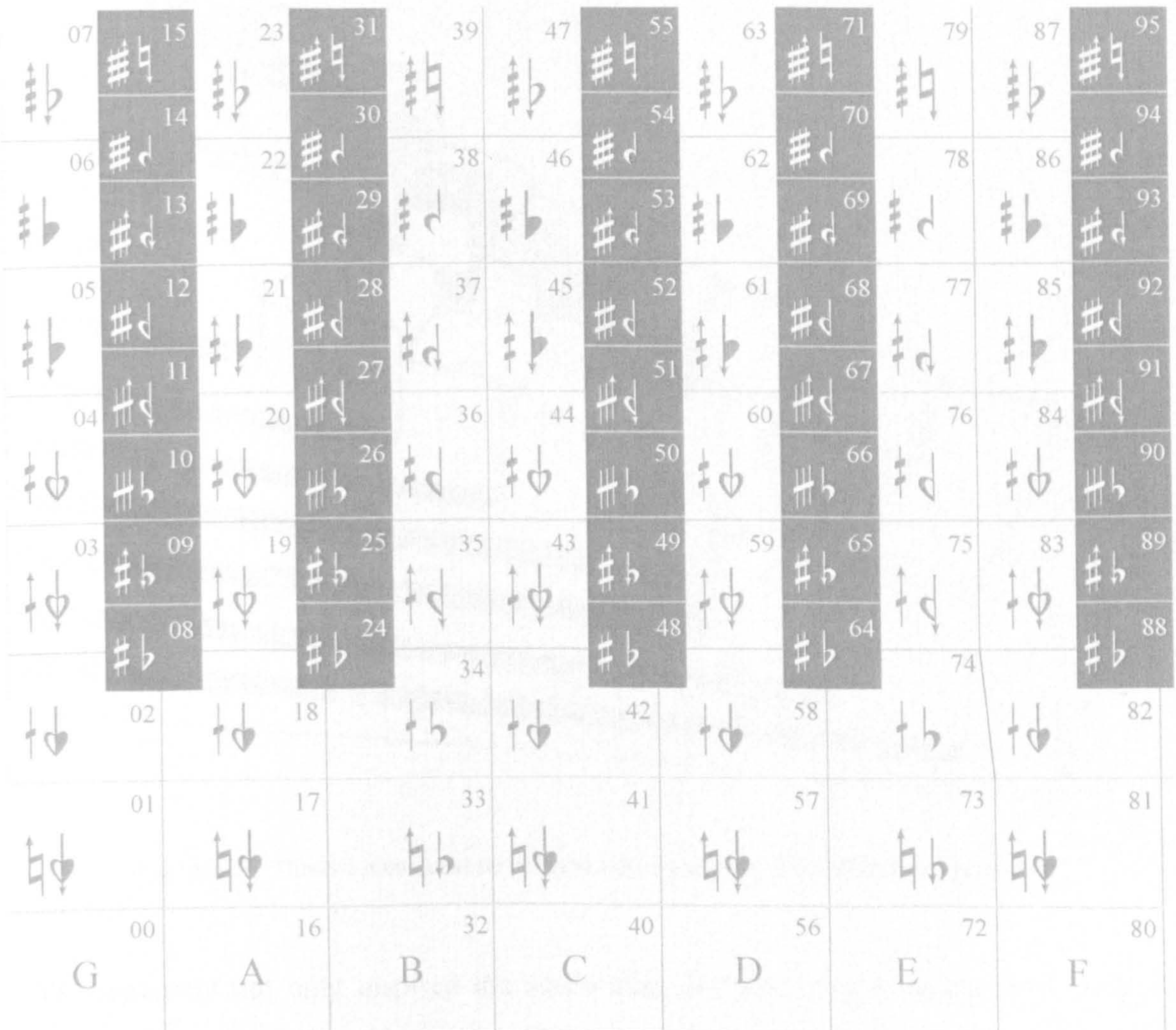

Fig. A3.28. *Ahualulco keyboard* with 96-et numerical notation and the accidentals proposed.

[10] For this purpose, screens enlarging the image of the keyboards could also be placed around the space so the hands of the four performers are visible at all times to provide some corporeal expression to the performance.

The name of Carrillo's birth village, Ahualulco (since he already used his name for some of his instruments), is used here to refer to this layout.

This keyboard allows ultrachromatic pitch gliding by simply sliding the fingers upwards or downwards, following the patterns of the piano keys as can be observed in the three dimensional representation of a keyboard section in figure Fig. A3.29.

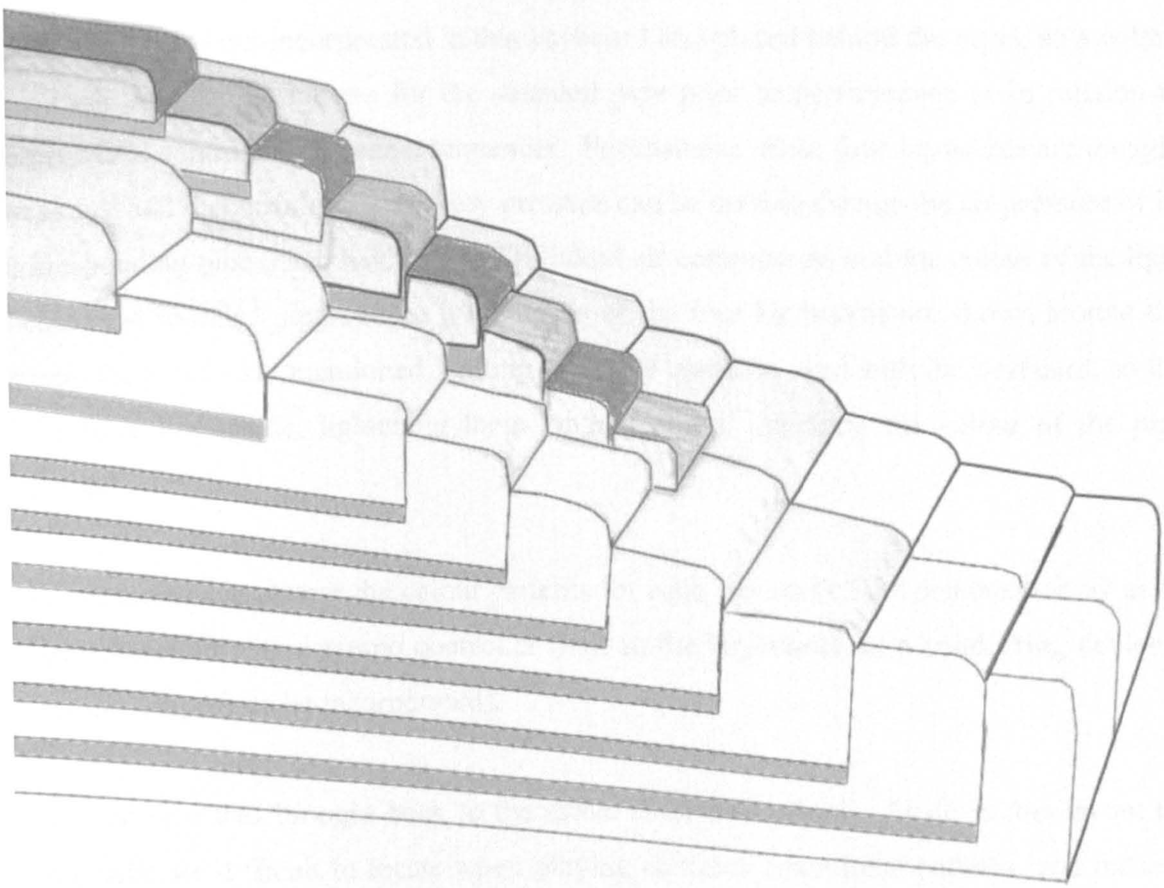

Fig. A3.29. Three-dimensional representation of a section of the *Ahualulco keyboard*.

This instrument not only inspired the succeeding decision of placing the conic bells in stands so they can be placed in a convenient way, but also inspired the concept of using the space as a musical instrument and consequently the design of a spherical auditorium, the Snowdome (see Ch. 4).

The zigzag pitch patterns designed for this group gain spatial dimensionality with this instrument since the pitch changes are also accompanied with a spiral movement around the auditorium. This concept also inspires other instruments from the groups that follow.

Unlike most of the keyboard instruments, the *spiral-rotary organ* with *Ahualulco keyboard* was designed to incorporate high corporeal expression elements. The keyboard employs four performers, and their positioning (as previously mentioned), as well as having their hands projected in screens, enhances corporeal expression. Colour lights are activated with a MIDI system incorporated in this keyboard and placed behind the pipes, so a colour for each pipe can be chosen for the sounded pipe prior to performance or in relation to other MIDI controllers or even a sequencer. For instance, these four keyboards are thought of as full MIDI controllers, so the key pressure can be used to change the air pressure of its corresponding pipe (each having a MIDI linked air compressor) and the colour of the light behind the sounded pipe. Since live images of the four keyboards are shown around the space, the previously mentioned lighting principle could be used with the keyboard, so the keys have lids inside, lightening them when playing, matching the colour of the pipe sounded.

The composer can choose the colour patterns for each moment of the composition by using a sequencer run with a tempo controller (link to the keyboards, or a conducting device if dynamic tempo is to be incorporated).

A related idea was brought back to the *spiral conic bellophone*. Since in this layout the conic bells are difficult to locate when playing complex microtonal patterns, and patterns do exist according to the played scale, a set of individual lights pointing to each bell and a switchboard lightening the microtonal scale being used was thought of as a pedagogical idea for instrument demonstrations and even for rehearsals and training exercises.

This idea used with the *spiral-rotary* organ with *Ahualulco keyboard* led to the adoption of three-dimensional visual simulations to reduce experimentation cost.

The use of a spherical space as part of the instrument suggests considering spherical coordinates towards calculations when projecting the sound in the space. Eight sound channels and speakers can be used around a spherical testing space to accompany the three dimensional visual simulation as part of the design and composing processes is considered at this early stage, and can be used in general for any design including a mechanised bellophone with bells placed around the audience.

A3.3.1.8 The *spiral-tin oboe* (with conic core) (Ih)

The origin of this conic core reed instrument was to apply the sliding-key-on-rail concept (diagram in Fig. A3.30) to an oboe with five cuts (Fig. A3.31). A sliding key is placed on a longitudinal structure that has a hole and that slides along a railing system, always covering the longitudinal cut on the instrument and always making enough pressure against the cut to stop the air coming out if the hole is covered. Keys ought to be made so they always come back to the original position (graded prior to performance). A system to lock a key temporarily in a desired position during performance is to be incorporated.

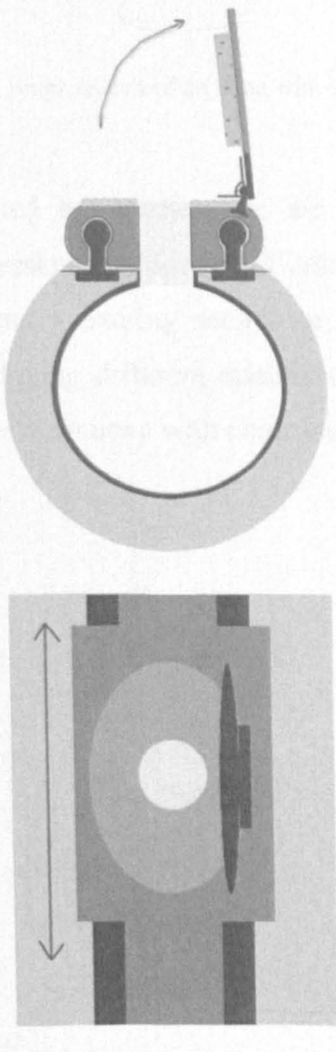

Fig. A3.30. *Sliding-key-on-rail* diagram.

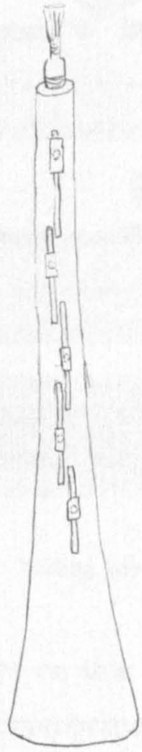

Fig. A3.31. A rough sketch of an oboe with 5 sliding keys.

This system has not been tested but sealing the air from coming out and placing overlapping sliding keys will present additional difficulties when employing curvilinear structures. Experimentation and mastering sealing and positioning sliding keys on a regular oboe (Fig. A3.31), employing different materials too, would be advisable before working on prototypes of the *spiral tin oboe* with conic core and sliding keys (Fig. A3.32).

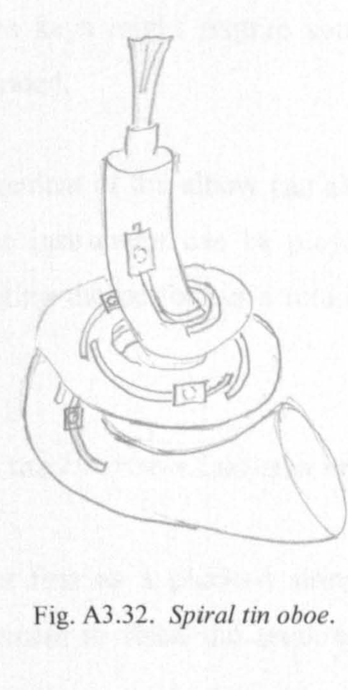

Fig. A3.32. *Spiral tin oboe*.

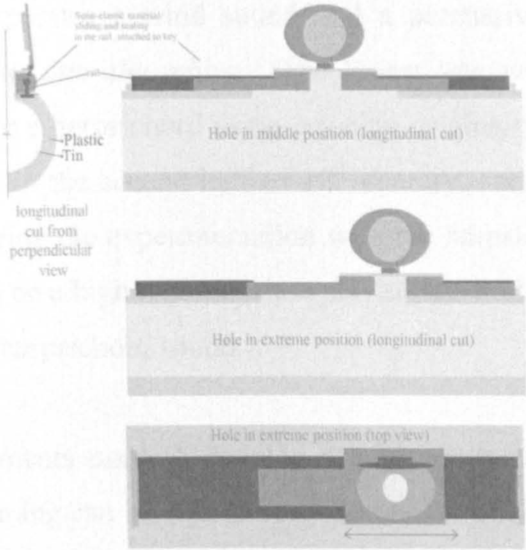

Fig. A3.33. Sliding key views.

The structure supporting the sliding keys on this conical helix layout would require a slightly flexible material, apart from the appropriate springs to bring the key support back in place. Hard silicone could be used for this purpose, or a material with similar characteristics. A lock to keep a sliding key in a required position could also improve the capabilities of this instrument. This way, the rotation of the fingers around the instrument could also involve the rotation of the hands and a movement of the elbows forwards and backwards that could intensify the corporeal expression during performance.

The zigzag exercises proposed for the non-cylindrical helix group (I) can be performed smoothly for the range covered by a slide key without requiring much practice. The overlapping pitch areas between keys might require some time mastering when wider zigzag pitch movements are intended.

The forward and backward movement of the elbow can also be used with the *spiral conic bellophone* when gliding, if the instrument can be played without looking at the keys behind, in other words substituting the performer's rotation covering 180° of the layout with each arm.

A3.3.1.9 The *lucent tree* and the *Harrison Luo-abu mbira* (Ii)

The *lucent tree* was conceived first as a plucked string instrument. Later on it was developed into a hybrid instrument to fulfil the requirements of this group. The new derived instrument incorporates a wind sound and a percussive shaking sound and is denominated the *Harrison Luo-abu mbira.* The lucent tree was inspired by a college experiment composing for a harpsichord using a tuning originally proposed by the British horologist John Harrison in the second half of 18th century, and rediscovered by Charles Lucy in the 1980s.[11] During the experimentation with the harpsichord, it was noticed that the beating partials heard on a high register when playing the mid-pitch range enhanced the brightness of the regular harpsichord sound.

Let us describe the elements used to develop the lucent tree starting with the tuning employed. Harrison's tuning can be considered, like most meantone tunings, to be part of an infinite spiral of flattened fifths. This spiral in most of the cases reaches a point in which the whole interval gets very close to a specific number of octaves. And when the process is repeated to get closer to an octave until the difference from the closest octave is too small to be perceived, the spiral becomes a cyclic toroidal spiral of fifths (which is the shape obtained by joining one end of a spring with the other), rather than an infinite spring growing in both directions. Although Harrison's tuning has this property (or potential), it was originally proposed as a diatonic scale in which the octave is divided into Pi (1200 ¢/π) to obtain the third 381.971863 ¢ (or two consecutive major tones: TH=190.9859317 ¢).[12] Therefore, the equivalent semitone in his tuning system (sH) can be obtained by resolving the following equation:

$$2\,sH + 5\,TH = 1200\ ;\ sH = (1200 - 5\,TH)/2 = 122.5351707\ ¢$$

Following the fifth pattern in the diatonic scale (T-T-s-T), we can obtain the fifth with the relative pattern TH-TH-sH-TH, ending up with a value of 695.4929659 ¢ (Harrison fifth from now onwards, and represented by VH).

Having obtained the Harrison fifth, we can add consecutive fifths, transposing them to the first octave to obtain equal temperaments containing Harrison's tuning. The interval formed by 88 consecutive Harrison fifths produces an interval that is 3.381 ¢ sharper than 51 octaves. By flattening a Harrison fifth by 1/88th of this comma (0.03 ¢), we get the 88-et fifth. Going further in the circle of Harrison fifths (VH=695.4929659 ¢), we find that

[11] Lucy, Charles E.H. 1986. *Pitch, Pi, and Other Musical Paradoxes (A Practical Guide to Natural Microtonality)*. London: author.
[12] The pure major third being 386.31 ¢ and the difference 4.34 ¢.

the interval formed by 1420 Harrison fifths is 0.0115 ¢ sharper than 823 octaves. This is exceptional since no fifth in the sequence gets closer to an octave up in the spiral until the 105413th fifth, and almost by the same amount (0.0097 ¢ above the closest octave). The 105413-et, is not considered here a practical solution, not even for theoretical purposes.

The 0.0115 ¢ comma produced by 1420 Harrison fifths can be divided into each of the 1420 Harrison fifths, by flattening each of them 0.0000081 ¢ to obtain the relative equal temperament, in this case the 1420-et. But we do not need to care about such a small reduction. Even our ears would not appreciate the full comma (0.0115 ¢) if we were to use a circle of 1420 Harrison fifths. Therefore in terms of theory and practice the 1420-et is here considered the end of the spiral of Harrison fifths, constituting a cyclic toroidal spiral of fifths. For example, if we start with C and want to find the Harrison semitone (sH=122.5351707 ¢) in the cyclic toroidal spiral of fifths, we can go 1415 fifths towards the right of the toroid (1415xVH or G220# using traditional double sharp notation with up to 202 sharps in the toroidal model). We can simplify the process and get to the same point by going five fifths to the right (5xVH or Db). Consequently half of the toroidal should ideally be used with up to 101 sharps and the other half using up to 101 flats, since enharmonic intervals have a comma of 0.0115 ¢ difference which is not worth differentiating in this system.

The 88-et is not included in the 1420-et, and the discrepancies between the 88-et degrees and the closest intervals in the 1420-et vary mainly between 0.1 ¢ up to 0.4 ¢. In fact, there is a close approximation of an 88-et degree every 16 degrees of the 1420-et (with the exception of 17 degrees every 7 degrees in the 88-et scale). The 88-et can be considered a practical solution to extend Harrison's tuning if the 3.381 ¢ comma does not considerably affect the composition or sound produced by the instruments when using two enharmonic values for the same position in the toroidal spiral of fifths.

The chromatic step of the 1420-et (0.845070423 ¢) is here denominated lucent, in honour of the research on John Harrison done by C. Lucy.[13] The lucent is used as a chromatic step for the lucent tree (Fig. A3.34), an instrument aiming to demonstrate the aural limitations perceiving microdiscrete-sliding pitch (see Glossary) as sliding pitch, and all possible

[13] Lucy, Charles E. H. 1986. *Pitch, Pi, and Other Musical Paradoxes (A Practical Guide to Natural Microtonality)*. London: Published by author.

micro-intervals to be found in Harrison's tuning. The lucent tree uses metal strings placed between the inside of the spiral and the edge. In the edge a rail system carrying sliding plucking units is placed. Performers and demonstrators can either pluck specific strings to play an interval or chord,[14] or slide a plucking device fitted in edge rail to demonstrate sliding intervals and chords or even changing intervals and chords when different plucking speeds are used. The results are extremely visual and also an effective hands-on-the-instrument way to teach the targeted subject, tuning measuring units.[15] With 1421 strings, a second instrument can also be tuned in cent steps for comparison and demonstrations starting from the same pitch at the bottom (and consequently reducing up to one tone the notes at the top of the octave).

Harrison's tuning can be considered a meantone such as the other tunings of the period that were seeking more consonant thirds by compromising the consonance of the fifth. But, what makes this tuning unique among most early tunings is the fact that it was devised using a transcendental number. What is mysterious about this tuning, and probably due to the lack of information available, is the reason why Harrison uses the same number required to express the radiation of sound equally in all directions (I is the intensity of the sound at a distance r, and W refers to the power of the source):[16]

$$I = \quad W / 4\pi r^2 \qquad (\text{Watts/m}^2)$$

Spherical coordinates, also employing number π (when measuring angles in radians), can be used to describe the propagation of the sound in a three-dimensional space. John Harrison could have thought of using π thinking of some kind of relation between the sound propagation and the tuning, but still in 2011, this matter remains unknown. The *lucent tree* (Fig. A3.34) can be used as a tool for future research.

This pedagogical and research instrument is named *lucent tree* after the tuning unit previously proposed (*L¢*) and its arboreal resemblance. Sliding plucking units can be easily fitted and taken off with a clutch system, so several of them can be placed simultaneously in the desired place at any time in the middle of a performance. Although

[14] With false nails similar to the ones used by *koto* players, and ideally square-shaped nails as the ones used by the Ikuta *koto* school (opposed to the pointed ones used by the Yamada *koto* school).
[15] While it also takes the acoustical properties of Harrison's theories to the limits of human perception.
[16] Horoshenkov, K.V. 2011. *Environmental Noise Control (Lecture 4).* School of Engineering, Design and Technology, University of Bradford, UK. http://www.staff.brad.ac.uk/kvhorosh/CV6505M/lecture_04.pdf

this instrument has been designed for pedagogical and research purposes, it could also be used for compositional practice when requiring slow graded changes of pitch in time. Glides can be provided for most tunings when using 1420 notes per octave, since it approximates well enough to the requirements of most tunings. The tone colour produced with a chord or interval doing parallel glissando using the closest *lucent* is likely to have a brighter tone quality than the closest cent, although this needs to be proven in practice and probably as part of future research in timbre.

A chart comparing *lucents* (*L¢*) with cents (¢) is provided in Fig. A3.35, indicating the intervals that are close to the 88-et degrees in bold font. These are found every 16 degrees in the 1420-et scale, apart from a few exceptions in which the interval requires 17 degrees, in which case the font is bold and italic.

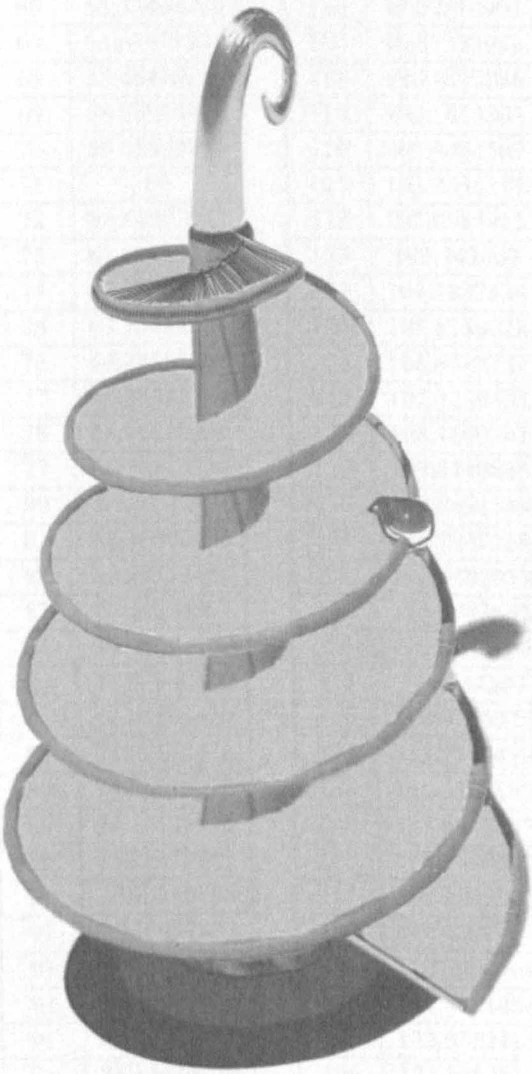

Fig. A3.34. Frame and stand for the *lucent tree* (also *glissachord*) with a few strings indicated.

A Comparison between *lucents* and cents (1420-et and 1200-et)

L¢	¢	L¢	¢	L¢	¢	L¢	¢
0	**0**	50	42.25352113	100	84.50704225	150	126.7605634
1	0.845070423	51	43.09859155	101	85.35211268	151	127.6056338
2	1.690140845	52	43.94366197	102	86.1971831	152	128.4507042
3	2.535211268	53	44.78873239	103	87.04225352	153	129.2957746
4	3.38028169	54	45.63380282	104	87.88732394	154	130.1408451
5	4.225352113	55	46.47887324	105	88.73239437	155	130.9859155
6	5.070422535	56	47.32394366	106	89.57746479	156	131.8309859
7	5.915492958	57	48.16901408	107	90.42253521	157	132.6760563
8	6.76056338	58	49.01408451	108	91.26760563	158	133.5211268
9	7.605633803	59	49.85915493	109	92.11267606	159	134.3661972
10	8.450704225	60	50.70422535	110	92.95774648	160	135.2112676
11	9.295774648	61	51.54929577	111	93.8028169	161	**136.056338**
12	10.14084507	62	52.3943662	112	94.64788732	162	136.9014085
13	10.98591549	63	53.23943662	113	**95.49295775**	163	137.7464789
14	11.83098592	64	54.08450704	114	96.33802817	164	138.5915493
15	12.67605634	65	***54.92957746***	115	97.18309859	165	139.4366197
16	**13.52112676**	66	55.77464789	116	98.02816901	166	140.2816901
17	14.36619718	67	56.61971831	117	98.87323944	167	141.1267606
18	15.21126761	68	57.46478873	118	99.71830986	168	141.971831
19	16.05633803	69	58.30985915	119	100.5633803	169	142.8169014
20	16.90140845	70	59.15492958	120	101.4084507	170	143.6619718
21	17.74647887	71	60	121	102.2535211	171	144.5070423
22	18.5915493	72	60.84507042	122	103.0985915	172	145.3521127
23	19.43661972	73	61.69014085	123	103.943662	173	146.1971831
24	20.28169014	74	62.53521127	124	104.7887324	174	147.0422535
25	21.12676056	75	63.38028169	125	105.6338028	175	147.8873239
26	21.97183099	76	64.22535211	126	106.4788732	176	148.7323944
27	22.81690141	77	65.07042254	127	107.3239437	177	**149.5774648**
28	23.66197183	78	65.91549296	128	108.1690141	178	150.4225352
29	24.50704225	79	66.76056338	129	**109.0140845**	179	151.2676056
30	25.35211268	80	67.6056338	130	109.8591549	180	152.1126761
31	26.1971831	81	**68.45070423**	131	110.7042254	181	152.9577465
32	**27.04225352**	82	69.29577465	132	111.5492958	182	153.8028169
33	27.88732394	83	70.14084507	133	112.3943662	183	154.6478873
34	28.73239437	84	70.98591549	134	113.2394366	184	155.4929577
35	29.57746479	85	71.83098592	135	114.084507	185	156.3380282
36	30.42253521	86	72.67605634	136	114.9295775	186	157.1830986
37	31.26760563	87	73.52112676	137	115.7746479	187	158.028169
38	32.11267606	88	74.36619718	138	116.6197183	188	158.8732394
39	32.95774648	89	75.21126761	139	117.4647887	189	159.7183099
40	33.8028169	90	76.05633803	140	118.3098592	190	160.5633803
41	34.64788732	91	76.90140845	141	119.1549296	191	161.4084507
42	35.49295775	92	77.74647887	142	120	192	162.2535211
43	36.33802817	93	78.5915493	143	120.8450704	193	163.0985915
44	37.18309859	94	79.43661972	144	121.6901408	194	***163.943662***
45	38.02816901	95	80.28169014	145	**122.5352113**	195	164.7887324
46	38.87323944	96	81.12676056	146	123.3802817	196	165.6338028
47	39.71830986	97	**81.97183099**	147	124.2253521	197	166.4788732
48	**40.56338028**	98	82.81690141	148	125.0704225	198	167.3239437
49	41.4084507	99	83.66197183	149	125.915493	199	168.1690141

L¢	¢	L¢	¢	L¢	¢	L¢	¢
200	169.0140845	250	211.2676056	300	253.5211268	350	295.7746479
201	169.8591549	251	212.1126761	301	254.3661972	351	296.6197183
202	170.7042254	252	212.9577465	302	255.2112676	352	297.4647887
203	171.5492958	253	213.8028169	303	256.056338	353	298.3098592
204	172.3943662	254	214.6478873	304	256.9014085	354	299.1549296
205	173.2394366	255	215.4929577	305	257.7464789	355	**300**
206	174.084507	256	216.3380282	306	258.5915493	356	300.8450704
207	174.9295775	257	217.1830986	307	***259.4366197***	357	301.6901408
208	175.7746479	258	**218.028169**	308	260.2816901	358	302.5352113
209	176.6197183	259	218.8732394	309	261.1267606	359	303.3802817
210	**177.4647887**	260	219.7183099	310	261.971831	360	304.2253521
211	178.3098592	261	220.5633803	311	262.8169014	361	305.0704225
212	179.1549296	262	221.4084507	312	263.6619718	362	305.915493
213	180	263	222.2535211	313	264.5070423	363	306.7605634
214	180.8450704	264	223.0985915	314	265.3521127	364	307.6056338
215	181.6901408	265	223.943662	315	266.1971831	365	308.4507042
216	182.5352113	266	224.7887324	316	267.0422535	366	309.2957746
217	183.3802817	267	225.6338028	317	267.8873239	367	310.1408451
218	184.2253521	268	226.4788732	318	268.7323944	368	310.9859155
219	185.0704225	269	227.3239437	319	269.5774648	369	311.8309859
220	185.915493	270	228.1690141	320	270.4225352	370	312.6760563
221	186.7605634	271	229.0140845	321	271.2676056	371	**313.5211268**
222	187.6056338	272	229.8591549	322	272.1126761	372	314.3661972
223	188.4507042	273	230.7042254	323	**272.9577465**	373	315.2112676
224	189.2957746	274	**231.5492958**	324	273.8028169	374	316.056338
225	190.1408451	275	232.3943662	325	274.6478873	375	316.9014085
226	**190.9859155**	276	233.2394366	326	275.4929577	376	317.7464789
227	191.8309859	277	234.084507	327	276.3380282	377	318.5915493
228	192.6760563	278	234.9295775	328	277.1830986	378	319.4366197
229	193.5211268	279	235.7746479	329	278.028169	379	320.2816901
230	194.3661972	280	236.6197183	330	278.8732394	380	321.1267606
231	195.2112676	281	237.4647887	331	279.7183099	381	321.971831
232	196.056338	282	238.3098592	332	280.5633803	382	322.8169014
233	196.9014085	283	239.1549296	333	281.4084507	383	323.6619718
234	197.7464789	284	240	334	282.2535211	384	324.5070423
235	198.5915493	285	240.8450704	335	283.0985915	385	325.3521127
236	199.4366197	286	241.6901408	336	283.943662	386	326.1971831
237	200.2816901	287	242.5352113	337	284.7887324	387	**327.0422535**
238	201.1267606	288	243.3802817	338	285.6338028	388	327.8873239
239	201.971831	289	244.2253521	339	**286.4788732**	389	328.7323944
240	202.8169014	290	**245.0704225**	340	287.3239437	390	329.5774648
241	203.6619718	291	245.915493	341	288.1690141	391	330.4225352
242	**204.5070423**	292	246.7605634	342	289.0140845	392	331.2676056
243	205.3521127	293	247.6056338	343	289.8591549	393	332.1126761
244	206.1971831	294	248.4507042	344	290.7042254	394	332.9577465
245	207.0422535	295	249.2957746	345	291.5492958	395	333.8028169
246	207.8873239	296	250.1408451	346	292.3943662	396	334.6478873
247	208.7323944	297	250.9859155	347	293.2394366	397	335.4929577
248	209.5774648	298	251.8309859	348	294.084507	398	336.3380282
249	210.4225352	299	252.6760563	349	294.9295775	399	337.1830986

L¢	¢
400	338.028169
401	338.8732394
402	339.7183099
403	**340.5633803**
404	341.4084507
405	342.2535211
406	343.0985915
407	343.943662
408	344.7887324
409	345.6338028
410	346.4788732
411	347.3239437
412	348.1690141
413	349.0140845
414	349.8591549
415	350.7042254
416	351.5492958
417	352.3943662
418	353.2394366
419	354.084507
420	***354.9295775***
421	355.7746479
422	356.6197183
423	357.4647887
424	358.3098592
425	359.1549296
426	360
427	360.8450704
428	361.6901408
429	362.5352113
430	363.3802817
431	364.2253521
432	365.0704225
433	365.915493
434	366.7605634
435	367.6056338
436	**368.4507042**
437	369.2957746
438	370.1408451
439	370.9859155
440	371.8309859
441	372.6760563
442	373.5211268
443	374.3661972
444	375.2112676
445	376.056338
446	376.9014085
447	377.7464789
448	378.5915493
449	379.4366197

L¢	¢
450	380.2816901
451	381.1267606
452	**381.971831**
453	382.8169014
454	383.6619718
455	384.5070423
456	385.3521127
457	386.1971831
458	387.0422535
459	387.8873239
460	388.7323944
461	389.5774648
462	390.4225352
463	391.2676056
464	392.1126761
465	392.9577465
466	393.8028169
467	394.6478873
468	**395.4929577**
469	396.3380282
470	397.1830986
471	398.028169
472	398.8732394
473	399.7183099
474	400.5633803
475	401.4084507
476	402.2535211
477	403.0985915
478	403.943662
479	404.7887324
480	405.6338028
481	406.4788732
482	407.3239437
483	408.1690141
484	**409.0140845**
485	409.8591549
486	410.7042254
487	411.5492958
488	412.3943662
489	413.2394366
490	414.084507
491	414.9295775
492	415.7746479
493	416.6197183
494	417.4647887
495	418.3098592
496	419.1549296
497	420
498	420.8450704
499	421.6901408

L¢	¢
500	**422.5352113**
501	423.3802817
502	424.2253521
503	425.0704225
504	425.915493
505	426.7605634
506	427.6056338
507	428.4507042
508	429.2957746
509	430.1408451
510	430.9859155
511	431.8309859
512	432.6760563
513	433.5211268
514	434.3661972
515	435.2112676
516	**436.056338**
517	436.9014085
518	437.7464789
519	438.5915493
520	439.4366197
521	440.2816901
522	441.1267606
523	441.971831
524	442.8169014
525	443.6619718
526	444.5070423
527	445.3521127
528	446.1971831
529	447.0422535
530	447.8873239
531	448.7323944
532	**449.5774648**
533	450.4225352
534	451.2676056
535	452.1126761
536	452.9577465
537	453.8028169
538	454.6478873
539	455.4929577
540	456.3380282
541	457.1830986
542	458.028169
543	458.8732394
544	459.7183099
545	460.5633803
546	461.4084507
547	462.2535211
548	463.0985915
549	***463.943662***

L¢	¢
550	464.7887324
551	465.6338028
552	466.4788732
553	467.3239437
554	468.1690141
555	469.0140845
556	469.8591549
557	470.7042254
558	471.5492958
559	472.3943662
560	473.2394366
561	474.084507
562	474.9295775
563	475.7746479
564	476.6197183
565	**477.4647887**
566	478.3098592
567	479.1549296
568	480
569	480.8450704
570	481.6901408
571	482.5352113
572	483.3802817
573	484.2253521
574	485.0704225
575	485.915493
576	486.7605634
577	487.6056338
578	488.4507042
579	489.2957746
580	490.1408451
581	**490.9859155**
582	491.8309859
583	492.6760563
584	493.5211268
585	494.3661972
586	495.2112676
587	496.056338
588	496.9014085
589	497.7464789
590	498.5915493
591	499.4366197
592	500.2816901
593	501.1267606
594	501.971831
595	502.8169014
596	503.6619718
597	**504.5070423**
598	505.3521127
599	506.1971831

L¢	¢
600	507.0422535
601	507.8873239
602	508.7323944
603	509.5774648
604	510.4225352
605	511.2676056
606	512.1126761
607	512.9577465
608	513.8028169
609	514.6478873
610	515.4929577
611	516.3380282
612	517.1830986
613	**518.028169**
614	518.8732394
615	519.7183099
616	520.5633803
617	521.4084507
618	522.2535211
619	523.0985915
620	523.943662
621	524.7887324
622	525.6338028
623	526.4788732
624	527.3239437
625	528.1690141
626	529.0140845
627	529.8591549
628	530.7042254
629	**531.5492958**
630	532.3943662
631	533.2394366
632	534.084507
633	534.9295775
634	535.7746479
635	536.6197183
636	537.4647887
637	538.3098592
638	539.1549296
639	540
640	540.8450704
641	541.6901408
642	542.5352113
643	543.3802817
644	544.2253521
645	**545.0704225**
646	545.915493
647	546.7605634
648	547.6056338
649	548.4507042

L¢	¢
650	549.2957746
651	550.1408451
652	550.9859155
653	551.8309859
654	552.6760563
655	553.5211268
656	554.3661972
657	555.2112676
658	556.056338
659	556.9014085
660	557.7464789
661	558.5915493
662	***559.4366197***
663	560.2816901
664	561.1267606
665	561.971831
666	562.8169014
667	563.6619718
668	564.5070423
669	565.3521127
670	566.1971831
671	567.0422535
672	567.8873239
673	568.7323944
674	569.5774648
675	570.4225352
676	571.2676056
677	572.1126761
678	**572.9577465**
679	573.8028169
680	574.6478873
681	575.4929577
682	576.3380282
683	577.1830986
684	578.028169
685	578.8732394
686	579.7183099
687	580.5633803
688	581.4084507
689	582.2535211
690	583.0985915
691	583.943662
692	584.7887324
693	585.6338028
694	**586.4788732**
695	587.3239437
696	588.1690141
697	589.0140845
698	589.8591549
699	590.7042254

L¢	¢
700	591.5492958
701	592.3943662
702	593.2394366
703	594.084507
704	594.9295775
705	595.7746479
706	596.6197183
707	597.4647887
708	598.3098592
709	599.1549296
710	**600**
711	600.8450704
712	601.6901408
713	602.5352113
714	603.3802817
715	604.2253521
716	605.0704225
717	605.915493
718	606.7605634
719	607.6056338
720	608.4507042
721	609.2957746
722	610.1408451
723	610.9859155
724	611.8309859
725	612.6760563
726	**613.5211268**
727	614.3661972
728	615.2112676
729	616.056338
730	616.9014085
731	617.7464789
732	618.5915493
733	619.4366197
734	620.2816901
735	621.1267606
736	621.971831
737	622.8169014
738	623.6619718
739	624.5070423
740	625.3521127
741	626.1971831
742	**627.0422535**
743	627.8873239
744	628.7323944
745	629.5774648
746	630.4225352
747	631.2676056
748	632.1126761
749	632.9577465

L¢	¢
750	633.8028169
751	634.6478873
752	635.4929577
753	636.3380282
754	637.1830986
755	638.028169
756	638.8732394
757	639.7183099
758	**640.5633803**
759	641.4084507
760	642.2535211
761	643.0985915
762	643.943662
763	644.7887324
764	645.6338028
765	646.4788732
766	647.3239437
767	648.1690141
768	649.0140845
769	649.8591549
770	650.7042254
771	651.5492958
772	652.3943662
773	653.2394366
774	654.084507
775	***654.9295775***
776	655.7746479
777	656.6197183
778	657.4647887
779	658.3098592
780	659.1549296
781	660
782	660.8450704
783	661.6901408
784	662.5352113
785	663.3802817
786	664.2253521
787	665.0704225
788	665.915493
789	666.7605634
790	667.6056338
791	**668.4507042**
792	669.2957746
793	670.1408451
794	670.9859155
795	671.8309859
796	672.6760563
797	673.5211268
798	674.3661972
799	675.2112676

L¢	¢
800	676.056338
801	676.9014085
802	677.7464789
803	678.5915493
804	679.4366197
805	680.2816901
806	681.1267606
807	**681.971831**
808	682.8169014
809	683.6619718
810	684.5070423
811	685.3521127
812	686.1971831
813	687.0422535
814	687.8873239
815	688.7323944
816	689.5774648
817	690.4225352
818	691.2676056
819	692.1126761
820	692.9577465
821	693.8028169
822	694.6478873
823	**695.4929577**
824	696.3380282
825	697.1830986
826	698.028169
827	698.8732394
828	699.7183099
829	700.5633803
830	701.4084507
831	702.2535211
832	703.0985915
833	703.943662
834	704.7887324
835	705.6338028
836	706.4788732
837	707.3239437
838	708.1690141
839	**709.0140845**
840	709.8591549
841	710.7042254
842	711.5492958
843	712.3943662
844	713.2394366
845	714.084507
846	714.9295775
847	715.7746479
848	716.6197183
849	717.4647887

L¢	¢
850	718.3098592
851	719.1549296
852	720
853	720.8450704
854	721.6901408
855	**722.5352113**
856	723.3802817
857	724.2253521
858	725.0704225
859	725.915493
860	726.7605634
861	727.6056338
862	728.4507042
863	729.2957746
864	730.1408451
865	730.9859155
866	731.8309859
867	732.6760563
868	733.5211268
869	734.3661972
870	735.2112676
871	**736.056338**
872	736.9014085
873	737.7464789
874	738.5915493
875	739.4366197
876	740.2816901
877	741.1267606
878	741.971831
879	742.8169014
880	743.6619718
881	744.5070423
882	745.3521127
883	746.1971831
884	747.0422535
885	747.8873239
886	748.7323944
887	**749.5774648**
888	750.4225352
889	751.2676056
890	752.1126761
891	752.9577465
892	753.8028169
893	754.6478873
894	755.4929577
895	756.3380282
896	757.1830986
897	758.028169
898	758.8732394
899	759.7183099

L¢	¢
900	760.5633803
901	761.4084507
902	762.2535211
903	763.0985915
904	***763.943662***
905	764.7887324
906	765.6338028
907	766.4788732
908	767.3239437
909	768.1690141
910	769.0140845
911	769.8591549
912	770.7042254
913	771.5492958
914	772.3943662
915	773.2394366
916	774.084507
917	774.9295775
918	775.7746479
919	776.6197183
920	**777.4647887**
921	778.3098592
922	779.1549296
923	780
924	780.8450704
925	781.6901408
926	782.5352113
927	783.3802817
928	784.2253521
929	785.0704225
930	785.915493
931	786.7605634
932	787.6056338
933	788.4507042
934	789.2957746
935	790.1408451
936	**790.9859155**
937	791.8309859
938	792.6760563
939	793.5211268
940	794.3661972
941	795.2112676
942	796.056338
943	796.9014085
944	797.7464789
945	798.5915493
946	799.4366197
947	800.2816901
948	801.1267606
949	801.971831

L¢	¢
950	802.8169014
951	803.6619718
952	**804.5070423**
953	805.3521127
954	806.1971831
955	807.0422535
956	807.8873239
957	808.7323944
958	809.5774648
959	810.4225352
960	811.2676056
961	812.1126761
962	812.9577465
963	813.8028169
964	814.6478873
965	815.4929577
966	816.3380282
967	817.1830986
968	**818.028169**
969	818.8732394
970	819.7183099
971	820.5633803
972	821.4084507
973	822.2535211
974	823.0985915
975	823.943662
976	824.7887324
977	825.6338028
978	826.4788732
979	827.3239437
980	828.1690141
981	829.0140845
982	829.8591549
983	830.7042254
984	**831.5492958**
985	832.3943662
986	833.2394366
987	834.084507
988	834.9295775
989	835.7746479
990	836.6197183
991	837.4647887
992	838.3098592
993	839.1549296
994	840
995	840.8450704
996	841.6901408
997	842.5352113
998	843.3802817
999	844.2253521

L¢	*¢*
1000	**845.0704225**
1001	845.915493
1002	846.7605634
1003	847.6056338
1004	848.4507042
1005	849.2957746
1006	850.1408451
1007	850.9859155
1008	851.8309859
1009	852.6760563
1010	853.5211268
1011	854.3661972
1012	855.2112676
1013	856.056338
1014	856.9014085
1015	857.7464789
1016	858.5915493
1017	***859.4366197***
1018	860.2816901
1019	861.1267606
1020	861.971831
1021	862.8169014
1022	863.6619718
1023	864.5070423
1024	865.3521127
1025	866.1971831
1026	867.0422535
1027	867.8873239
1028	868.7323944
1029	869.5774648
1030	870.4225352
1031	871.2676056
1032	872.1126761
1033	**872.9577465**
1034	873.8028169
1035	874.6478873
1036	875.4929577
1037	876.3380282
1038	877.1830986
1039	878.028169
1040	878.8732394
1041	879.7183099
1042	880.5633803
1043	881.4084507
1044	882.2535211
1045	883.0985915
1046	883.943662
1047	884.7887324
1048	885.6338028
1049	**886.4788732**

L¢	*¢*
1050	887.3239437
1051	888.1690141
1052	889.0140845
1053	889.8591549
1054	890.7042254
1055	891.5492958
1056	892.3943662
1057	893.2394366
1058	894.084507
1059	894.9295775
1060	895.7746479
1061	896.6197183
1062	897.4647887
1063	898.3098592
1064	899.1549296
1065	**900**
1066	900.8450704
1067	901.6901408
1068	902.5352113
1069	903.3802817
1070	904.2253521
1071	905.0704225
1072	905.915493
1073	906.7605634
1074	907.6056338
1075	908.4507042
1076	909.2957746
1077	910.1408451
1078	910.9859155
1079	911.8309859
1080	912.6760563
1081	**913.5211268**
1082	914.3661972
1083	915.2112676
1084	916.056338
1085	916.9014085
1086	917.7464789
1087	918.5915493
1088	919.4366197
1089	920.2816901
1090	921.1267606
1091	921.971831
1092	922.8169014
1093	923.6619718
1094	924.5070423
1095	925.3521127
1096	926.1971831
1097	**927.0422535**
1098	927.8873239
1099	928.7323944

L¢	*¢*
1100	929.5774648
1101	930.4225352
1102	931.2676056
1103	932.1126761
1104	932.9577465
1105	933.8028169
1106	934.6478873
1107	935.4929577
1108	936.3380282
1109	937.1830986
1110	938.028169
1111	938.8732394
1112	939.7183099
1113	**940.5633803**
1114	941.4084507
1115	942.2535211
1116	943.0985915
1117	943.943662
1118	944.7887324
1119	945.6338028
1120	946.4788732
1121	947.3239437
1122	948.1690141
1123	949.0140845
1124	949.8591549
1125	950.7042254
1126	951.5492958
1127	952.3943662
1128	953.2394366
1129	954.084507
1130	***954.9295775***
1131	955.7746479
1132	956.6197183
1133	957.4647887
1134	958.3098592
1135	959.1549296
1136	960
1137	960.8450704
1138	961.6901408
1139	962.5352113
1140	963.3802817
1141	964.2253521
1142	965.0704225
1143	965.915493
1144	966.7605634
1145	967.6056338
1146	**968.4507042**
1147	969.2957746
1148	970.1408451
1149	970.9859155

L¢	*¢*
1150	971.8309859
1151	972.6760563
1152	973.5211268
1153	974.3661972
1154	975.2112676
1155	976.056338
1156	976.9014085
1157	977.7464789
1158	978.5915493
1159	979.4366197
1160	980.2816901
1161	981.1267606
1162	**981.971831**
1163	982.8169014
1164	983.6619718
1165	984.5070423
1166	985.3521127
1167	986.1971831
1168	987.0422535
1169	987.8873239
1170	988.7323944
1171	989.5774648
1172	990.4225352
1173	991.2676056
1174	992.1126761
1175	992.9577465
1176	993.8028169
1177	994.6478873
1178	**995.4929577**
1179	996.3380282
1180	997.1830986
1181	998.028169
1182	998.8732394
1183	999.7183099
1184	1000.56338
1185	1001.408451
1186	1002.253521
1187	1003.098592
1188	1003.943662
1189	1004.788732
1190	1005.633803
1191	1006.478873
1192	1007.323944
1193	1008.169014
1194	**1009.014085**
1195	1009.859155
1196	1010.704225
1197	1011.549296
1198	1012.394366
1199	1013.239437

L¢	*¢*
1200	1014.084507
1201	1014.929577
1202	1015.774648
1203	1016.619718
1204	1017.464789
1205	1018.309859
1206	1019.15493
1207	1020
1208	1020.84507
1209	1021.690141
1210	**1022.535211**
1211	1023.380282
1212	1024.225352
1213	1025.070423
1214	1025.915493
1215	1026.760563
1216	1027.605634
1217	1028.450704
1218	1029.295775
1219	1030.140845
1220	1030.985915
1221	1031.830986
1222	1032.676056
1223	1033.521127
1224	1034.366197
1225	1035.211268
1226	**1036.056338**
1227	1036.901408
1228	1037.746479
1229	1038.591549
1230	1039.43662
1231	1040.28169
1232	1041.126761
1233	1041.971831
1234	1042.816901
1235	1043.661972
1236	1044.507042
1237	1045.352113
1238	1046.197183
1239	1047.042254
1240	1047.887324
1241	1048.732394
1242	**1049.577465**
1243	1050.422535
1244	1051.267606
1245	1052.112676
1246	1052.957746
1247	1053.802817
1248	1054.647887
1249	1055.492958

L¢	*¢*
1250	1056.338028
1251	1057.183099
1252	1058.028169
1253	1058.873239
1254	1059.71831
1255	1060.56338
1256	1061.408451
1257	1062.253521
1258	1063.098592
1259	***1063.943662***
1260	1064.788732
1261	1065.633803
1262	1066.478873
1263	1067.323944
1264	1068.169014
1265	1069.014085
1266	1069.859155
1267	1070.704225
1268	1071.549296
1269	1072.394366
1270	1073.239437
1271	1074.084507
1272	1074.929577
1273	1075.774648
1274	1076.619718
1275	**1077.464789**
1276	1078.309859
1277	1079.15493
1278	1080
1279	1080.84507
1280	1081.690141
1281	1082.535211
1282	1083.380282
1283	1084.225352
1284	1085.070423
1285	1085.915493
1286	1086.760563
1287	1087.605634
1288	1088.450704
1289	1089.295775
1290	1090.140845
1291	**1090.985915**
1292	1091.830986
1293	1092.676056
1294	1093.521127
1295	1094.366197
1296	1095.211268
1297	1096.056338
1298	1096.901408
1299	1097.746479

L¢	*¢*
1300	1098.591549
1301	1099.43662
1302	1100.28169
1303	1101.126761
1304	1101.971831
1305	1102.816901
1306	1103.661972
1307	**1104.507042**
1308	1105.352113
1309	1106.197183
1310	1107.042254
1311	1107.887324
1312	1108.732394
1313	1109.577465
1314	1110.422535
1315	1111.267606
1316	1112.112676
1317	1112.957746
1318	1113.802817
1319	1114.647887
1320	1115.492958
1321	1116.338028
1322	1117.183099
1323	**1118.028169**
1324	1118.873239
1325	1119.71831
1326	1120.56338
1327	1121.408451
1328	1122.253521
1329	1123.098592
1330	1123.943662
1331	1124.788732
1332	1125.633803
1333	1126.478873
1334	1127.323944
1335	1128.169014
1336	1129.014085
1337	1129.859155
1338	1130.704225
1339	**1131.549296**
1340	1132.394366
1341	1133.239437
1342	1134.084507
1343	1134.929577
1344	1135.774648
1345	1136.619718
1346	1137.464789
1347	1138.309859
1348	1139.15493
1349	1140

L¢	*¢*
1350	1140.84507
1351	1141.690141
1352	1142.535211
1353	1143.380282
1354	1144.225352
1355	**1145.070423**
1356	1145.915493
1357	1146.760563
1358	1147.605634
1359	1148.450704
1360	1149.295775
1361	1150.140845
1362	1150.985915
1363	1151.830986
1364	1152.676056
1365	1153.521127
1366	1154.366197
1367	1155.211268
1368	1156.056338
1369	1156.901408
1370	1157.746479
1371	1158.591549
1372	***1159.43662***
1373	1160.28169
1374	1161.126761
1375	1161.971831
1376	1162.816901
1377	1163.661972
1378	1164.507042
1379	1165.352113
1380	1166.197183
1381	1167.042254
1382	1167.887324
1383	1168.732394
1384	1169.577465
1385	1170.422535
1386	1171.267606
1387	1172.112676
1388	**1172.957746**
1389	1173.802817
1390	1174.647887
1391	1175.492958
1392	1176.338028
1393	1177.183099
1394	1178.028169
1395	1178.873239
1396	1179.71831
1397	1180.56338
1398	1181.408451
1399	1182.253521

L¢	*¢*
1400	1183.098592
1401	1183.943662
1402	1184.788732
1403	1185.633803
1404	**1186.478873**

L¢	*¢*
1405	1187.323944
1406	1188.169014
1407	1189.014085
1408	1189.859155
1409	1190.704225

L¢	*¢*
1410	1191.549296
1411	1192.394366
1412	1193.239437
1413	1194.084507
1414	1194.929577

L¢	*¢*
1415	1195.774648
1416	1196.619718
1417	1197.464789
1418	1198.309859
1419	1199.15493
1420	**1200**

Fig. A3.35. Comparison between *lucents* and cents (1420-et and 1200-et).

Notice that the 12-et has four notes in common with the 1420-et and another eight that are 0.2816901¢ apart from the closest *lucent* step (Fig. A3.36).

The 12-et and 1420-et compared			
	Closest 1420-et interval		
12-et (¢)	L¢	¢	Difference (¢)
0	0	0	0
100	118	99.71830986	0.2816901
200	237	200.2816901	0.2816901
300	355	300	0
400	473	399.7183099	0.2816901
500	592	500.2816901	0.2816901
600	710	600	0
700	828	699.7183099	0.2816901
800	947	800.2816901	0.2816901
900	1065	900	0
1000	1183	999.7183099	0.2816901
1100	1302	1100.28169	0.2816901
1200	1420	1200	0

Fig. A3.36. Comparison between *lucents* and semitones (12-et).

The most consonant interval in just intonation, the pure fifth (ratio 3/2), differs by approximately 0.25 ¢ from the closest step in the 1420-et and the next consonance, the pure major third (ratio 5/4), by 0.12 ¢. These small discrepancies are not substantial when considering low number ratios and therefore 1420-et could be used to apply just intonation.

Although the *lucent tree* does not follow the pattern for this group for the creative-comparative strategy, it served as an inspiration for an instrument that was developed soon after as a hybridising idea incorporating other sound producing actions as part of the instrument capabilities. This instrument follows a similar spiral pattern to the one used for the *lucent tree*, incorporating a weighted railing-plucking device for the realisation of microdiscrete gliding pitch. The new instrument employs the 88 notes from the 1420-et that approximate to the 88-et, this tuning being devised by using 88 consecutive Harrison fifths transposed to the first octave when exceeding the octave. Instead of plucking strings, it plucks metal spikes with planar shape (as used for *mbiras*). It also incorporates elements from a Kenyan horn to provide an axial structure to support the spiral. This horn is named *abu* and belongs to the Luo community of Kenya (Fig. A3.37). In the same way that the *abu* joins together three or four gourds to form a large tube,[17] here also four sections (Fig. A3.37) are joined together to form a tube (in this case straight), the last globular section imitating the West African *shekere* (bottle gourd with beaded skirt) as a shaker and extension of the wind instrument, so in this case with a wide hole at the bottom. All these elements cannot be sounded at the same time by one action unlike the *waterslap* (slapping action). In order to sound all the elements at once, additional players have to be incorporated in the performance, not only gaining sonority but also corporeal expression.

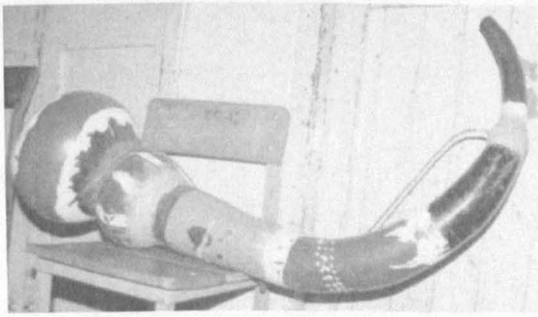

Fig. A3.37. *Abu* from the Luo community of Kenya.

[17] Senoga-Zake, G. W. 2000. *Folk Music of Kenya*. Revised edition. Nairobi, Kenya: Uzima Press.

This instrument requires carving four blocks of wood for four different sections that mount together to form a long blowing tube with two globular endings. The ending globular section rests on a small stand with a support band. It has a spiral frame (developed around the tube) with thumb piano tongues (they can be made from hammered bicycle spikes) following the edge of the spiral. The tongues are plucked by a heavy weighted plucking device that can slide around the spiral in one direction or the other while another performer can blow and another one can shake a stone net placed around the lower globular section of the instrument (D in Fig. A3.39)

This instrument can achieve faster glissando than the *lucent tree* thanks to the tuning and faster plucking speed, since this can be done by rotating the blowing mouth area so the plucking device gains momentum either in one direction or the other. The name of this instrument integrates the name Harrison, honouring his tuning discovery, with the *mbira* and *Luo-abu* terms incorporated from the African folklore. It is named the *Harrison Luo-abu mbira.*

Looking at the diagram in Fig. A3.39, we can see a detail of the tube connected to the mouth-piece (block A) so the rotation of the instrument does not affect the blowing action. There are also two sliding keys placed at the end of this top part that can be used for ornamental effects with glissando capability included. The fine-tuning of the instrument can be done by turning part D so the thread of C coil-fitted in section D is adjusted.

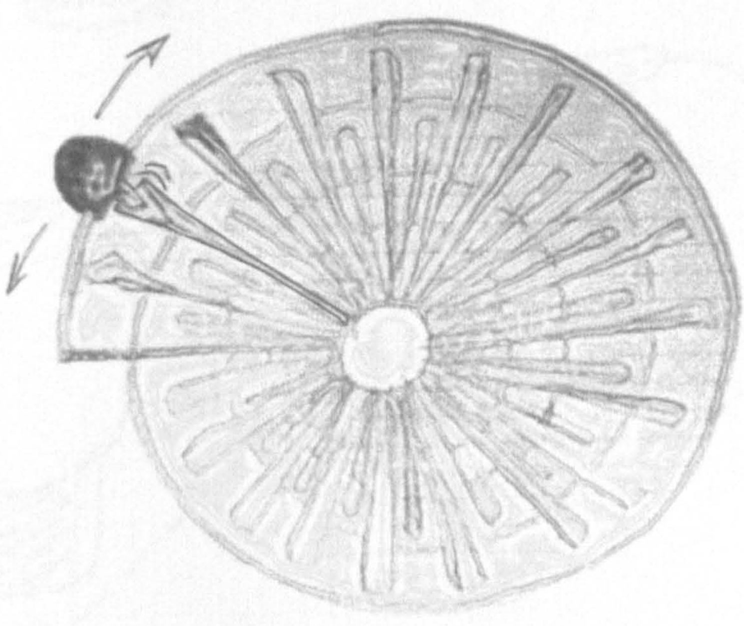

Fig. A3.38. View from below to above of the spikes and rail system without frame.

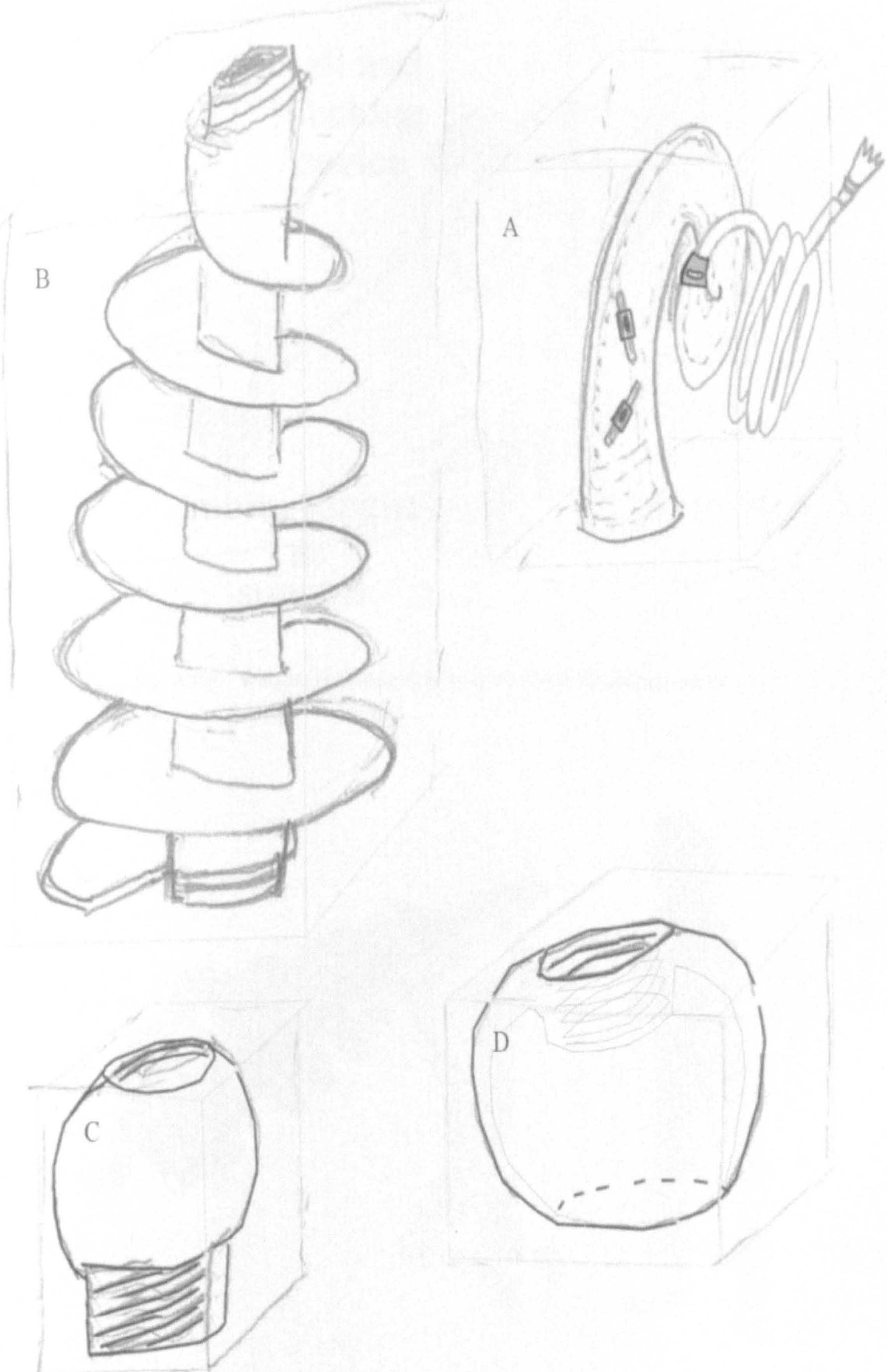

Fig. A3.39. Four blocks of wood from which the *Harrison Luo-abu mbira* is carved.

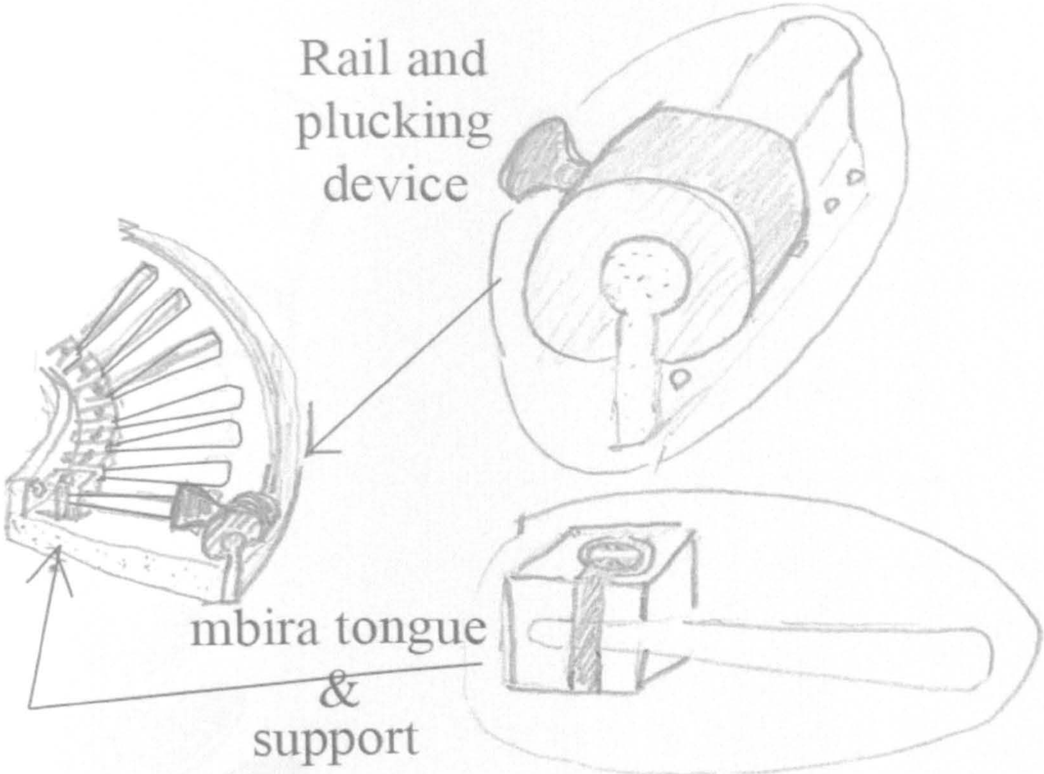

Fig. A3.40. Weighted plucking device on rail and spike support details.

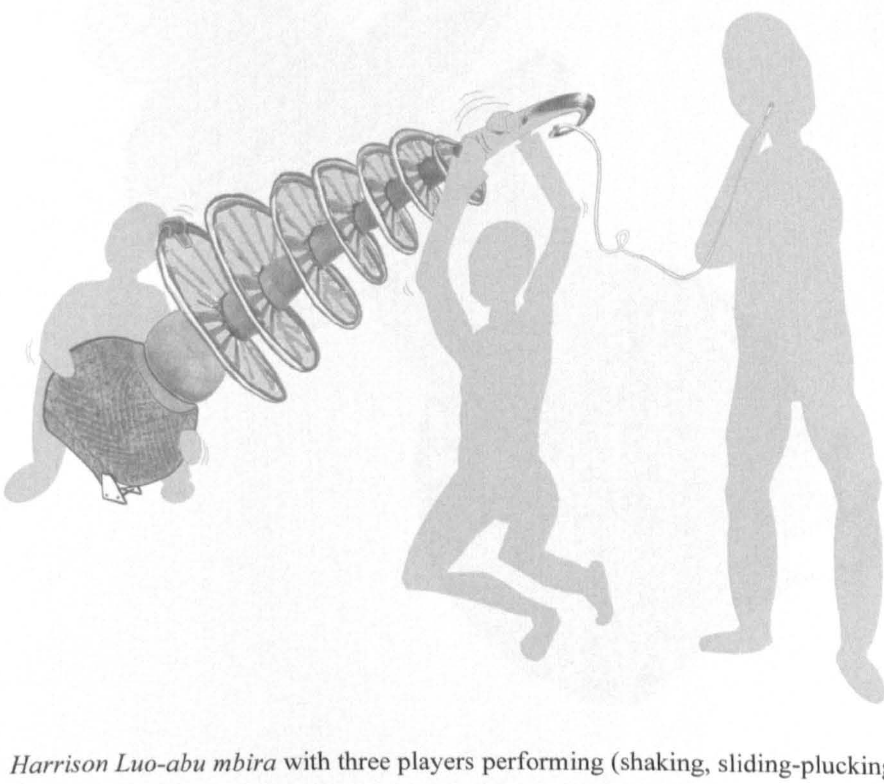

Fig. A3.41. *Harrison Luo-abu mbira* with three players performing (shaking, sliding-plucking and blowing).

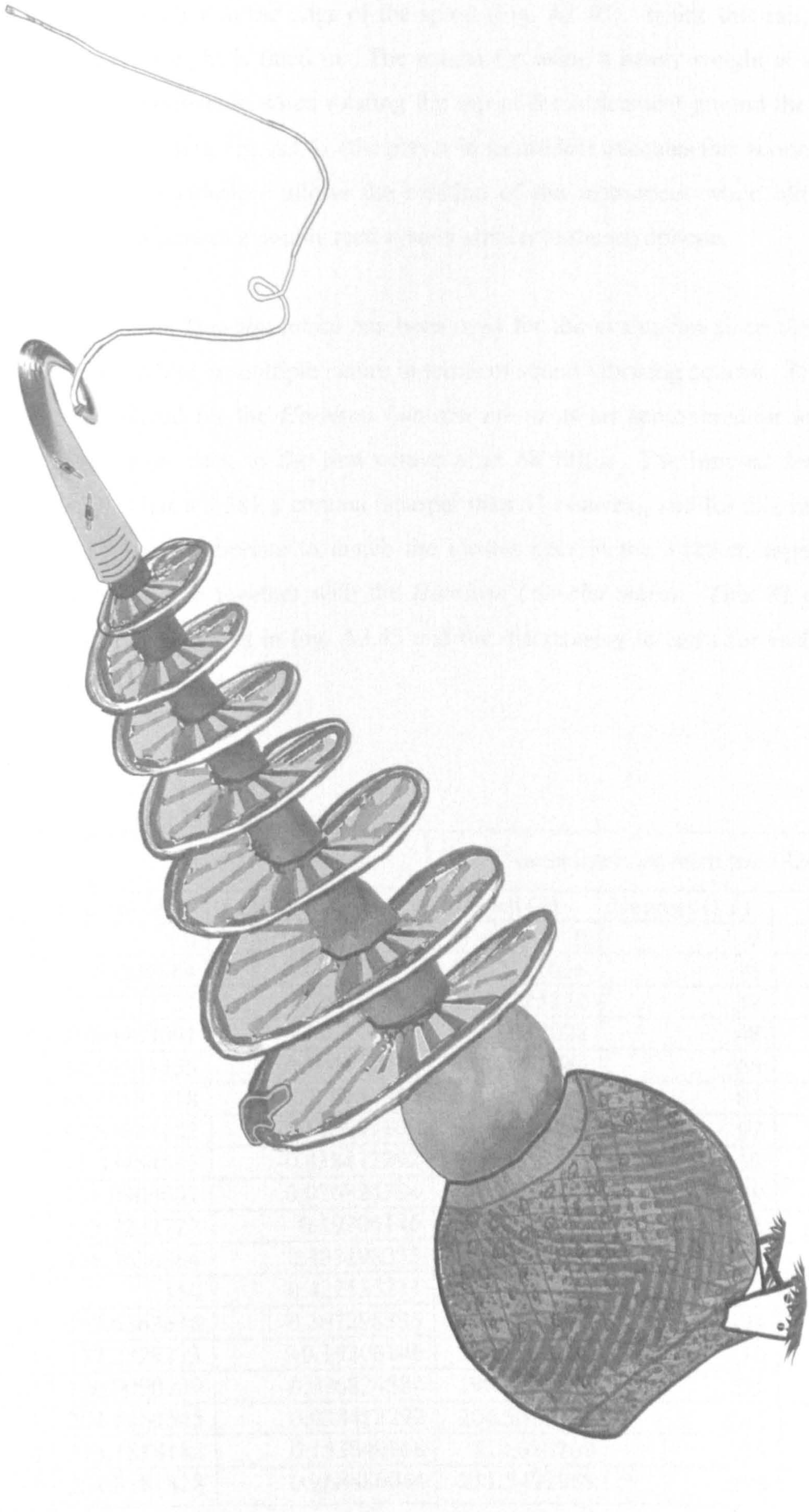

Fig. A3.42. Harrison *Luo-abu mbira* (88-et).

The metal rail is fitted at the edge of the spiral (Fig. A3.40). Inside this rail, a plucking device of heavy weight is fitted in. The reason for using a heavy weight is to allow the device to gain momentum when rotating the top of the instrument around the axis of the instrument as shown in Fig. A3.41 (the player in the middle executes this action). The tube attached to the mouthpiece allows the rotation of the instrument while blowing. The mouthpiece incorporates a double reed system similar to the saxophone.

Only the *Harrison Luo-abu* mbira has been used for the evaluation since the *lucent tree* does not have hybrid or multiple nature in terms of sound vibrating actions. The 88-et was initially considered for the *Harrison Luo-abu mbira* as an approximation to Harrison's tuning that comes back to the first octave after 88 fifths. The interval formed by 88 *Harrison fifths* has a 3.381 ¢ comma (sharper than 51 octaves), and for this reason is here considered more appropriate to match the closest note in the 1420-et, especially when using the *lucent tree* together with the *Harrison Luo-abu mbira.* This 88 notes-to-the-octave tuning is provided in Fig. A3.43 and the discrepancy in cents for each step in the 88-et are also indicated.

88-et			Closest intervals from the 1420-et		
Step	Interval (¢)	1420-et discrep.	Interval (¢)	Degrees (L¢)	Cont.
0	0	0	0	0	16
1	13.63636364	0.115236876	13.52112676	16	16
2	27.27272727	0.230473752	27.04225352	32	16
3	40.90909091	0.345710627	40.56338028	48	16
4	54.54545455	-0.384122919	***54.92957746***	65	17
5	68.18181818	-0.268886044	68.45070423	81	16
6	81.81818182	-0.153649168	81.97183099	97	16
7	95.45454545	-0.038412292	95.49295775	113	16
8	109.0909091	0.076824584	109.0140845	129	16
9	122.7272727	0.19206146	122.5352113	145	16
10	136.3636364	0.307298335	136.056338	161	16
11	150	0.422535211	149.5774648	177	16
12	163.6363636	-0.307298335	***163.943662***	194	17
13	177.2727273	-0.19206146	177.4647887	210	16
14	190.9090909	-0.076824584	190.9859155	226	16
15	204.5454545	0.038412292	204.5070423	242	16
16	218.1818182	0.153649168	218.028169	258	16
17	231.8181818	0.268886044	231.5492958	274	16

88-et			Closest intervals from the 1420-et		
Step	Interval (¢)	1420-et discrep.	Interval (¢)	Degrees (L¢)	Cont.
18	245.4545455	0.384122919	245.0704225	290	16
19	259.0909091	-0.345710627	***259.4366197***	307	17
20	272.7272727	-0.230473752	272.9577465	323	16
21	286.3636364	-0.115236876	286.4788732	339	16
22	300	0	300	355	16
23	313.6363636	0.115236876	313.5211268	371	16
24	327.2727273	0.230473752	327.0422535	387	16
25	340.9090909	0.345710627	340.5633803	403	16
26	354.5454545	-0.384122919	***354.9295775***	420	17
27	368.1818182	-0.268886044	368.4507042	436	16
28	381.8181818	-0.153649168	381.971831	452	16
29	395.4545455	-0.038412292	395.4929577	468	16
30	409.0909091	0.076824584	409.0140845	484	16
31	422.7272727	0.19206146	422.5352113	500	16
32	436.3636364	0.307298335	436.056338	516	16
33	450	0.422535211	449.5774648	532	16
34	463.6363636	-0.307298335	***463.943662***	549	17
35	477.2727273	-0.19206146	477.4647887	565	16
36	490.9090909	-0.076824584	490.9859155	581	16
37	504.5454545	0.038412292	504.5070423	597	16
38	518.1818182	0.153649168	518.028169	613	16
39	531.8181818	0.268886044	531.5492958	629	16
40	545.4545455	0.384122919	545.0704225	645	16
41	559.0909091	-0.345710627	***559.4366197***	662	17
42	572.7272727	-0.230473752	572.9577465	678	16
43	586.3636364	-0.115236876	586.4788732	694	16
44	600	0	600	710	16
45	613.6363636	0.115236876	613.5211268	726	16
46	627.2727273	0.230473752	627.0422535	742	16
47	640.9090909	0.345710627	640.5633803	758	16
48	654.5454545	-0.384122919	***654.9295775***	775	17
49	668.1818182	-0.268886044	668.4507042	791	16
50	681.8181818	-0.153649168	681.971831	807	16
51	695.4545455	-0.038412292	695.4929577	823	16
52	709.0909091	0.076824584	709.0140845	839	16
53	722.7272727	0.19206146	722.5352113	855	16
54	736.3636364	0.307298335	736.056338	871	16
55	750	0.422535211	749.5774648	887	16
56	763.6363636	-0.307298335	***763.943662***	904	17
57	777.2727273	-13.71318822	777.464789	920	16
58	790.9090909	-0.076824584	790.9859155	936	16
59	804.5454545	0.038412292	804.5070423	952	16
60	818.1818182	0.153649168	818.028169	968	16
61	831.8181818	0.268886044	831.5492958	984	16

88-et			Closest intervals from the 1420-et		
Step	Interval (¢)	1420-et discrep.	Interval (¢)	Degrees (L¢)	Cont.
62	845.4545455	0.384122919	845.0704225	1000	16
63	859.0909091	-0.345710627	***859.4366197***	1017	17
64	872.7272727	-0.230473752	872.9577465	1033	16
65	886.3636364	-0.115236876	886.4788732	1049	16
66	900	0	900	1065	16
67	913.6363636	0.115236876	913.5211268	1081	16
68	927.2727273	0.230473752	927.0422535	1097	16
69	940.9090909	0.345710627	940.5633803	1113	16
70	954.5454545	-0.384122919	***954.9295775***	1130	17
71	968.1818182	-0.268886044	968.4507042	1146	16
72	981.8181818	-0.153649168	981.971831	1162	16
73	995.4545455	-0.038412292	995.4929577	1178	16
74	1009.090909	0.076824584	1009.014085	1194	16
75	1022.727273	0.19206146	1022.535211	1210	16
76	1036.363636	0.307298335	1036.056338	1226	16
77	1050	0.422535211	1049.577465	1242	16
78	1063.636364	-0.307298335	***1063.943662***	1259	17
79	1077.272727	-0.19206146	1077.464789	1275	16
80	1090.909091	-0.076824584	1090.985915	1291	16
81	1104.545455	0.038412292	1104.507042	1307	16
82	1118.181818	0.153649168	1118.028169	1323	16
83	1131.818182	0.268886044	1131.549296	1339	16
84	1145.454545	0.384122919	1145.070423	1355	16
85	1159.090909	-0.345710627	***1159.43662***	1372	17
86	1172.727273	-0.230473752	1172.957746	1388	16
87	1186.363636	-0.115236876	1186.478873	1404	16
88	1200	0	1200	1420	16

Fig. A3.43. Comparison between the 88-et and its substitute contained in the 1420-et.

Considering that there is an average absolute deviation from the 88-et intervals of 0.211267761¢ in relation to the closest intervals from the 1420-et, considering the thumb piano sound quality produced by the *Harrison Luo-abu mbira* pitches adjustments between approximately 0.1 cents and 0.4 cents, would not make any difference to the sound perceived while the accumulative error would be avoided.

The *Harrison Luo-abu mbira* requires high coordination skills when performing the zigzag glissando patterns proposed in group I, since the player ought to perform the rotation with one hand while positioning the plucking device with the other and even using the hand for plucking (moving the plucking device with one hand) when the pattern requires quick changes of direction for short spans of pitch. Even if two players were used for this purpose, the coordination between the players would also require high skill.

The last two prototypes of the *conic bellophone* find inspiration in the development process of the *Harrison Luo-abu mbira*, in the sense that they incorporate additional sound producing actions. The *lucent tree* and the *Harrison Luo-abu mbira* inspired succeeding instrument developments that that were developed from scratch starting from a tuning concept.

A3.3.2 Prototype group 2: Cylindrical-helix layouts

The main idea behind this shape is to improve the continuity in sequential microdiscrete pitch achievements developed when following the spiral layout. In this case, this is mainly done by trying to improve parallel glissandi capabilities. When using a mallet instrument, it would be ideal to achieve parallel glissandi by simply keeping the distance between two mallets in one hand equal. The same concept also applies to keyboards and any other instruments that keep the same interval when the distance between the sound activating contact points is kept constant.

In this group, the performer follows rotation movements around his body (as the axis of the rotation) in the same way as with the non-cylindrical helix layout group. If the sounding bodies get smaller going up in a spring (for example), the arms can have more expansive movement, which is ideal for mallet instruments. When employing twist and rotation of the chest (combined with a rotation of the head), the visualisation is clearer when the smaller sounding bodies are placed in the higher part of a cylindrical helix shaped frame.

All the performer's movements in general explained for the non-cylindrical helix also apply to this group, with the already mentioned difference that the arms are more comfortable playing in the upper register in this group, when the smaller sounding bodies are placed on top of the cylindrical spring-like frame with the performer inside the frame.

The same zigzag exercise exploring proposed for the previous group is here implemented using two mallets in one hand, trying several different intervals, or the equivalent for keyboards or other instruments involving different activating actions. If we use numerical notation for the 96-et, the smallest step zigzag exercise would be: 0-1-2-1-2-3-2-3-4-3-4-5, etc., and the parallel zigzag glissando one tone above: 16-17-18-17-18-19-18-19-20-19-20-21, etc.

When considering the axis of a cylindrical helix frame in vertical position, the same frame can also be used with an internal and external layout of sounding bodies at the same time. When placing the contact points used to produce the sounds in a cylindrical helix layout with a horizontal axis, the layout can be implemented with several frames if the sounding bodies are placed outside the frame.

A3.3.2.1 *Coil conic bellophone* (II_a)

The *coil conic bellophone* with the internal and external layouts incorporated already improves the *spiral conic bellophone* by only requiring one single frame to support both layouts of *conic bells*, while the striking points are always at an ideal distance to apply vertical and diagonal glissando.

In order to achieve the zigzag pattern, 180 degrees can be comfortably covered with each hand, and with two mallets in each hand two different parallel glissandi at the same time can be also achieved. If the striking points are kept equal throughout the whole range, the glissandi will have a constant pitch interval, and if this distance gets closer as one goes up in the register, the interval gets smaller as one increases pitch (clockwise direction when looking above for the internal layout, and anticlockwise for the external layout).

The *coil conic bellophone* and all the instruments from this group that can take internal and external layout of sound producing bodies constitute a body of instruments that share group performance functional capabilities. This functionality refers to the use of a group of performers to play one single instrument and in most of the cases requiring coordination between the players involving parallel movements, which are ideal for choreographing the performance.

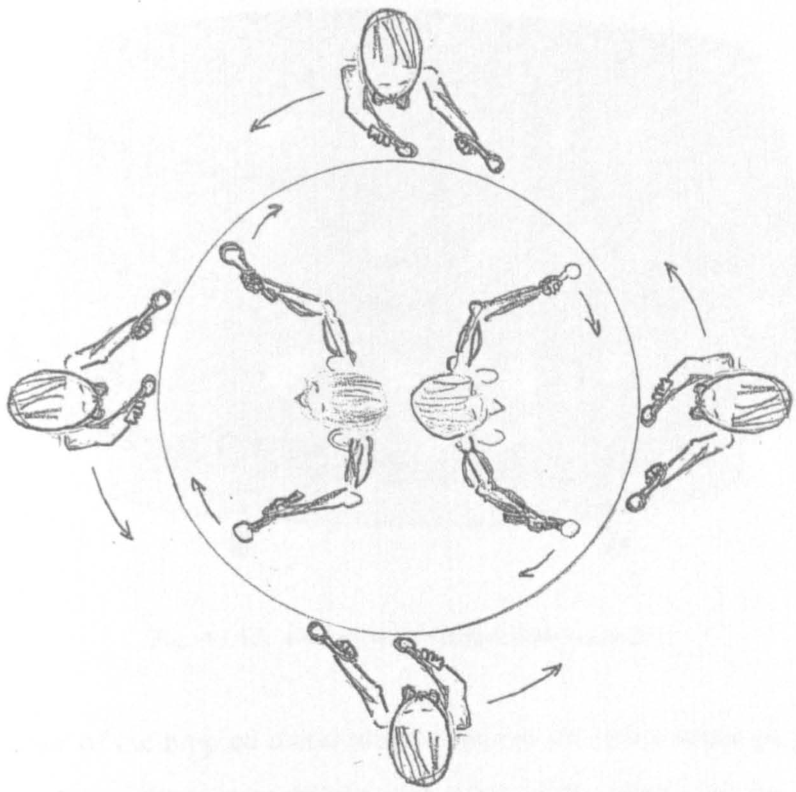

Fig. A3.44. Sliding upward rotations inside and outside the *coil conic bellophone*'s frame.

A3.3.2.2 *Coil sarunay* (or samurai skirt) (II_b)

The brightness of the *sarunay*, a native tuned percussion instrument from Philippines, is considered ideal for the devising of a micro-intervallic and sliding pitch instrument that can provide a fairly unique piercing metal sound. The *coil sarunay* design starts with a long sequence of nippled metal plates strung together (such as the ones of the *sarunay*) which are mounted on a wooden skirt of rounded panels, supported by six bars leaning on a cylindrical frame (see Fig. A3.45, in which three circles have been used instead of a spiral, here considered an ideal shape for the achievement of microdiscrete-sliding pitch). The possibility of also incorporating a similar skirt (but concave instead of convex) in the inner area of the cylindrical frame is considered a high register pitch extension. Both wooden skirts have holes where the resonator for the corresponding key can be fitted (if required), always considering the space left between the skirt and the cylindrical supporting structure.

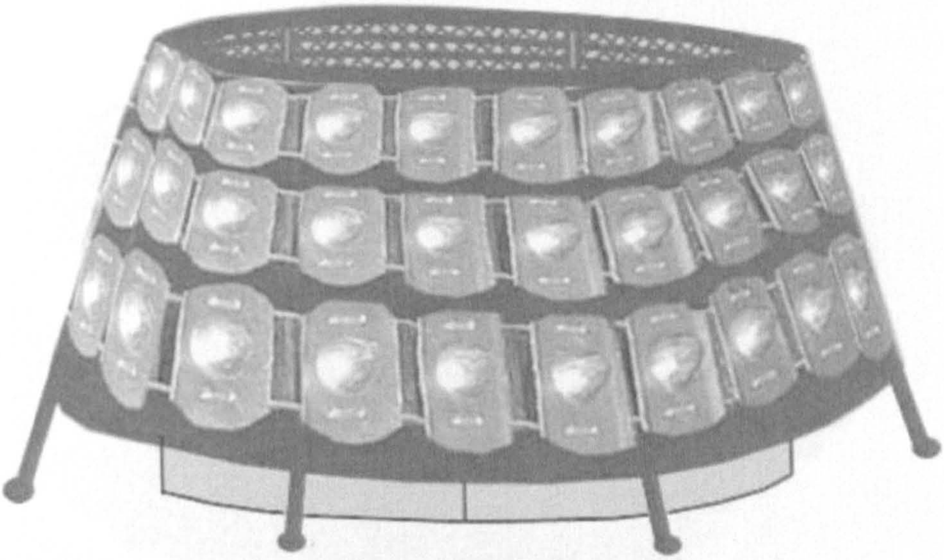

Fig. A3.45. *Coil sarunay* (external layout only).

The rounded shape of the nippled metal plates requires precision when playing. However, this shape allows the sticks to gain momentum when sliding them for the achievements of glissandi. The zigzag pattern with parallel glissandi proposed for this group, can be achieved in the outer layout by means of two players following the required sequence. One single player can also achieve the same pattern, if the chosen interval can be reached in a comfortable position. When using the inner layout, one player can achieve the same exercise, covering any interval contained in the layout. In order to get the notes lined up in vertical, the appropriated ratio for the cylinder has to be chosen in relation to the considered chromatic step.

The resonators used with the *sarunay* inspired some of the ideas considered for the last *conic bellophone* prototype, since it also incorporates resonators.

A3.3.2.3 *Ring of roses* (*mokugyophone* or *temple blockophone coil*) (II_c)

The *ring of roses* consists of Japanese temple blocks following a micro-interval sequence in chromatic order around a cylindrical helix frame (see Fig. A3.46, Fig. A3.47 and Fig. A3.48). This instrument can be conceived by means of extending its upper range, and incorporating an internal layout for one or two additional players.

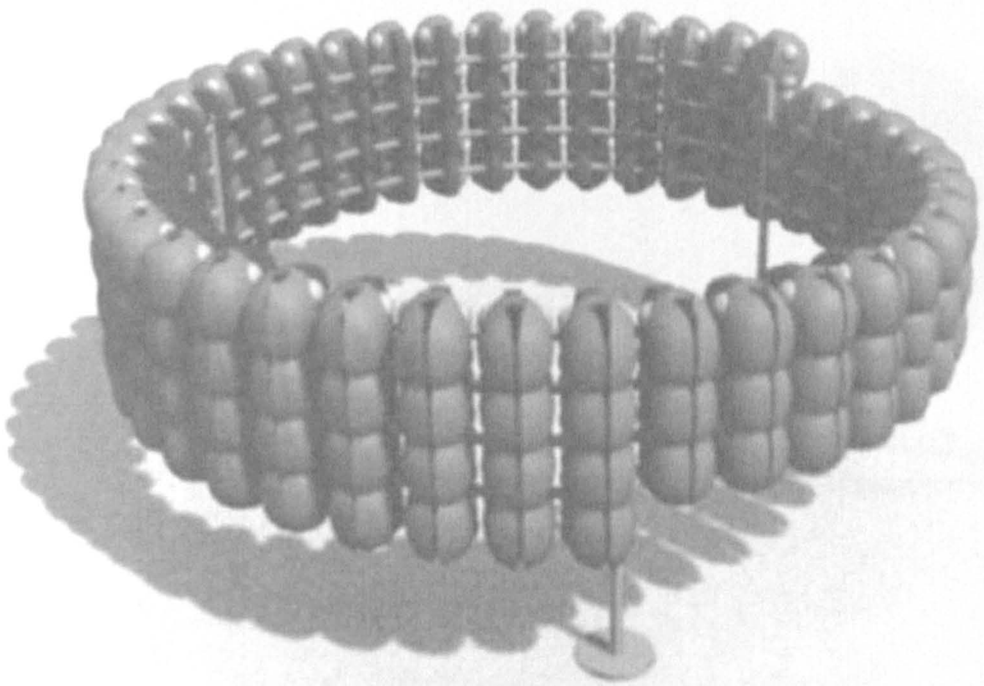

Fig. A3.46. *Ring of roses* in external layout (side view).

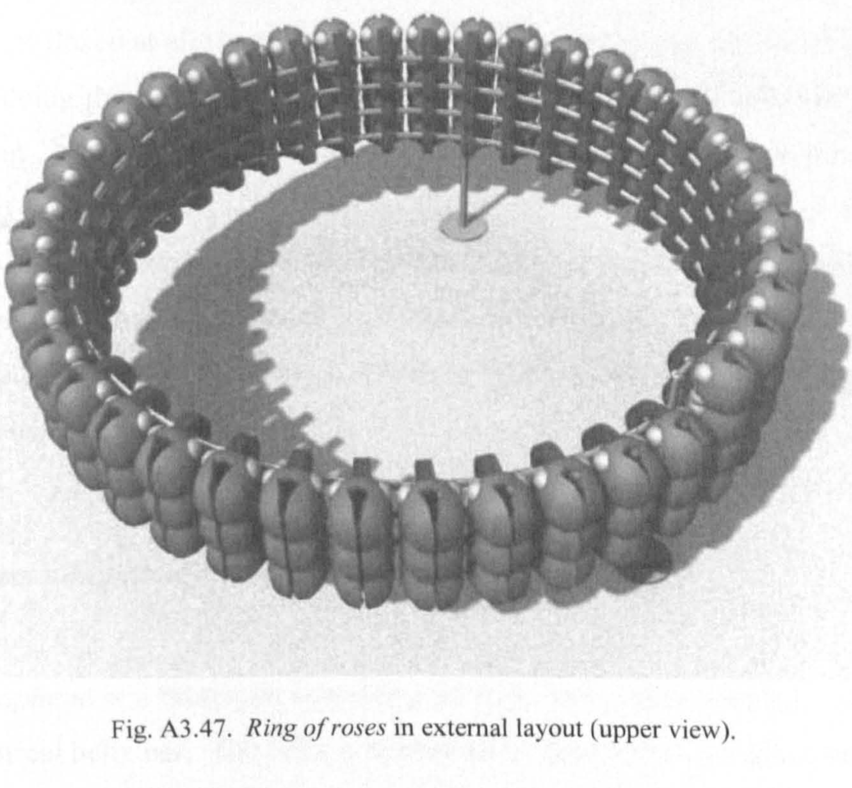

Fig. A3.47. *Ring of roses* in external layout (upper view).

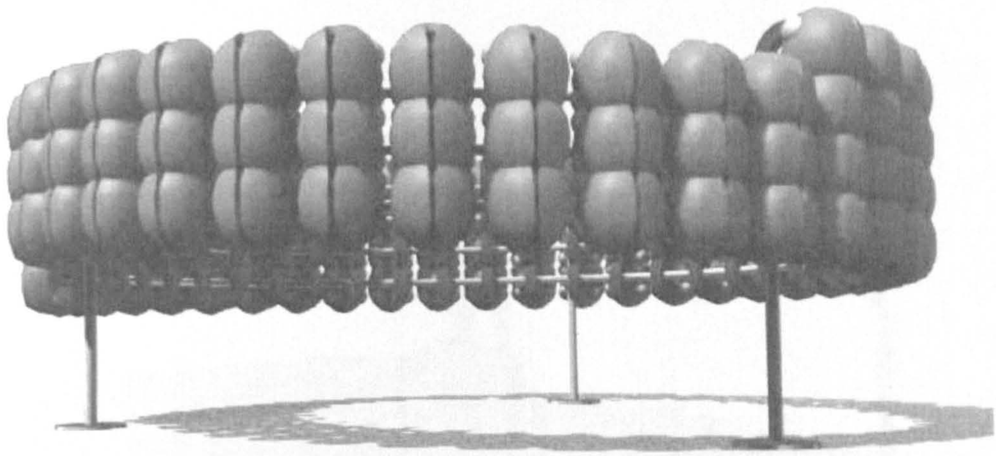

Fig. A3.48. *Ring of roses* in external layout (low side view).

The zigzag pattern using parallel glissandi proposed for this group requires an intense exercise involving strength and balance, especially required for the external players to keep the heavy wooden sticks sliding smoothly at the side of the player (who has to walk fast or even run to keep the appropriate gliding speed. The changes of direction also require that the legs are kept flexed at all times (knees bent). This exercise can comfortably take up to four players (doing the same pattern, and equally placed around the helix) or six if using the inner layout. It is an ideal warm up exercise for group performances on the instrument.

All of the *conic bellophone* layouts can adopt the bent knee technique previously explained for this instrument, since it can be used towards an effective performance on the lower notes (in position) or even towards an effective achievement of diagonal (and vertical) glides across the layout.

A3.3.2.4 *Bass tubaphone* (or *bass tube-o-phone*) (II_d)

The *bass tubaphone* is a prototype consisting of wide brass tubes hanging from the nodes from a cylindrical helix bar. The helix is supported by four poles curved on top, and joined together in one point to provide stronger support to the whole set of tubes (Fig. A3.49 and

Fig. A3.50). This instrument is designed so it can be played from the outside, the inside, or both.

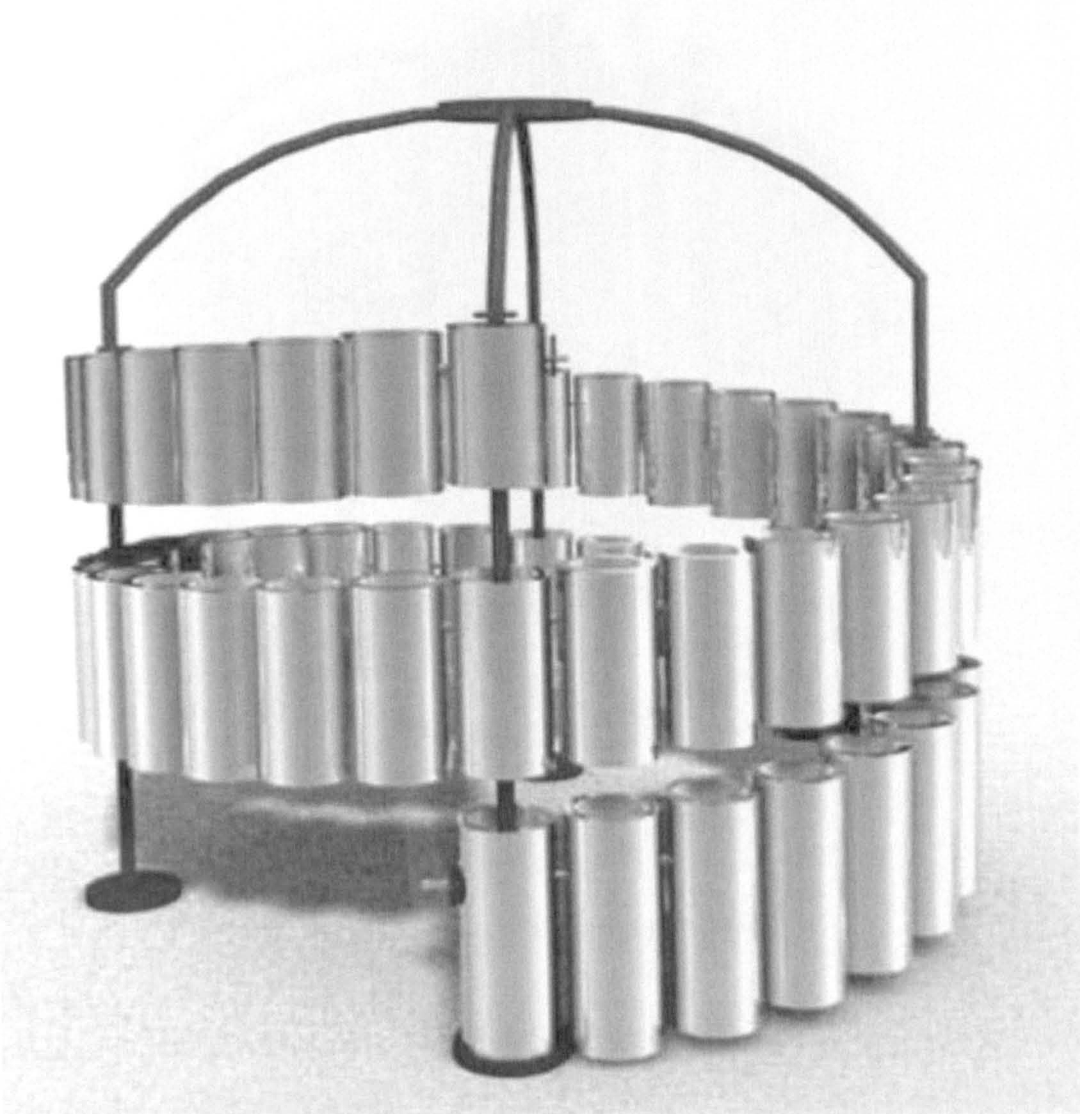

Fig. A3.49. *Bass tubaphone* (frontal perspective).

The tubes have all the same diameter to keep striking points at equal distances between next-door tubes (the thickness changes to keep an even tone). The space between neighbouring tubes in the spiral is kept constant, and ideal striking points drawing a linear spiral, so parallel glissandi with both parts changing pitch at the same pace can be easily achieved. This is done by keeping the distance between mallets constant and hitting the tubes at contiguous extremes of the chosen tubes. The zigzag pattern proposed for this group is easy to achieve when sliding mallets and playing from the inside, but if striking each single note, trying to raise the volume or emphasise the attack, the technique could be very difficult due to the verticality of the striking points.

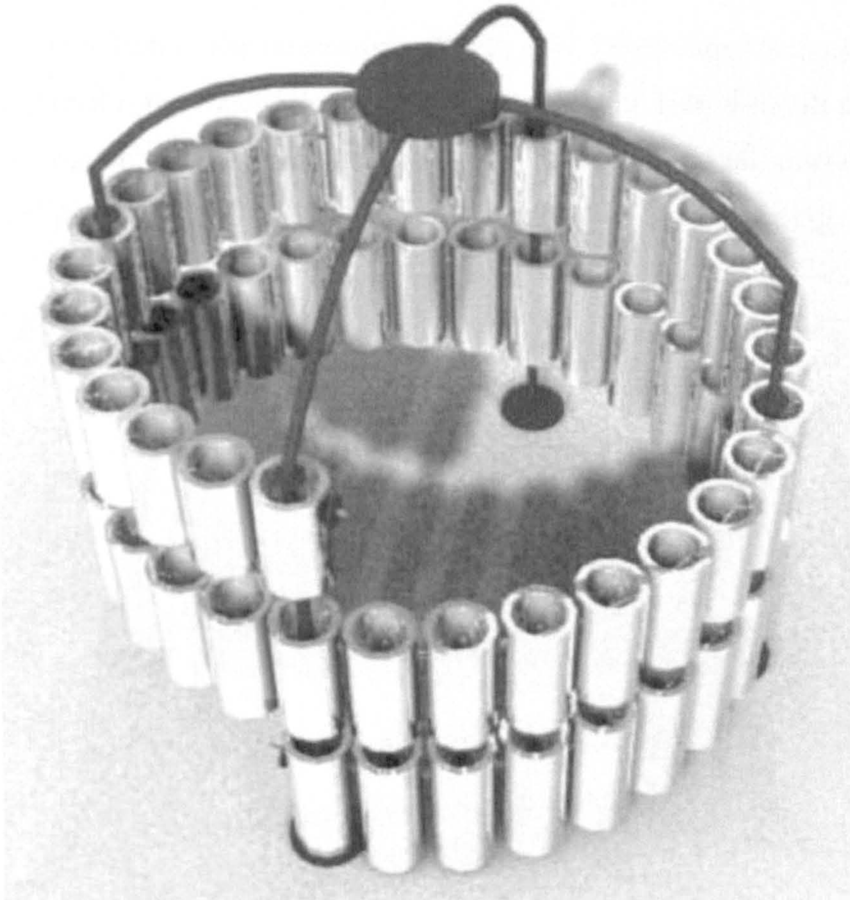

Fig. A3.50. *Bass tubaphone* (aerial view).

By having the poles going through the tubes, this design avoids having gaps that are not suitable for micro-discrete sliding pitch mallet instruments. The poles are covered with sponge to stop the tubes hitting the poles and making additional unwanted sounds

The *conic bellophone* receives little feedback from this variant cylindrical helix design; what is important about experimenting with tubes is that they can be obtained in a wide range of diameters, thicknesses and materials, making them an ideal media for experimentation with shallow metal bodies that can help to predict the acoustical behaviour when working with shapes different from the tube. This research does not experiment with a wide range of variant materials with the *conic bell*, but using tubes would be the starting point for such research in a future on a low budget basis.

The use of poles going through the tubes inspired the *concentric conic bellophone* (P46 / VI_6) in which bars going through the sounding bodies (*conic bells*) are also employed.

A3.3.2.5 *Rotary harps* (II_e)

This design exploits further the mechanism of the *cyclic Whitechapel bellophone* (P_2 / I_b). It has two additional rolls, which are cylindrical. It would be very difficult to play a harp in which the strings are placed forming a cylindrical helix, and instead several cylinders in graded sizes are placed in rotating horizontal axes, supported by a frame (Fig. A3.51).

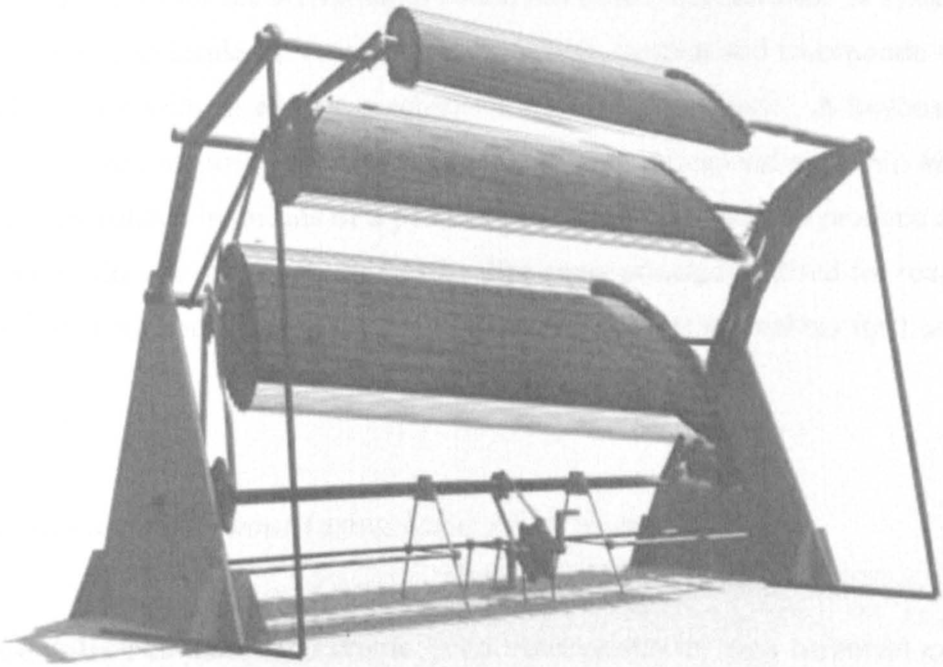

Fig. A3.51. *Rotary Harps.*

The lowest note for each cylinder is the longest string, which can be used as a starting point for an upward microdiscrete pitch glide towards the highest note (the shortest in the cylinder). This glide can be continued with a skilful change to the lowest note of the following cylinder (since they are supposed to have the same tuning) and proceeding in the same way to keep the upward direction. If the glide requires a change of direction at the highest note of the cylinder then there is no change of direction required since the notes are tuned in the same way no matter which half of the cylinder is used to descend. The main reason for doing so is to provide the capability of playing fast microdiscrete up-down cyclic gliding sequence. This idea needs to be explored further through other designs so as to cover other intervals rather than the interval covered by each cylinder.

Using plectrum nails, the composition proposed for this group can be easily achieved. The parallel glissando can be achieved in a wide range of different intervals. The zigzag movements present some difficulties when there is a change or cylinder involved, but is still possible since one note is shared between each two contiguous cylinders.

There are several ways in which the *coil conic bellophone* could benefit from incorporating a pedalling mechanism for the activation of sound activation mechanisms. A system could be used to roll helices inside the resonators and prolong, sustain and incorporate a vibrato quality as it is done with an electric mechanism with the vibraphone. A keyboard could switch a mechanism to push rubber wheels against the corresponding *conic bell* while those wheels are rotated by means of a pedalling mechanised system to produce a friction sound similar to the one of the *singing bowls*. The same principal utilised for rotating sets of brushes (for continuous fixed pitch brushing sound) or rotating mallets for fast tremolo effects.

A3.3.2.6 *Uchiwa taikophone* (using *kazura suzu* as mallets) (II_f)

The *uchiwa taiko,* like most hand drums, is an instrument with high corporeal expression capabilities. When tuned chromatically in semitones or in quartertones, one performer could be assigned to each drum so the performance can be minutely choreographed. The handle used by the *uchiwa taiko* can easily be fitted into a frame and taken out for group performance passages within the same composition if an easy to handle clamp system is incorporated into the frame.

With membranophones, we are unlikely to appreciate intervals smaller than quartertones, but eighthtones and sixteenthtones can always be used to slow down the change of pitch in time when performing a microdiscrete glide. Since an *uchiwa taiko* cannot be tuned once it has been made, the concept here conceived is a mechanism consisting of two circles that fit into the other by means of a screwing system, covering the edges of the *uchiwa taiko* and making a slight pressure against the leather, so when they are rotated in opposite direction against each other, the membrane is either tightened or loosened, allowing fine-tuning (Fig. A3.52).

A cylindrical helix frame for the *uchiwa taiko* drums also allows the performance of several players moving around the frame or a player (or two) placed inside to achieve faster microdiscrete-sliding-pitch passages (Fig. A3.54)

The zigzag pattern proposed for this group can only be achieved through mallet striking techniques (rather than sliding techniques) in the outer layout. In the inner layout, sliding mallet techniques are possible but there is a danger of hitting the frames. Therefore the frames ought to be protected with soft material that does not produce sound when hit. The amplitude of the sound when sliding the mallets though is not very loud. The parallel glissando required for this pattern can be achieved if both notes can be reached by one player in the inner layout, but a second player in either the inner or outer layout is required if striking techniques are employed.

Using clamps so the *conic bells* can be removed and used with a mallet (or with inner clappers and a handle as handbells) is a possibility for all prototypes of the *conic bellophone* that have been developed through the comparative process with this design.

The *kazura suzu* is a handset of jingle bells, which are hung from a little tree-like structure supported with a handle used to hold and shake the instrument (Fig. A3.53). Extending the handle to have a mallet for striking the *uchiwa taiko*, while the bells are producing a shaking sound –with the option of also incorporating a muting rubber cover hanging from the set, increases the corporeal expression when the *uchiwa taikos* are played individually by a large group of performers. Adding a rubber bag hanging from each set is considered to cover and mute the sleigh bells when necessary.

Fig. A3.52. An example of *uchiwa taiko* placed in a regular frame.

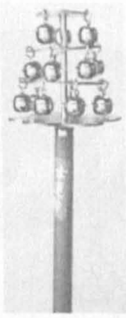

Fig. A3.53. *Kazura suzu.*

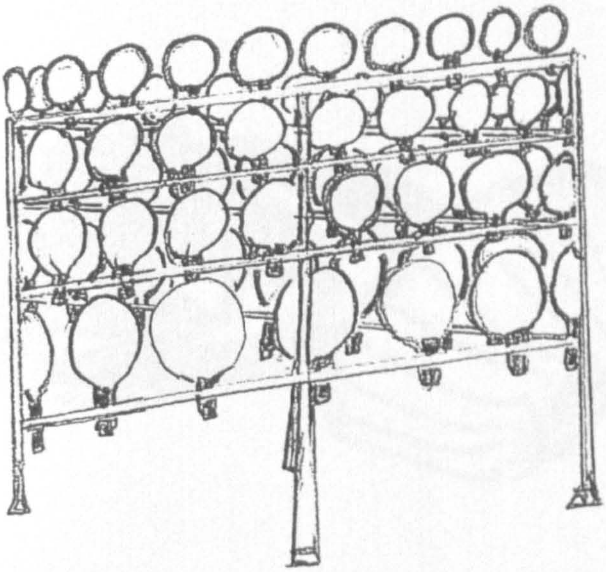

Fig. A3.54. *Uchiwa taikophone.*

A3.3.2.7 *Sliding French horn* (II_g)

Since we are dealing with a blown instrument, and the French horn tube is already in coil layout, we have adopted Carrillo's sixteenthtone French horn (see Appx 1) as a starting point. The idea is to add two different types of slide mechanisms, one involving pitch and another involving pitch and timbre. In order to slide pitch and change timbre simultaneously, this design incorporates an adjustable bell (Fig. A3.55 - Fig. A3.58).

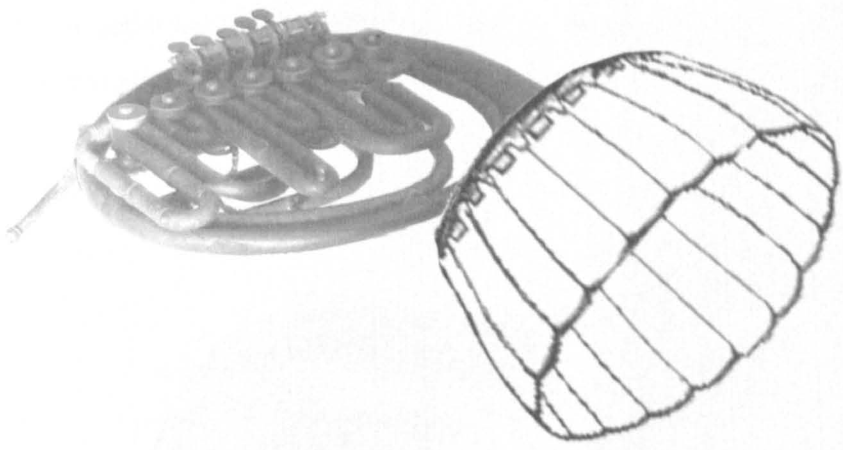

Fig. A3.55. Carrillo's Sixteenthtone French Horn with adjustable bell in cylindrical position.

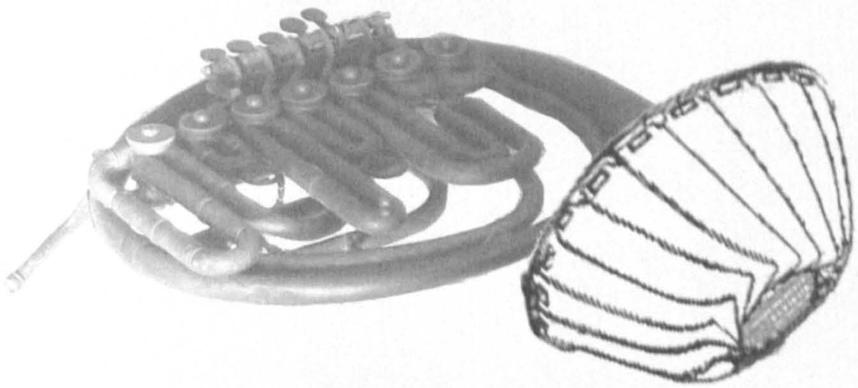

Fig. A3.56. Carrillo's Sixteenthtone French Horn with adjustable bell in muted position.

The creation of an adjustable *conic bell* using a similar mechanism is also considered. However, it would require experimenting with different materials, thicknesses and mechanisms (that can keep the plaques tight next to each other). It would require serious dedication to come out with a system keeping the appropriate tightness of the plaques, and therefore it is only suggested here for possible future experimentation.

The *sliding French horn* not only extends Carrillo's legacy by using Carrillo's sixteenthtone French horn model as a starting point, but also by providing a sixteenthtone graded sliding mechanism with marks carved in the metal. These marks allow the player to do the proposed zigzag exercise pattern for this group for any microtonal interval contained in the sixteenthtone scales either by means of pure pitch glide or simulation by playing the chromatic sixteenthtone scale.

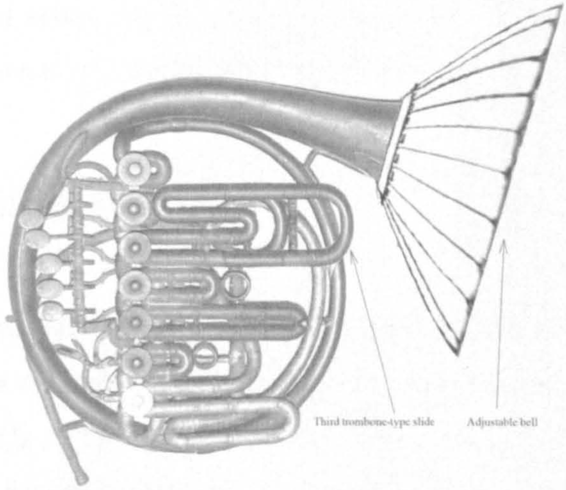

Fig. A3.57. Sketch for a *sliding French horn* (slide has been added) with adjustable bell in normal position.

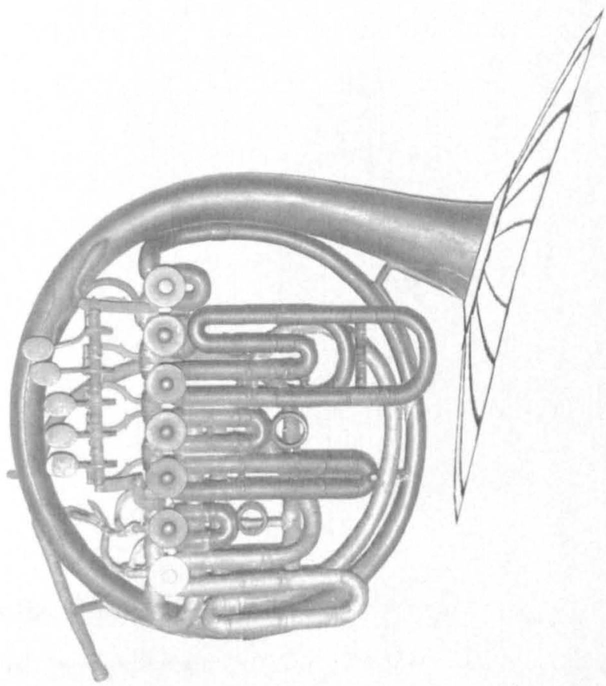

Fig. A3.58. Sketch of a *sliding French horn* with adjustable bell in widest position.

The sliding French horn can achieve the zigzag pattern proposed for this group with pure glides using the sliding mechanism (also in combination with tone colouring but only up to approximately a major third or even a fourth. By means of microdiscrete pitch in sixteenthtones there are no limits apart from the range of the instrument, although the speed at which can be achieved is relatively slower.

The bell of the *sliding French horn* suggests working with adjustable *conic bells*, and although this idea is not taken any further in this research, the use of morphing sounding bodies (specially idiophones) is an interesting approach to experiment with.

A3.3.2.8 *Ceramic coil flute* (II_h)

This ceramic coil is sustained with bracers, and it could also be conceived as a double reed instrument. The idea is to place several sliding keys using the same mechanism proposed for the *spiral tin oboe* (I_h / P8), but on a ceramic flute sustained by braces and shaped as shown in Fig. A3.59. An interesting variant for this aerophone would be to use a double reed in the mouth-piece.

Fig. A3.59. *Ceramic-coil flute.*

The problem with the sliding keys on this instrument is that when the full range is to be covered, the back of the performer side will be difficult to control with precision, although introducing unusual movements to do so can resolve this matter while increasing the corporeal expression value of the instrument. So, at least at low speed, the zigzag pattern for this group can be performed, and there is no need to say that the parallel glissando would require another instrument and player.

Using the instrument as a costume is something very unusual that would not be recommended for *conic bells* since they are heavy. But a few *conic bells* could be placed hanging in diagonal from a belt with supports around it and all in the middle of a performance with any layout of *conic bellophone*, as far as the *conic bells* are easy to clamp to both frames.

A3.3.2.9 *Cooperative ceramic basso profundo recorder* (II_i)

This design consists of a ceramic recorder of exceptionally low range (around 2.5m for a lower C) which is blown by several players. By having the flute laid in a cylindrical helix, it allows several players to be around the instrument blowing it and coordinating their playing (Fig. A3.60).

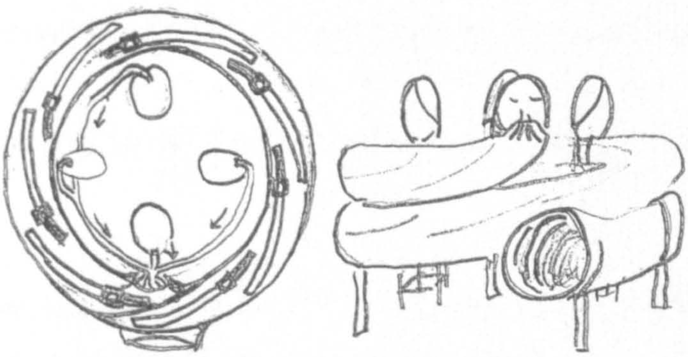

Fig. A3.60. Basic diagrams showing aerial and side views of the *cooperative-ceramic basso-profundo flute*.

The blowing of four people produces the high pressure required in a pre-camera that blows into this instrument. The four players have overlapping sliding keys placed around the instrument so the note can be passed from one player to another throughout the range with skilful coordination among players.

The zigzag pattern chosen can be achieved for any interval and at any desired speed, which makes this instrument ideal for this, while another instrument and four players do the parallel movement.

The *conic bellophone* allows the polyphony that *cooperative ceramic basso profundo flute* does not have. In order to achieve simultaneous sliding tones with and external layout of the *coil conic bellophone* it would involve several players and choreographed movements to synchronise them, which add a strong visual impact (corporeal expression) to the musical performance.

A3.3.3 Prototype group 3: Trapezoidal layouts

The main idea behind this shape is to achieve linear sequential microdiscrete pitch, keeping the distance between sounding bodies equal even if the size substantially decreases, and in fact following the trapezium formed by the sounding bodies once the gap size is fixed.

The movement is restricted in comparison to previous groups, since there is no rotation required, and the movements are linear (within a row, diagonal or horizontal).

The composition prepared for this layout is *One row study* (*Study No 1*: Sc. 1/ DVD1-tk 1/ CD-tk 1).

A regular trapezium can be positioned in many different ways for the achievements of layouts: vertical (Fig. A3.61), horizontal, diagonal and free.

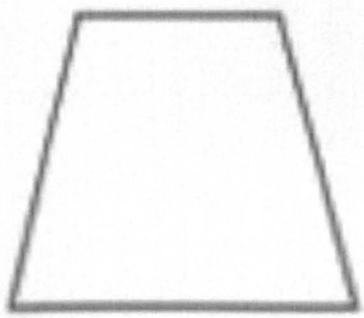

Fig. A3.61. A vertical trapezium.

A3.3.3.1 The trapezoidal conic bellophone (III_a)

The *trapezoidal conic bellophone* was designed as single side instrument tuned to the 96-et and a double side instrument tuned to the 192-et (Fig. A3.62).

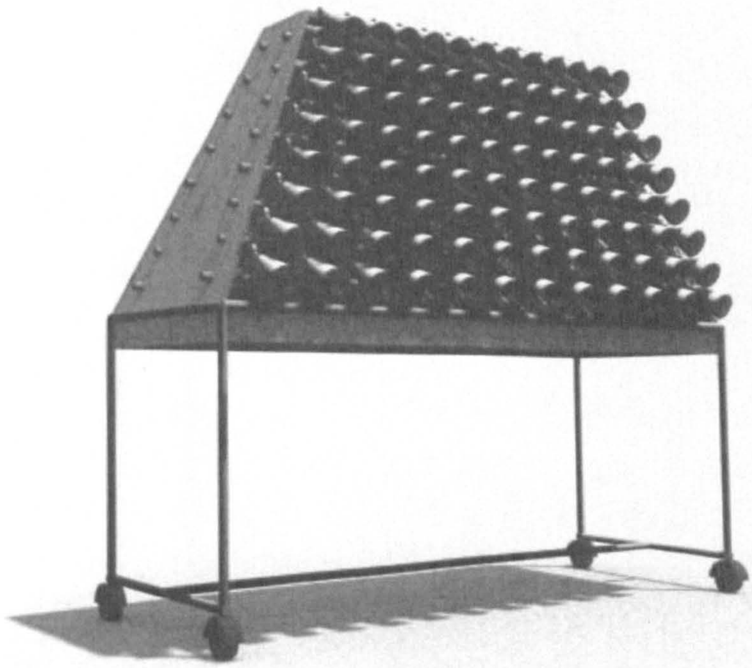

Fig. A3.62. *192-et trapezoidal conic bellophone.*

The composition *One row study* was originally devised in the *96-et trapezoidal conic bellophone*, in which each row contains a tone range.

The double-side model (above) has two different 96-et layouts a thirty-second tone apart from each other. With two players (one at each side), this version of the trapezoidal conic bellophone is potentially an instrument with high corporeal expression.

A3.3.3.2 *Trapezoidal-Whitechapel bellophone*s (96-et and 192-et) (III_b)

The sound clarity of the Whitechapel handbells led us to experiment not only with the 96-et (Fig. A3.63) but also with the 192-et (Fig. A3.64), so the achievements in this model could be compared with the ones of the *trapezoidal conic bellophone.*

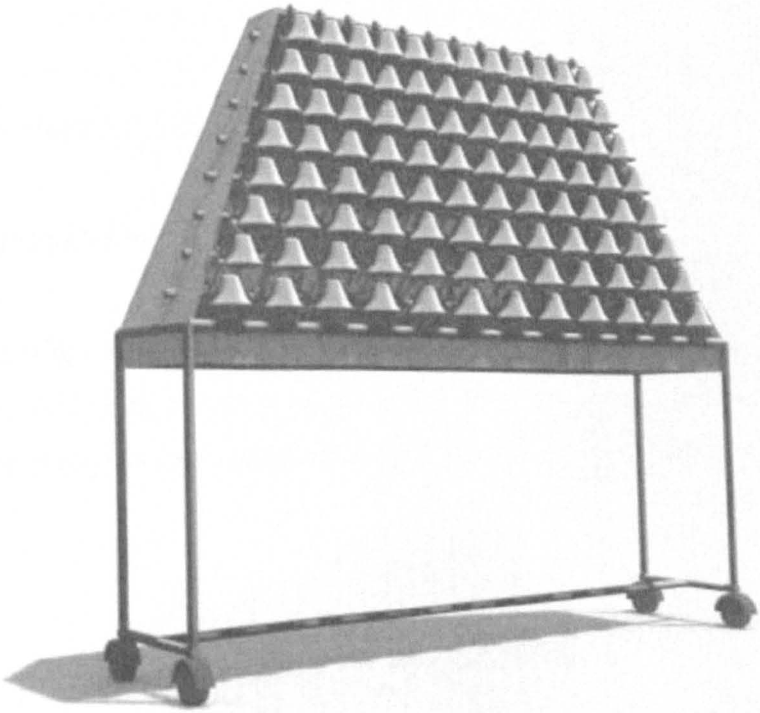

Fig. A3.63. *Trapezoidal-Whitechapel 96-et bellophone.*

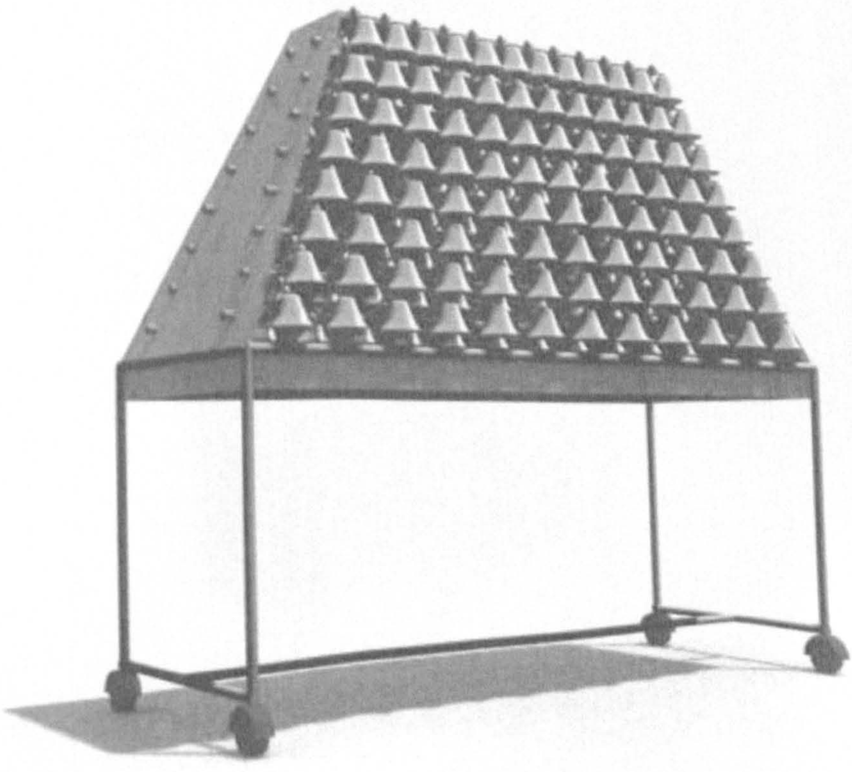

Fig. A3.64. *Trapezoidal-Whitechapel 192-et bellophone.*

One row study, is easily playable in both models, and sampled versions of this study played using 192-et with conic bells compared with Whitechapel bells show that the Whitechapel bell rings too long to use microdiscrete pitch.

A3.3.3.3 *Trapezoidal clavescrapophone* (III_c)

This instrument (Figs. A3.65 and A3.66) is based on pitched *guiro*-like sound producing unit which instead of being a hollow stick, is a solid stick with a cut across and undulated scraping surface, thought to also produce a pitched sound when struck with mallets.

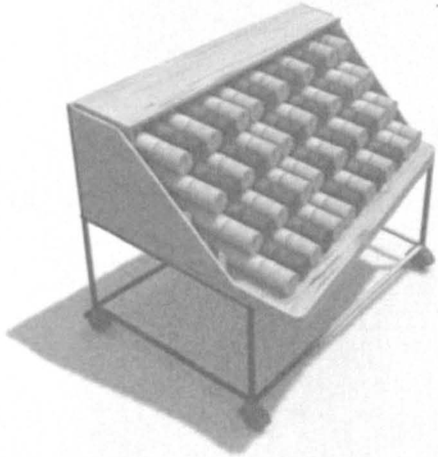

Fig. A3.65. *Trapezoidal clavescrapophone* (48-et).

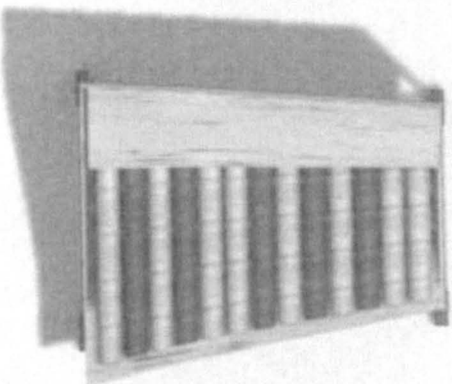

Fig. A3.66. *Trapezoidal clavescrapophone* (48-et) (aerial view).

One row study, is achievable in this 48-et layout by simply following the same steps as for the 96-et. One could consider the conic bells to have stripes (produce by cuts) to incorporate scraping action sounds.

A3.3.3.4 *Trapezoidal boncaphones* (96-et and 192-et) (III_d)

Arrays of square chimes (also named *boncas*), where initially considered to achieve the 48-et (Fig. A3.67), but the clarity of these sounding units allowed to come up with more challenging designs achieving 96-et (Fig. A3.68) and 192-et (Fig. A3.69).

Fig. A3.67. *Trapezoidal boncaphone* (48-et).

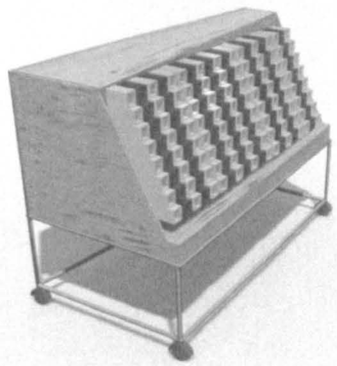

Fig. A3.68. *Trapezoidal boncaphone* (96-et).

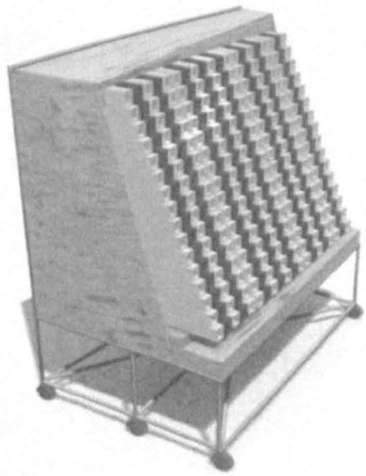

Fig. A3.69. *Trapezoidal boncaphone* (192-et).

One row study, is achievable in the three models using chromatic steps for each. The purity and high sustains of the square chimes invites the usage of muting systems (polymicrotonality).

A3.3.3.5 The *harp-mbira* (II_e)

This instrument (Fig. A3.70) consists of either marimba tongues or rounded plaques, which are attached to strings, so when the tongues are struck or plucked, the resonating strings are excited and vibrate, producing a unique overall sound.

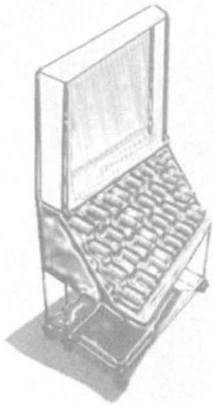

Fig. A3.70. The *harp-mbira*.

The composition *One row study*, can easily be performed on this instrument, tuned to the 48edo if the chromatic step is used in the same way as for sixteenthtones.

The *harp-mbira* suggests an incorporation of strings to prototype 13 of the *conic bellophone* coming from the inside of the bell, so as to ring in sympathy with the bell.

A3.3.3.6 *Water drumophone* (III_f)

This instrument consists of a chromatic set of water drums attached to a system similar to the one used by carillons so the string lifts the waterdrum and hits it just before letting it drop back onto its corresponding water container (see Fig. A3.71).

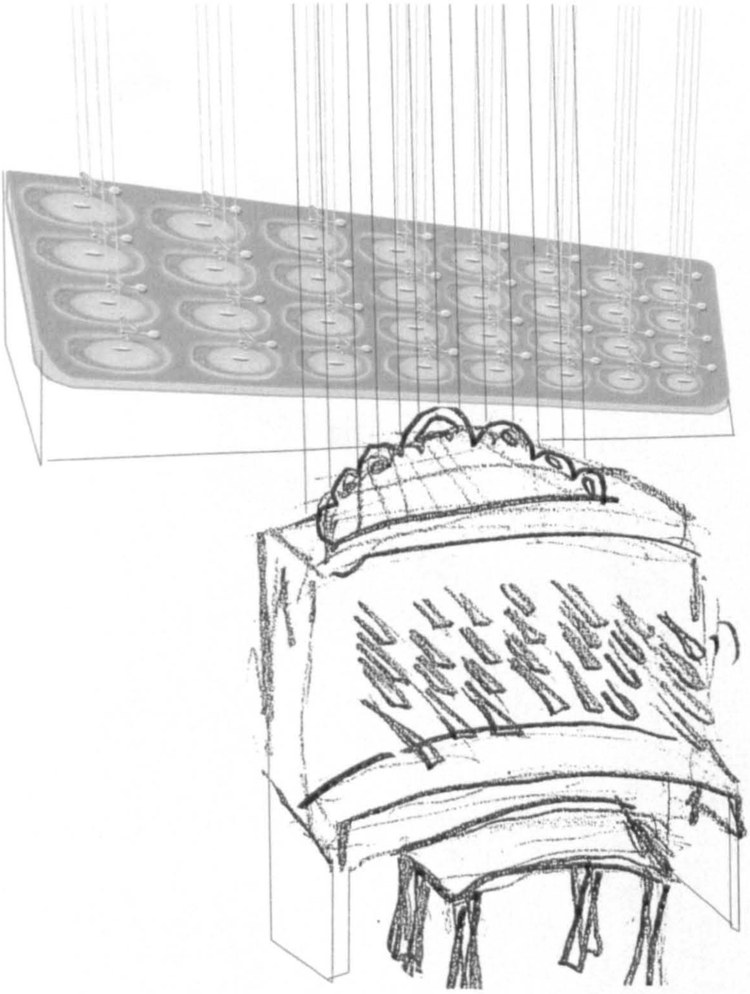

Fig. A3.71. *Water drumophone.*

One row study, can only be played at a very slow speed but is still possible to achieve either using the semitone or the quartertone as a chromatic step.

A3.3.3.7 *Sliding tecomate flute* (with buzzing membrane) (III_g)

This instrument uses sliding keys on a flute using the resonator from the marimba from Guatemala (tecomate) with its buzzing membrane to make a flute (Fig. A3.72). The buzzing membrane is made with the outer skin of a cow's intestine (dried with salt) lying on top of a ring made with black rosin from bees.

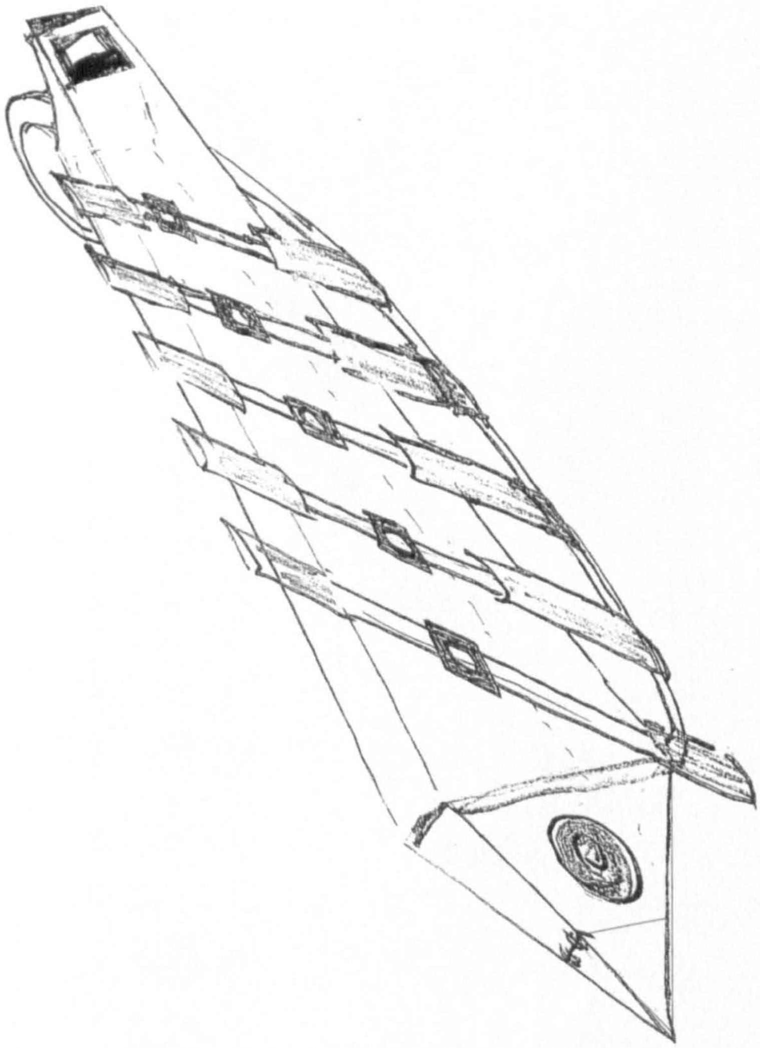

Fig. A3.72. *Sliding tecomate flute.*

The composition *One row study* is smoothly playable using sliding pitch but almost impossible using microdiscrete-sliding pitch. The use of a buzzing membrane is later on proposed for the last prototype (14) of the *conic bellophone* using resonators

A3.3.3.8 Sliding-tin-tecomate oboe (III_h)

This instrument (Fig. A3.73) is like the previous but using tin instead of cedar wood, and two sliding keys instead of five. The end of the tecomate can also be partially opened for experimentation.

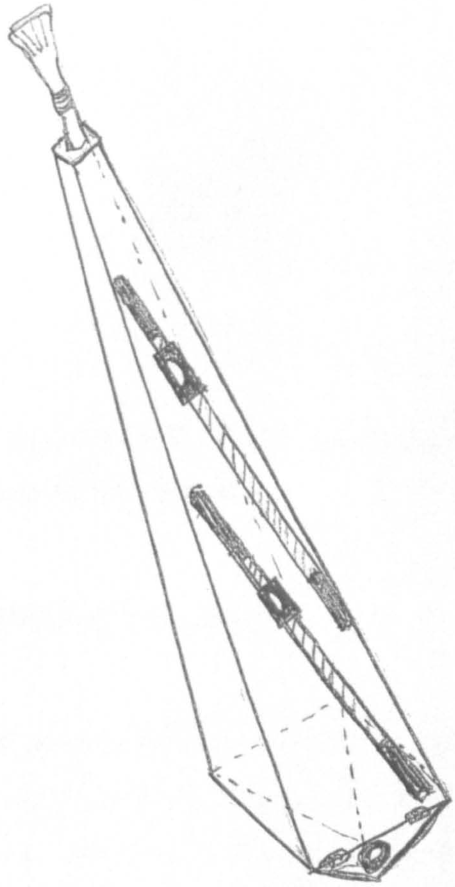

Fig. A3.73. *Sliding-tin-tecomate oboe.*

The composition *One row study*, is also easy to play with sliding pitch and difficult with microdiscrete pitch, if not pointless.

A3.3.3.9 *Pianimbira* (III_i)

It consists of an *Ahualulco keyboard* with mbira plucking mechanisms (that open the corresponding valves of the piani (with decay) and then produce the same note with mbira sound, expanding the length of the previous tone with a transformation of its timbre.

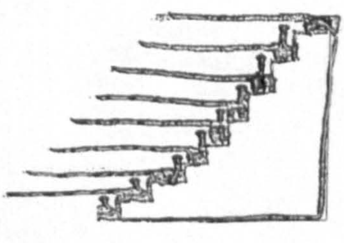

Fig. A3.74. *Pianimbira* plucking mechanism and electronic switch suggestion.

Fig. A3.75. *Pianimbira.*

The composition *One row study*, is achievable but the microdiscrete pitch slide going downwards is not as fast as upwards movement.

3.3.4 Other prototype groups (IV to XIV)

So far, §A3.3 has shown the process involved in the creative-comparative design process followed in the research method and Case Study, with §A3.3.1 (337-363) providing an example of full development and documentation, while §A3.3.2 (pp. 364-371), and §A3.3.3 (pp. 372-460), providing an example of how these ideas can also be kept brief to keep the creative-comparative process pace a bit faster, and without much concern about possible details for construction towards future works.[18] Groups IV - XIV have been treated as instruments defined by their values with a slight hint implied in the instrument's name without providing any further details to show another way of working with the idea rather than the design, and although in many cases sketches were drawn and details written down, it was not considered necessary since they were used mainly as concepts.[19]

To follow, a sketch from group X, which is included to illustrate previous citations: A 400 bowl version of the *440-bowlophone* in group XI (XI_i), consequently covering only an octave range (octave not included, see Fig. A3.76), and another two diagrams indicating with black marks, the 96-et scale in (used by Carrillo) in Fig. A3.77, and the 43-note just intonation scale used by Partch (Fig. A3.78).

[18] This shows how the instrument-development-led composer could approach the proposed creative-comparative method for simply comparing and sketching possible future ideas without developing them.
[19] This shows an approach for merely comparative design without interest in developing possible additional instruments.

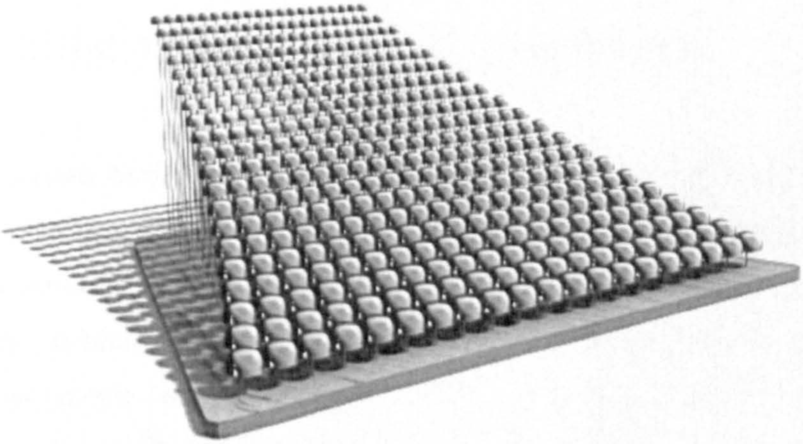

Fig. A3.76. 400-note version of the *440-bowlophone.*

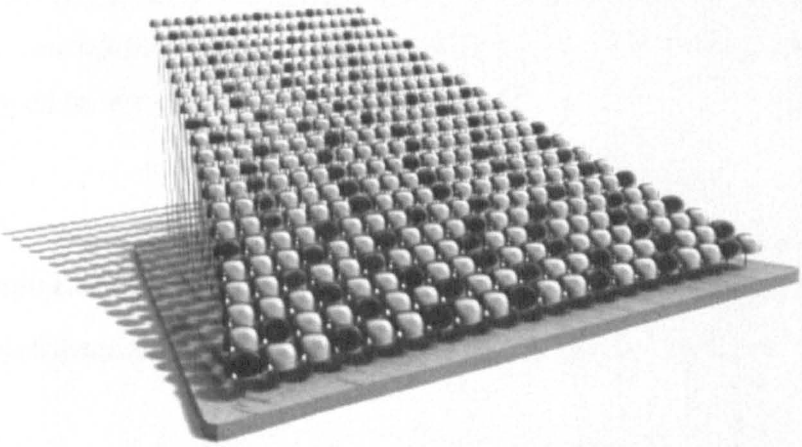

Fig. A3.77. 400-note version of the *440-bowlophone*: 96-et scale with black marks.

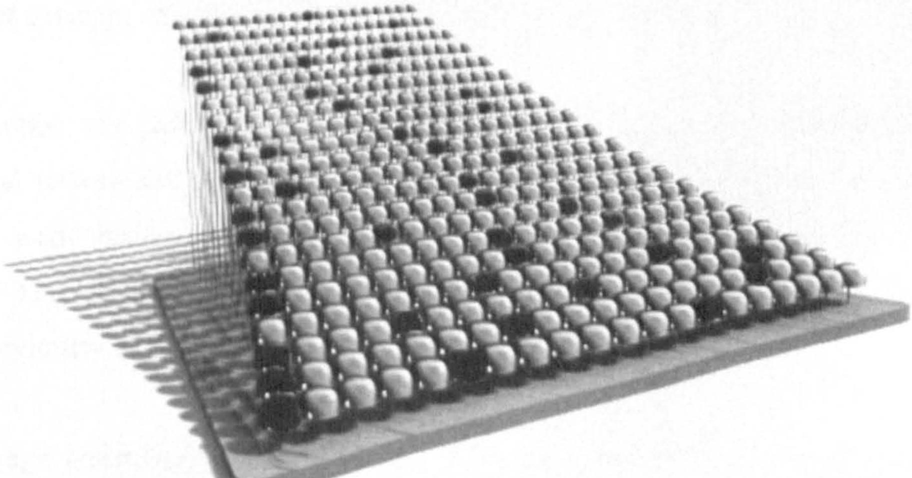

Fig. A3.78. 400-note version of the *440-bowlophone*: Partch's 43-note just intonation scale with black marks.

A3.4 Evaluations, charts and conclusion

Each of the fourteen prototypes of the *conic bellophone* is here compared with the eight variant conceptual instruments in their group towards an evaluative process. The variant conceptual instruments for the first group were described, and sketched for second and third groups as an illustrative example of how far can the composer go with the variant conceptual instruments, and if necessary explore alternative instrumentation with the compositions and multiple instrument designs. In this section the previous three groups are represented by their values, while the instruments of other eleven groups are defined by their values (and implying name). The evaluation charts for each group are provided with detail, followed by the ones providing the average values and comparing the different groups, so a conclusion can be made concerning the creative-comparative approach method employed for the Case Study.

A3.4.1 Evaluation charts used for the fourteen prototype of the bellophone development and a comparison of the average values

The period in which a prototype was developed was initially referred to as bellophone development phase. So as avoid introducing too many new terms and making the reading cumbersome, the term prototype is widely used instead, although here it refers to the actual instrument concept, regardless of how advance its development is.

In this section, the prototype evaluation takes place. Most of the evaluations define the conceptual instrument required for the creative-comparative process, and some of the concepts went further providing additional instrumentation towards the composition *Seasons*. The charts for each of the 14 groups are provided with specific values for each aspect previously defined (Figs A3.79 to A3.92).

The average instrument capabilities of glissando, microtonality, timbre and corporeal expression (in numerical value), are provided on pp. 470-472 (Fig. A3.93), concluding with a graph synthesising the development process of the *conic bellophone* (Fig. A3.94).

NON-CYL.HELIX LAYOUTS

Group I

		Glissando					Microtones			Timbre									C.E.		
		Max.possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max.sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Accuteness	Sustain's duration	Thinness	Metallicness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst.layout dimens.	Possible sound-initiation processes
I_a	Spiral Conic Bellophone	2	2	2	2.5	1.5	3	1.5	2	1	3	3	2.5	3	2	2	3	2.5	3.5	3	2
I_b	Cyclic Whitechapel Bellophone	3	2	2.5	3	1	3	1	1	2	2	3	2	2	3	2	2	2.5	1	3	2
I_c	Stand-a-key Spiral Bass Marimba	1	1	1	3	1	1	1	1	3	1	2	1	1	2	0	0	0.5	3.5	3	2
I_d	Spiral T'Rungophone	3	2	2	3	1	1	1	1.5	0.5	1	2	2	2	0	1	0.5	2	2	3	1
I_e	Spiral Harp	1.5	3	2.5	3	1	3	1	0.5	1	0	3	2	2	2	2	0	2	3.5	3	1
I_f	Spiral Splashophone	0.5	3	2	3	1	1	0	0.5	0.5	0	1	2	3	1	0.5	0.5	3	2	2	2
I_g	Spiral Rotary Pipe Organ /Abual.Keyb	2	3.5	3	3	3	3	3	3	2	0.5	2.5	1	0	3.5	2	0.5	2	2	0.5	1
I_h	Spiral Tin Oboe (Conic Core)	1	2.5	2.5	2	0	1	3	3	2	0.5	3	2.5	1	3.5	3	0.5	2.5	1	0.5	1
I_i	Harrison Luo-Abu Mbira	3	3	1	3	0	3	0	0	1	1	2	1.5	2	1	0.5	1	2	3	3	3

Fig. A3.79. Non-cylindrical helix layouts group – evaluation chart.

CYLINDRIC HELIX LAYOUTS

Group II

		Glissando					Microtones			Timbre									C.E.		
		Max.possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max.sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Accuteness	Sustain's duration	Thinness	Metallicness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst.layout dimens.	Possible sound-initiation processes
II_a	Coil Conic Bellophone	1.5	1.5	1.5	3	1	3	0.5	1	1	3	3	2.5	3	2	2	3	2.5	4	3	2
II_b	Coil Sarunay	1	1.5	1	3	1	1	0.5	1	1.5	3	3	2	3	3	2	3	3	4	3	1
II_c	Ring of Roses (Mokugyouphone)	1.5	2	1	3	1	1	0.5	0.5	0.5	2	3	2	3	1	1	1	1	3.5	3	1
II_d	Bass Tubaphone	2	1.5	1	3	1	2	0.5	0.5	3	3	3	1.5	2	3	2	1.5	1.5	3.5	3.5	2
II_e	Rotary Harps	3	3	2	2	2	3	0.5	0.5	2.5	1	3	2	2	2	3	0	2	1	3	1
II_f	Uchiwa Taikophone (K.Suzu ma.	1	1	1	2	1	1	0	0.5	3	3	1	2	3	1	2	2	2	3.5	3	2
II_g	Sliding French Horn	3.5	3	3	2	0	3.5	0	2.5	3	1	3	1.5	1	3.5	1	2	2	1	1	1
II_h	Ceramic Coil Flute	3	2	3	1	0	1	0	2	2	0.5	3	2	1	3.5	2	0	2	3	2	1
II_i	Cooperative Ceramic B.Prf.Flute	3	1.5	2	1	0	3	0	3	2	0.5	3	1.5	1	3	2	1	3	3.5	3	3

Fig. A3.80. Cylindrical helix layouts group – evaluation chart.

TRAPEZOIDAL LAYOUTS

Group III

	Glissando					Microtones			Timbre									C.E.		
	Max. possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max. sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Accuteness	Sustain's duration	Thinness	Metallicness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst. layout dimens.	Possible sound-initiation processes
III$_a$ Trapezoidal Conic Bellophone	3	1	2	2	2	3	3	3	1	3	3	2.5	3	2	2	3	2.5	2	2	2
III$_b$ Trapezoidal W.Bellophones(96&192)	3	1	2	2	2	3.5	3	3	2.5	2	3	2.5	3	3	2.5	3	3	2	2	2
III$_c$ Trapezoidal Clavescrapophone	3	1.5	2	2	2	2	3	3	3	3	2	2	2	1	2	0	2	2	2	2
III$_d$ Trapezoidal Boucaphones(MIDI96&192)	2.5	1.5	1.5	3	3	3.5	3	3	2.5	1.5	3	2	3	3	3	3	3	2	2	2
III$_e$ Trapezoidal Harp-mbira	1	1.5	1	2	2	1	2	2	2	2	3	1.5	2	2.5	2	2.5	2.5	2	1	2
III$_f$ Water Drumophone	1	1.5	1	2	1	1	2	2	2	2	1	1.5	2	1	1.5	0	2	2	1.5	2
III$_g$ Sliding Tecomate Flute (buzz.m.)	3	2	3	1	0	1	0	3	1.5	1	2	2	1	3.5	2	0	2	1	1	2
III$_h$ Sliding Tin Tecomate Oboe	3	2	3	1	0	1	0	3	2	2	2.5	2	1	3.5	2	2.5	3	1	1	1
III$_i$ Piani-mbira	2	1.5	2	3	3	3	3	3	2	3	2	2	2.5	3.5	2.5	2.5	3	1	2.5	2

Fig. A3.81. Trapezoidal layouts group – evaluation chart.

SQUARE LAYOUTS

Group IV

	Glissando					Microtones			Timbre									C.E.		
	Max. possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max. sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Accuteness	Sustain's duration	Thinness	Metallicness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst. layout dimens.	Possible sound-initiation processes
IV$_a$ Square Conic Bellophone	1.5	1	1	1	2	3	2	2	1	3	3	2.5	3	2	2	3	2.5	2	2	2
IV$_b$ Square Rotating Matsumushiphone	2	1	1	1.5	2	2	1	2	2	2.5	2	3	3	3	3	3	3	2	2	1
IV$_c$ Square Buzzing Lithophone	2	1	2	2	2	2	2	2	3	3	3	2.5	3	2	3	1	3	1	2	1
IV$_d$ Square stepped Bonangophone	1	1	1	2	1	1	2	2	3	3	3	1.5	2	3	2.5	3	3	1	2	1
IV$_e$ Cubic Mbira	2	1	1	1.5	1	2	2	2	2	3	2	1.5	2	2	2	3	3	1	2	1
IV$_f$ Square Booms (10x10)	2	1	1.5	2	1	1	2	2	2	1	2	1	1	1	2	0	3	1	2	1
IV$_g$ Square Panpipe (buzz.memb./zig-z	2	1	2	2	0	1	1	2	2	2	2	1.5	1	3.5	2	0	3	1	1.5	1
IV$_h$ Square Ahualulco Chromelodeon	2.5	3	2.5	3	3	3	3	3	2	2	2	1.5	1	3.5	2	1	3	3.5	2.5	2
IV$_i$ Chinese Opera Gongophone (Midi	2	1	2	3	3	1	3	3	3	2	0	2	2.5	2.5	2	3	3	1	2	1

Fig. A3.82. Square layouts group – evaluation chart.

RECTANGULAR LAYOUTS

Group V

		Glissando					Microtones			Timbre									C.E.		
		Max.possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max.sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Accuteness	Sustain's duration	Thinness	Metallicness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst.layout dimens.	Possible sound-initiation processes
V_a	Rectangular Conic Bellophone	1.5	1	1	1	2	3	1	2	1	3	3	2.5	3	2	2	3	2.5	2	2	2
V_b	Trianglephone	3	1.5	2	2	2	2	1	1	2.5	3	3	2.5	3.5	2	3	3	3	1	1.5	1
V_c	Springophone	2	1	1.5	1.5	2	1	1	2	1.5	3	2	2	3.5	2	3	3	3	1	2.5	1
V_d	Tubular Springophone	1.5	1	1	1	1	1	0.5	1	2	2.5	2	2	3	2.5	2	3	3	1	2	1
V_e	Carrillo Sympathy Harp	3	1	2	2	2	3	2	2	2	2	2.5	2	2	3	3	3	3	1	3	1
V_f	Finger Rectangular Booms (8x6)	1.5	1	2	2	1	1	0.5	2	2	2.5	2	2	2	1	2	0	3	1	3	1
V_g	Ahualulco Portative Organ (Solar U	2	1	2.5	3	2	3	3	3	1	1	3	1.5	1	3.5	1	0	2	2	1	1
V_h	Double Sliding Bass Trombone	3	3	3	2	2	3.5	0	2	3	2	3	2	1	3.5	1	2	2	1	2.5	1
V_i	Marimbaflor	3	1	1.5	2	2	2	2	2	2	2.5	1	1.5	1.5	2	1.5	3	3	1	3	1

Fig. A3.83. Rectangular layouts group – evaluation chart.

CONCENTRIC LAYOUTS

Group VI

		Glissando					Microtones			Timbre									C.E.		
		Max.possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max.sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Accuteness	Sustain's duration	Thinness	Metallicness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst.layout dimens.	Possible sound-initiation processes
VI_a	Concentric Conic Bellophone	0.5	1	1	2	2	3	1	1	0.5	1	3	1	1	1	1	2	2.5	2	3	2
VI_b	Ekirophones (Thick bronze/alum.balls)	2	1	1	2	2	2	1	0.5	0.5	3	0.5	2	3	2	2.5	3	2.5	1	2	2
VI_c	Toroidal Hand Rotating Mbira	2	1	1	3	2	2	1	0.5	2	3	1	1.5	2.5	2	1.5	2	1.5	1	2	1
VI_d	Tettouphone	2	1	1.5	2	2	1	2	2	3	3	3	1.5	2	2.5	2	3	3	1	2	1
VI_e	Concentric Fretless Vase Lute (singl.	2	2	2	2	2	2	0.5	2	2	2	1	2	2	1	2.5	0.5	2	2	2.5	2
VI_f	Conc.Ceram.Drum (Double)	3.5	1	3	3	3	0.5	0.5	0.5	2.5	2	1	2	2	1	1.5	0.5	1	3.5	3	2
VI_g	Conc.Ring.Doubl.Ocarina (slid/wat.drone)	3	2	3	2	2	3	0	3	2	2	1	2	1	3.5	2	0.5	2	1	1.5	1
VI_h	Conc.Ceram.Oboe (slid.k./wat.dro)	3	2	3	3	3	3	0	3	2	2	1	2	1	3.5	1.5	0.5	3	1	2	1
VI_i	MIDI Mul.Conc.Cer.Drums (Ench.Forest)	3	2	3.5	3	3	1	3	3	2.5	2.5	1	2	2	1	2	1	1.5	3	3	2

Fig. A3.84. Concentric layouts group – evaluation chart.

ARCHED LAYOUTS I: 3 LEGS

Group VII

		Glissando					Microtones			Timbre									C.E.		
		Max.possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max.sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Acuteness	Sustain's duration	Thinness	Metallicness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst.layout dimens.	Possible sound-initiation processes
VII$_a$	Arched Conic Bellophone I (3S)	2	1	2	2	2	3	2	2	0.5	3	3	2	1	1	1	2	2.5	2	3	2
VII$_b$	Waterfall Gender (Slenthem)	1.5	1	2	2.5	2	2	3	2	2	3	3	2.5	3	2.5	3	3	3	2	2.5	2
VII$_c$	Waterfall Clavescrapophone	1	1	2	2	2	2	2	2	2	2	1	2	2.5	0.5	2	1	2	2	2	2
VII$_d$	Waterfall Copper Tubaphone	2	1	2	2	2	3	3	2	2	2.5	3	2.5	3	2.5	3	3	2.5	2	2.5	2
VII$_e$	Ceramic Arched Tongue boxes	1.5	1	1	2	2	1	2	3	1	2	2	1.5	2.5	1.5	2	1.5	2	2	2.5	1.5
VII$_f$	Sliding Bird Whistle	3	1.5	3	3	3	3	0	2	1.5	2	1	2	1	3.5	2	1.5	2	1	2	2
VII$_g$	Sliding Cooperative Arched Ocarina	3	2	3	2	2	3	2	2	1.5	1	3	2	1	3.5	1.5	1	2	3	1.5	1
VII$_h$	Cooperative Brass Sliding Arches (coil)	3	3	3	2	3	3	3	3	3	1.5	2	2	1	3.5	2.5	2	2.5	3	2	1.5
VII$_i$	Cooperative Kakkou Slide Whistle	3	2	3	2	2	3	2	2	1	1.5	1	2	1	3.5	2	1	2	3	2	1

Fig. A3.85. Arched layouts I group – evaluation chart.

ARCHED LAYOUT II: INDIV. STANDS

Group VIII

		Glissando					Microtones			Timbre									C.E.		
		Max.possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max.sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Acuteness	Sustain's duration	Thinness	Metallicness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst.layout dimens.	Possible sound-initiation processes
VIII$_a$	Arched Conic Bellophone II (16S)	2	1	2	2	2	3	2	2	1	2	3	3	2	2	2.5	2	2	2	3	2
VIII$_b$	Arched Stand-a-matsumushiphone	1	1	2	2	2	2	2	2	2.5	3	2.5	3	3.5	2	3	3	3	2	3	1
VIII$_c$	Arched Marimba (Stand-a-key)	1.5	2	1.5	2	1	1	1	2	3.5	2.5	3	1.5	2	2	1.5	0	1	2	2.5	1
VIII$_d$	Khong Wong Yaiophone	1	1	1	2	1	1	1	2	2.5	3	2	2	3	1.5	1.5	3	2.5	2	2.5	1
VIII$_e$	Carrillo Bridge Double Harp in 8ve stands	2.5	3	3	3	2	3	1	2	2	1	3	2.5	2	1.5	2.5	2	1	3	2.5	1
VIII$_f$	Arched Stand-a-splashophone	0.5	1	1	2	1	1	1	2	1	2	1	1	1.5	1	2	0	3	2	2	2
VIII$_g$	Arched Coop.Hototogisu Mouth Organ	3	3	2.5	1	1	1	3	3	1.5	1.5	1	1.5	1	3.5	3	0	3	3	2	1
VIII$_h$	Double polyphonic sliding oboe (2x2swtc/keyb.)	3	2	3	2	2	3	0	3	2	1.5	3	2	1	3.5	2	0.5	2.5	1	2.5	1
VIII$_i$	Ice Drums	1	1	1	2	1	1	0	2	1.5	3	2	1.5	2	1	1	0.5	0.5	2	3	1

Fig. A3.86. Arched layouts II group – evaluation chart.

ARCHED LAYOUT III: INDIV. STANDS & EXT.

Group IX

		Glissando					Microtones			Timbre									C.E.		
		Max. possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max. sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Accuteness	Sustain's duration	Thinness	Metallicness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst. layout dimens.	Possible sound-initiation processes
IX_a	Extended Arched Conic Bellophone (16S)	2	2	2	2	2	3	2	2	1	2.5	2	2.5	1.5	1.5	1.5	2.5	2	3	3	2
IX_b	Snail Jalatarang	2	1	2	2	2	1	2	2	2	3	2	2.5	3	2.5	3	1	3	1	3	1
IX_c	Porcupine Marimba (ceramic ass.stands)	2	2	2	3	2	3	3	3	2	2	2	2	2	2	2	1	3	1	2	1
IX_d	Arched Trungophone(ass.stands/cer.res)	1.5	1	1	2	2	3	2	2	2.5	3	2	2	3	2.5	2	3	3	2	2.5	1
IX_e	Sympathy Bowed Octavina (arched 5s)	3	2	3	2	2	2	0.5	2	1.5	1	3	2.5	2	3.5	2	1	3	1	1.5	2
IX_f	Arched Waterslapophone (ass.stands)	1.5	2	1	2	1	1	0	1	0.5	2	1	1	1.5	1	1.5	0.5	3	2	2.5	2
IX_g	Ext.Portative Organ with arch.pipe stands	2.5	2	2.5	3	2	3	3	3	3	1	3	1.5	1	3.5	2.5	1.5	3	1	1.5	1
IX_h	Bass 16th-tone Sliding Tuba	3.5	3	3	2	3	3	0	2	3.5	1.5	3	2	1	3.5	1	2.5	1.5	1	2	1
IX_i	Sympathy Arched Sarunyaophone (MIDI)	3	1	3	3	3	3	3	3	2.5	3.5	1	3	3	2	2	3	3	2	2.5	1

Fig. A3.87. Arched layouts III group – evaluation chart.

OTHER RANGES

Group X

		Glissando					Microtones			Timbre									C.E.		
		Max. possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max. sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Accuteness	Sustain's duration	Thinness	Metallicness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst. layout dimens.	Possible sound-initiation processes
X_a	Sopranino & Bass Conic Bellophones	2.5	1	1	3	1	3	1	2	3	3	2	2	3	1.5	2	3	2.5	1.5	2	2
X_b	Rotary Hoyureyophone (high range)	2.5	1	2	3	2	3	0.5	1	2	3	3	3	3.5	2	3.5	3	3.5	1	2	1
X_c	Rotary Piccolo block xylophone (kki)	2	1	2	3	3	1	0.5	1	2.5	2	1	2	2.5	1	2.5	0	3	1	2	1
X_d	220-stand Bowlophone	2	1	1	2	2	3.5	1	2	2	3	3	2	3	2	2.5	3	3	2	3	1
X_e	Dynamic piano and dynamic Baton	3.5	3.5	3	3	3	3	3	3	3	3	3	2.5	2.5	2.5	3	3	3	1	3	1
X_f	Solenoid assisted water streamophone	2	1	2	3	3	1	3	2	0.5	3	1	1.5	1	1	3	0.5	3	1	1	1
X_g	Ahuehuco Portative Hototogise Organ	2	1	2.5	3	3	3	3	3	1	3	1	1.5	1	3.5	2	0.5	2.5	1	1.5	1
X_h	Brass Sliding Organ (10-solen.-contr.)	3.5	1	3	3	3	3	3.5	2	3	1.5	3	2	1	3.5	2	2	2	2	1.5	1
X_i	Soprano & Bass Marimbaflorus	0.5	1	1	3	1	1	1	2	2.5	3	1	1.5	2	2	2	2	2.5	2	2.5	1

Fig. A3.88. Other changes group – evaluation chart.

MECH. INSTRUMENTS & SOUND ACTIVATORS

Group XI

		Glissando					Microtone			Timbre									C.E.		
		Max.possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max.sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Accuteness	Sustain's duration	Thinness	Metallicness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst.layout dimens.	Possible sound-initiation processes
XI_a	Mechanic Extended Conic Bellophone	3.5	2	2.5	3	3	3	3	3	3	3	2	2	3	1.5	2	3	2.5	2	3	2
XI_b	Mechanic Pyramid Carillon	3.5	1	2.5	3	3	3	3	3	3	3	3	2.5	3	3	3	3	3	1	3	1
XI_c	Mechanic 1200ET Boncaphone	3.5	1	2.5	3	3	3	3	3	2.5	1.5	3	2.5	3	3	2.5	3	2.5	3.5	3	2
XI_d	Mechanic Gongophone & keyboard	3	1	1	3	3	1	2	2	3	3	1	1.5	2.5	3	2	3	3	1	3	1
XI_e	Mechanic Spiral Rotary Harp	2.5	1	3	3	3	3	1	1	2	1	3	2.5	2	1.5	2.5	0.5	2	2	2.5	1
XI_f	Mech. Waterslapophone (Full r./additls)	3	3	2	3	3	1	3	3	2	3	1	1.5	1	1	3	0.5	3	2	2.5	3
XI_g	Mechanic Sliding Ocarinophone (10sl/ocs)	3	3	3	2	3	3.5	3	2	1.5	1	3	2	1	3.5	2	1	2.5	2	2	1
XI_h	Mechanic Sliding xuliophone (soled.ped.)	3.5	3	3	2	3	3.5	3.5	1	2.5	1.5	3	2	1	3.5	2.5	1	2.5	1	2	1
XI_i	Mechanic 440-Stand Bowlophone (Cont.Keyb)	3	1	2	3	3	3.5	3.5	3.5	2.5	3	2.5	2.5	3	2.5	3	3	3	2	2	2

Fig. A3.89. Mechanised instruments and sound activators group – evaluation chart.

MIDI CONTROLLERS

Group XII

		Glissando					Microtones			Timbre									C.E.		
		Max.possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max.sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Accuteness	Sustain's duration	Thinness	Metallicness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst.layout dimens.	Possible sound-initiation processes
XII_a	MIDI Ext. C.Bell. Pedal tempo controller	3	2	3	3	3	3	3	3	3	3	2	2	3	1.5	2	3	2.5	1	1.5	2
XII_b	Sld.Kalimba finger blockphn.contr&metal adder	3	2	3	3	3	2	2	2	2	2.5	2	2.5	2	2	2.5	1	3	1	1	2
XII_c	Octopentag. MIDI contr. for 1200-edo	2.5	2	3	2	2	3.5	2	2	2.5	2	3	3	3	2.5	3	3	3	1	1.5	2
XII_d	MIDI Matraca controller for rotary harps	3	2	3	3	3	3	0	0	3	3	3	3	3	2	1.5	3	2.5	3.5	3	1
XII_e	Linear Kalimba Contr. for Harps.192-edo	3	1	3	3	3	3	2	3	2	2.5	3	2.5	2	2	3	3	3	1	2	1
XII_f	MIDI hydroacoustic-installation controlle	2	2	2	3	3	1	1	3	2	2	1	1.5	1	2	2.5	1	3	1	2	2
XII_g	MIDI sliding lastrophone controller	2	1	3	3	3	1	1	1	3	2	0	2.5	2	2	0.5	0	1	1	2	1
XII_h	MIDI sliding 96-edo Alumi.chromelod.contr.	3	1	3	3	3	3	3	3	2	2	3	2	1	3	3	0	2	1	2	1
XII_i	Snowdome's MIDI Umbrella Chime Controller	3	3.5	3	3	3	3	3	3	3	3	2	3	3	3	2	3.5	3.5	1	3	1

Fig. A3.90. MIDI controllers group – evaluation chart.

PORTABILITY AND ERGONOMICS

Group XIII

		Glissando					Microtones			Timbre									C.E.		
		Max. possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max. sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Accuteness	Sustain's duration	Thinness	Metalliceness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst.layout dimens.	Possible sound-initiation processes
XIII_a	Compact Extended Conic Bellophone	3	2	2	3	3	3	3	3	3	3	2	2	3	1.5	2	3	2.5	2	2	2
XIII_b	MIDI Weather Bell Tower	3	2	3	3	3	3	3	3	2	3	3	3	3	2.5	3	3	3	1	3	2
XIII_c	Compact Square Buzzing Marimba	2	1	2	3	2	3	3	3	2	2	2	2	2	2	2	1	2	2	2.5	1
XIII_d	MIDI Chime Tree Pyramid	3	1	3	3	3	3	3	3	2	3	2	3	3.5	3	3	3	3.5	1	3	2
XIII_e	Compact Ceramic Water Cithraveena	3	2	2	2	1	2	2	2	1.5	3	1	2	2	2	2.5	2	2.5	1	1.5	2
XIII_f	Comp.MIDI Tap Ceram.24-edo Caterp.	3	1	3	3	3	1	1	2	2	2	1	2.5	2	1.5	1	1	1.5	3	3	2
XIII_g	Cer.&sld.-Panpipe&10-sld.key-96locks960-edo	3	3	3	3	3	3.5	3.5	3.5	2	1	1	2	1	3.5	3	0	1	1	2.5	2
XIII_h	Reed Cer.Abualulco Chromel. adj.96-9600-edo	3	1	2	3	3	3.5	3	3	2	2	3	1.5	1	3.5	2	1	3	1	2	1
XIII_i	Dyn.MIDI wat.envr.&chorus/ens.wat.bell-pagod.	3	3	3	3	3	3	3	3	2	2	2	2	1.5	3.5	3	2.5	3	3.5	3.5	3.5

Fig. A3.91. Portability and ergonomics group – evaluation chart.

PADTS ASPECTS & ADD.RESONATING BODIES

Group XIV

			Glissanc					Microt.			Timbre									C.E.		
			Max. possible Speed	Range (in octaves)	Evenness	Continuity through range	Simultaneous glissando playability	Semitone subdivision	Chords playability	Scales playability	Max. sustained vol. of pitched spectra	Sustained Inharmonicity	Sustained compactness	Attack's sharpness	Accuteness	Sustain's duration	Thinness	Metalliceness (hardness)	Brightness	Max. No. players per instrument	Perfmer's mov./Inst.layout dimens.	Possible sound-initiation processes
XIV_a	Pitch	Comp. Ext. Conic Bellphone with Resonators	3	2	2	3	3	3	3	3	3	3	2	2	3	3	2	2	2	2	2	2
XIV_b	Timbre	Arched MIDI sarunayophone.&regul.symp.	3	2	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	1	3	2
XIV_c		Bell tecomate tree & grad.buzzing membr.	2	1	2	3	2	3	3	3	2	2	2	2	2	2	2	1	2	2	3	1
XIV_d	Amplitude	Al..Ml.Tubaphone with grad.Resonators	3	1	3	3	3	3	3	3	2	3	2	3	4	3	3	3	4	1	3	2
XIV_e		Buzzing-Symp-stop.regul.prepared MIDI piano	3	2	2	2	1	2	2	2	2	3	1	2	2	2	3	2	3	1	2	2
XIV_f	Duration	Presure-sensor-D.Baton &Tim.Tap.Forest	3	1	3	3	3	1	1	2	2	2	1	3	2	2	1	1	2	3	3	2
XIV_g		Compressed Air Aeolic Harp (with d.baton /PATT)	3	3	3	3	3	3	4	4	2	1	2	2	1	4	3	1	2	1	3	2
XIV_h	Spat. Proj.	MIDI Spatial Oboe with bell clappers C.B.	3	1	2	3	3	4	3	3	3	3	3	2	2	4	2	2	3	4	2	1
XIV_i		Giant Mercury Sympathy Harp	3	3	3	2	3	1	2	2	2	3	2	2	2	4	3	3	3	4	4	4

Fig. A3.92. *PADTS* parameters and additional resonating bodies group – evaluation chart (see Abbreviations).

A3.4.2 The bellophone prototype development statistics: A comparison among averages from each group

In order to provide a constructive reference resource towards the understanding of creative-comparative process followed in this research, this section first provides a comprehensive list of the 126 instruments designed or defined (the ones with the 'a' as a subindex being the *conic bellophone* prototypes) with the average values and the name implications. Each instrument has a reference code starting with P to refer to the pitch research,[1] and the number for their position in the chart (Fig. A3.93). This is followed by a radar chart (Fig. A3.94) comparing the average total value for each of the 14 groups (grey line) with the one for the corresponding *conic bellophone* prototype (black line).

Notice in Fig. A3.94 that the line representing the average values for the *conic bellophone* (thick line), following a chronological clockwise order, embraces the line representing the average values for each group of creative-comparative instruments, proving that this creative comparison help to keep high standards in the search of microtonal and microdiscrete-sliding pitch (see Glossary) properties for the bellophone during its development.

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[1] This is done towards simplifying future comparison with other instruments to be developed as part of research in other *PADTS* parameters, amplitude, meter, timbre and spatial projection.

Instrument design evaluation chart for the creative-comparative study on pitch resources

Pitch Res. Ser. No.	Group-aspect symb.	Instrument Name	Glissando	Microtonal	Timbre	Corp. Expression	Total
			Evaluations (%)				
P 1	I_a	Spiral Conic Bellophone	67	72	81	94	79
P 2	I_b	Cyclic Whitechapel Bellophone	77	56	76	67	69
P 3	I_c	Stand-a-key Spiral Bass Marimba	47	33	39	94	53
P 4	I_d	Spiral TRungophone	73	39	41	67	55
P 5	I_e	Spiral Harp	73	50	52	83	65
P 6	I_f	Spiral Splashophone	63	17	43	67	47
P 7	I_g	Spiral Rotary Pipe Organ	97	100	52	39	72
P 8	I_h	Spiral Tin Oboe (Conic Core)	53	78	69	28	57
P 9	I_i	Harrison Luo-Abu Mbira	67	33	44	100	61
P 10	II_a	Coil Conic Bellophone	57	50	81	100	72
P 11	II_b	Coil Sarunay	50	28	87	89	63
P 12	II_c	Ring of Roses (Mokugyouphone)	57	22	54	83	54
P 13	II_d	Bass Tubaphone	57	33	76	100	67
P 14	II_e	Rotary Harps	80	44	65	56	61
P 15	II_f	Uchiwa Taikophone (K.Suzu ma.)	40	17	70	94	55
P 16	II_g	Sliding French Horn	77	67	67	33	61
P 17	II_h	Ceramic Coil Flute	60	33	59	67	55
P 18	II_i	Cooperative Ceramic B.Prf.Flute	50	67	63	106	71
P 19	III_a	Trapezoidal Conic Bellophone	67	100	81	67	79
P 20	III_b	Trapezoidal W.Bellophones(96&192)	67	106	91	67	82
P 21	III_c	Trapezoidal Clavescrapophone	70	89	63	67	72
P 22	III_d	Trapezoidal Boncaphones(96&192)	77	106	89	67	84
P 23	III_e	Trapezoidal Harp-mbira	50	56	74	56	59
P 24	III_f	Water Drumophone	43	56	48	61	52
P 25	III_g	Sliding Tecomate Flute (buzz.m.)	60	44	56	44	51
P 26	III_h	Sliding Tin Tecomate Oboe	60	44	76	33	53
P 27	III_i	Piani-mbira	77	100	85	61	81
P 28	IV_a	Square Conic Bellophone	43	78	81	67	67
P 29	IV_b	Square Rotating Matsumushiphone	50	56	91	56	63
P 30	IV_c	Square Buzzing Lithophone	60	67	87	44	65
P 31	IV_d	Square stepped Bonangophone	40	56	89	44	57
P 32	IV_e	Cubic Mbira	43	67	76	44	58
P 33	IV_f	Square Booms (10x10)	50	56	48	44	50
P 34	IV_g	Square Panpipe (buzz.memb./zig-z.)	47	44	63	39	48
P 35	IV_h	Square Ahualulco Chromelodeon	93	100	67	89	87
P 36	IV_i	Chinese Opera Gongophone (MIDI)	73	78	74	44	67

Pitch Res.Ser. No.	Group-aspect symb.	Instrument Name	Evaluations (%) Glissando	Microtonal	Timbre	Corporeal Expression	Total
P 37	V_a	Rectangular Conic Bellophone	43	67	81	67	**65**
P 38	V_b	Trianglephone	70	44	94	39	62
P 39	V_c	Springophone	53	44	85	50	58
P 40	V_d	Tubular Springophone	37	28	81	44	48
P 41	V_e	Carrillo Sympathy Harp	67	78	83	56	71
P 42	V_f	Finger Rectangular Booms (8x6)	50	39	61	56	51
P 43	V_g	Ahualulco Portative Organ (Solar U)	70	100	52	44	67
P 44	V_h	Double Sliding Bass Trombone	87	61	72	50	68
P 45	V_i	Marimbaflor	63	67	67	56	63
P 46	VI_a	Concentric Conic Bellophone	43	56	48	78	**56**
P 47	VI_b	Ekirophones (Thick bronze/alum.bals)	53	39	70	56	55
P 48	VI_c	Toroidal Hand Rotating Mbira	60	39	63	44	52
P 49	VI_d	Tettouphone	57	56	85	44	60
P 50	VI_e	Concentric Fretless Vase Lute (sing)	67	50	56	72	61
P 51	VI_f	Conc.Ceram.Drum (Double)	90	17	50	94	63
P 52	VI_g	Conc.Ring.Doubl.Ocarina(slid/wat.drone)	80	67	59	39	61
P 53	VI_h	Conc.Ceram.Oboe (slid.k./wat.dro)	93	67	61	44	66
P 54	VI_i	MIDI Mul.Conc.Cer.Drums (Ench.Forest)	97	78	57	89	80
P 55	VII_a	Arched Conic Bellophone I (3S)	60	78	59	78	**69**
P 56	VII_b	Waterfall Gender (Slenthem)	60	78	93	72	76
P 57	VII_c	Waterfall Clavescrapophone	53	67	56	67	61
P 58	VII_d	Waterfall Copper Tubaphone	60	89	89	72	78
P 59	VII_e	Ceramic Arched Tongue boxes	50	67	59	67	61
P 60	VII_f	Sliding Bird Whistle	90	56	61	56	66
P 61	VII_g	Sliding Cooperative Arched Ocarina	80	78	61	61	70
P 62	VII_h	Cooperative Brass Sliding Arches (coil)	93	100	74	72	85
P 63	VII_i	Cooperative Kakkou Slide Whistle	80	78	56	67	70
P 64	$VIII_a$	Arched Conic Bellophone II (16S)	60	78	72	78	**72**
P 65	$VIII_b$	Arched Stand-a-matsumushiphone	53	67	94	67	70
P 66	$VIII_c$	Arched Marimba (Stand-a-key)	53	44	63	61	55
P 67	$VIII_d$	Khong Wong Yaiophone	40	44	78	61	56
P 68	$VIII_e$	Carrillo Bridge Double Harp in 8ve stands	90	67	65	72	73
P 69	$VIII_f$	Arched Stand-a-splashophone	37	44	46	67	49
P 70	$VIII_g$	Arched Coop.Hototogisu Mouth Organ	70	78	59	67	68
P 71	$VIII_h$	Doubl.plphnic.sliding oboe (2x2swtc/key)	80	67	67	50	66
P 72	$VIII_i$	Ice Drums	40	33	48	67	47

Pitch Res.Ser. No.	Group-aspect symb.	Instrument Name	Glissando	Microtonal	Timbre	Corporeal Expression	Total
			Evaluations (%)				
P 73	IX_a	Extended Arched Conic Bellophone (16S)	67	78	63	89	74
P 74	IX_b	Snail Jalatarang	60	56	81	56	63
P 75	IX_c	Porcupine Marimba (ceramic ass.stands)	73	100	67	44	71
P 76	IX_d	Arched Trungophone(ass.stands/cer.res)	50	78	85	61	69
P 77	IX_e	Sympathy Bowed Octavina (arched 5s)	80	50	72	50	63
P 78	IX_f	Arched Waterslapophone (ass.stands)	50	22	44	72	47
P 79	IX_g	Ext.Portative Organ with arch.pipe stands	80	100	74	39	73
P 80	IX_h	Bass 16th-tone Sliding Tuba	97	56	72	44	67
P 81	IX_i	Sympathy Arched Sarunyaophone (MIDI)	87	100	85	61	83
P 82	X_a	Sopranino & Bass Conic Bellophones	57	67	81	61	66
P 83	X_b	Rotary Hoyureyophone (high range)	70	50	98	44	66
P 84	X_c	Rotary Piccolo Block-xylophone (kki)	73	28	61	44	52
P 85	X_d	220-stand Bowlophone	53	72	87	67	70
P 86	X_e	Dynamic piano and dynamic Baton	107	100	94	56	89
P 87	X_f	Solenoid assisted water streamophone	73	67	54	33	57
P 88	X_g	Ahualulco Portative Hototogise Organ	77	100	59	39	69
P 89	X_h	Brass Sliding Organ (10-solen.-contr.)	90	94	74	50	77
P 90	X_i	Soprano & Bass Marimbaflores	43	44	69	61	54
P 91	XI_a	Mechanic Extended Conic Bellophone	93	100	81	78	88
P 92	XI_b	Mechanic Pyramid Carillon	87	100	98	56	85
P 93	XI_c	Mechanic 1200ET Boncaphone	87	100	87	94	92
P 94	XI_d	Mechanic Gongophone & keyboard	73	56	81	56	66
P 95	XI_e	Mechanic Spiral Rotary Harp	83	56	63	61	66
P 96	XI_f	Mech. Waterslapophone (Full r./additls)	93	78	59	83	78
P 97	XI_g	Mechanic Sliding Ocarinophone (10sl/ocs)	93	94	65	56	77
P 98	XI_h	Mechanic Sliding Clarinetophone(soled.ped.)	97	89	72	44	76
P 99	XI_i	Mech. 440-Stand Bowlophone (Cont.Keyb.)	80	117	93	67	89
P 100	XII_a	MIDI Ext. C.Bell. Pedal tempo controller	93	100	81	50	81
P 101	XII_b	Sld.Kalimba fing.blockphn.contr&metal adder	93	67	72	44	69
P 102	XII_c	Octopentag. MIDI contr. for 1200ET	77	83	93	50	76
P 103	XII_d	MIDI Matraca controller for rotary harps	93	33	89	83	75
P 104	XII_e	Linear Kalimba Contr. for Harps.192ET	87	89	85	44	76
P 105	XII_f	MIDI hydroacoustic controller	80	56	59	56	63
P 106	XII_g	MIDI sliding lastrophone controller	80	33	48	44	51
P 107	XII_h	MIDI sliding 96ET Ahual.chromelod.contr.	87	100	67	44	74
P 108	XII_i	Snowdome's MIDI Umbrella Chime Controller	103	100	96	56	89

Pitch Res.Ser. No.	Group-aspect symb.	Instrument Name	Glissando	Microtonal	Timbre	Corporeal Expression	Total	
P 109	$XIII_a$	Compact Extended Conic Bellophone	87	100	81	67	**84**	
P 110	$XIII_b$	MIDI Weather Bell Tower	93	100	94	67	89	
P 111	$XIII_c$	Compact Square Buzzing Marimba	67	100	63	61	73	
P 112	$XIII_d$	MIDI Chime Tree Pyramid	87	100	96	67	87	
P 113	$XIII_e$	Compact Ceramic Water Cythraveena	67	67	69	50	63	
P 114	$XIII_f$	Comp.MIIDI Tap Ceram.24ET Caterp.	87	44	54	89	68	
P 115	$XIII_g$	Cer.10sld.-Panpipe&8-sld.key-96locks960ET	100	117	54	61	83	
P 116	$XIII_h$	Reed Cer.Ahualulco Chromel. 96-9600	80	106	70	44	75	
P 117	$XIII_i$	Dyn.MIDI wat.envr.&chorus/ens.wat.bell-pagod.	100	100	80	117	99	
P 118	XIV_a	Comp. Ext. Conic Bellphone & Resonators	87	100	81	67	**83**	Pitch
P 119	XIV_b	Arched MIDI sarunayophone.&regul.symp.	93	100	94	67	89	Timbre
P 120	XIV_c	Bell tecomate tree & grad.buzzing membr.	67	100	63	61	73	
P 121	XIV_d	Al..MI.Tubaphone with grad.Resonators	87	100	96	67	88	Amplit.
P 122	XIV_e	Buzzing-Symp-stop.regul.prepared MIDI piano	67	67	69	50	63	
P 123	XIV_f	Presure-sensor-D.Baton &Tim.Tap.Forest	87	44	54	89	68	Tempo
P 124	XIV_g	Compressed Air Aeolic Harp (with d.baton /PATT)	100	111	63	61	84	
P 125	XIV_h	MIDI Spatial Oboe with bell clappers C.B.	80	106	85	67	84	Spt.Prj.
P 126	XIV_i	Giant Mercury Sympathy Harp	90	56	81	117	86	

Fig. A3.93. Instrument design evaluation chart for the overall creative-comparative process.

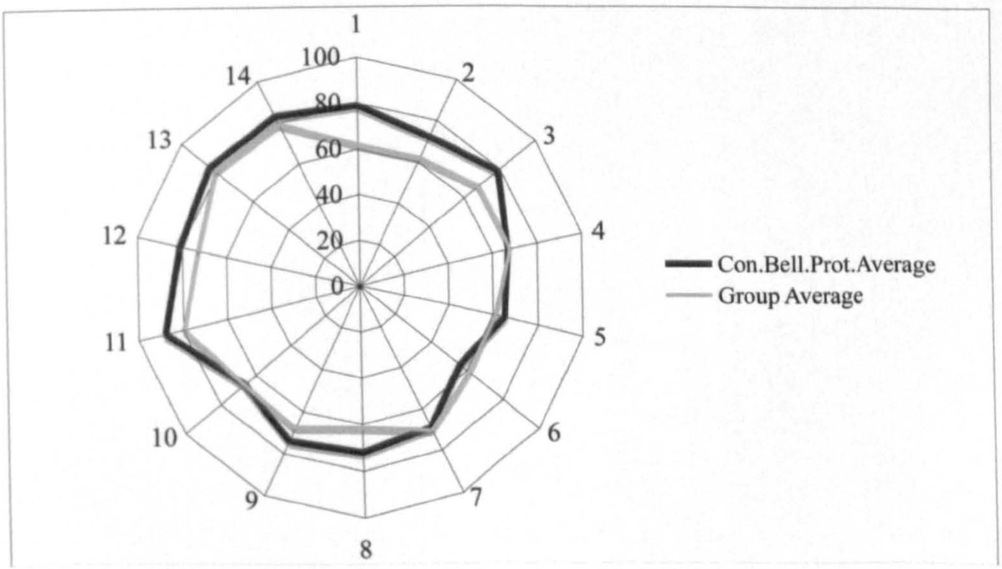


Fig. A3.94. Average value (in the 100 scale) among the ones for the different capabilities considered for each of the 14 *conic bellophone* prototypes (black line joins them) compared with an average of the average values obtained for each of the 8 conceptual instrument of the corresponding group (grey line joins them).

Appendix Four

Appendix Four: Concerts and demonstrations - feedback, programs and reviews

These documents to follow constitute a record of performances and demonstrations (which have been valuable in this research), and of feedback, both external and from performers, which has contributed to the instrument and compositional developments involved in this research (Figs. A4.1-A4.6).

A4.1 Lecture demonstration at the *Wild Dog 4 Festival* (15 September 2006, The Space, London)

A brief explanation was given of the various shapes and arrangements of bells considered; conical symmetry and the extended Stein-Couper notation (proposed on pp. 54-58) were explained. This was followed by a performance of *Improvisatory patterns for 4 hands* (Sc. 8), which demonstrated the sound of the most recent model of *conic bells*, *the spun bells*. The tuning arrangement used consisted of a single gently curving row of bells in sixteenthtones leading directly to a continuation of the same row in eighthtones. The arched mono-linear disposition of the bells used here is one of the several possible settings of the spun bells when placed on stands.

A video recording of this performance (DVD1-tk 8) shows how the players looked at each other for clues when they changed improvisation patterns, and how they skilfully managed to synchronise with each other. At one point the players use the backs of the mallets, showing how the timbre produced when performing glissandi with these bells can be changed, according to the sound activators s used.

Following the demonstration a member of the audience suggested that an air-pressure machine could produce a windy metallic glissando by blowing inside the cones.

The SPNM review with performance program card (Fig. A4.1), together with the review of a Croatian newspaper (Fig. A4.2) are documented as follows:

A4.1.1 SPNM review with programme (September 2006)

Live Review: WILD DOG 4: NAKED (SPNM on-line reviews)

Reviewed by **Jerry Wigens**

The Space, Friday 15 September 2006
Christopher Redgate (oboe/cor anglais), duo Contour: Stephen Altoft (trumpet) Lee Ferguson (percussion) Holly Wisker, Janina Moninska (live art), Tony Salinas (composer for bellophone)

The evening, set in this intimate and friendly venue, consisted of performance art, film and music, all of it impressively professional and well presented.

Tony Salinas gave a fascinating demonstration of his 96 note-to-the-octave bellophone before the main event. I was relieved to learn that the bells were tuned mechanically by the arduous application of file and tuner, and that Tony was in fact a mere mortal in terms of pitch discernment! The presque-glissandi were reminiscent of calibrated water gong sounds, and the instrument's capacity to hover around specific pitch areas with micro-movements was enchanting.

It featured in one of the eight short pieces improvised by duo Contour to accompany old home movies. Film of a fishing expedition enabled Lee Ferguson to explore the instrument's potential for wavering, nautical bell sounds. The duo's later accompaniment to Donald Bousted's *in your dreams* was an effective electro-acoustic soundtrack carefully conceived to complement the film's mirror imagery and split-screen techniques.

Of the other films shown, Paulo Henrique's *Contract with the Skin* was outstanding. Originally a dance performance with its soundtrack partly generated by the performers' movements, it explored facets of our relationship with our outer layer. The film was accompanied by a wonderful soundtrack, impressively realised by Rui Leitao, who had created an intriguing acousmatic tapestry with voice-derived and material sounds.

Earlier, to start the main event, the Host Artists Group had shown the 36 1-minute shorts created for their *Host 4 Cinema Project*. These were all visually captivating, and several featured stunning soundtracks. Of particular note was Bocman's sound on Neil Webb's shattering mirror piece *Underworld* and the menacing, treated cello sounds of Sarah Moody in Laura Hardman's beach drama *Aversion Therapy*.

Oboist Christopher Redgate's performances were their usual inspired combination of technical precision and inventiveness. Seemingly effortless circular breathing featured on his 5-minute improvisation *...the sting of the bee*, and his interpretations of Andriessen's frenetic *A Flower Song 2*, Denissow's subtle multiphonics in *Solo for Oboe* and Carter's lyrical cor anglais writing in *A Six Letter Letter* were a real pleasure.

Holly Wisker's silent nude performance piece, *Untitled*, with its echoes of Yoko Ono and Bobby Baker, involved members of the audience stamping her body with selected words which, alas, I never saw. Janina Moninska's *Hair as Metonomy* was an altogether livelier affair taking the form of a tongue-in-cheek lecture on the post-modern condition of our relations with head, underarm and pubic hair. Very informative and funny.

send an email with 'join' in the header to: wilddog@microtonalprojects.co.uk

Fig. A4.1. SPNM review with programme (September 2006).

A4.1.2 *Glas Istre* Newspaper Review (The Voice of Istre, Pula, Istria, Croatia. November 2006 edition).

Suvremena umjetnička kretanja u svijetu multimedija: jedno londonsko iskustvo - »Wild Dog 4«

Večer ultimate arta!

Dr. Donald Bousted, londonski skladatelj, najveći je »krivac« za ovaj festival koji su u svim dosadašnjim izdanjima uvijek krasili novi, hrabri i smjeli potezi i inicijative u suvremenoj umjetnosti, kao i na ovoj svjetskoj premijeri, 96-mikrotonalnog bellophonea, instrumenta od jedne oktave, koji sadrži čak 96 elemenata...

Zabilježio Petar ĆURIĆ

Prošlog sam mjeseca svjedočio posve neobičnom glazbenom događaju u Londonu, festivalu »Wild Dog«, nastupivši u dijelu tog spektakla održanom u istočnom dijelu grada. Danas on ima reputaciju najboemskijeg dijela velegrada jer je u njemu najveća koncentracija umjetničkih galerija svih vrsta, a umjetnost se živi i udiše 24 sata na dan, ili »around the clock«, kako Englezi kažu. Najvažniji dio festivala bila je svjetska premijera novog izuma, 96-mikrotonalnog bellophonea, instrumenta od jedne oktave, no budući da je mikrotonalan sadrži čak 96 elemenata...

Ipak, ono što me ponajviše fasciniralo u ovom izdanju toga jednodnevnog festivala, petosatnog programa koji je održan četvrti put zaredom, ovaj put u ostacima nekadašnje crkve a danas kultnog sastajališta umjetnika i ljubitelja moderne, klubu The Space, bila je doista nevjerojatna raznovrsnost umjetničkog izraza. Dr. Donald Bousted, londonski skladatelj, multimedijalni umjetnik i prvi čovjek mikrotonalne glazbe u Europi – najveći je »krivac« za ovaj festival koji su i dosad uvijek krasili novi, hrabri i smjeli potezi i inicijative. Ovo četvrto izdanje nastavilo je tragovima multimedijalnog umjetničkog izričaja ili »mixed media arta«, kako to Bousted naziva.

Ni mi u Istri ne zaostajemo

Htio bih pojasniti naziv »multimedij« (multimedia) ili umjetnost izmiješanih medijskih artističkih izričaja (mixed media art). Naime, svi ti pojmovi nerazdvojni su sinonimi za putove i kretanja u umjetnosti danas. Jasno je da ni mi u Istri nismo zaostali za svijetom baš toliko i da i kod nas postoje težnje i kretanja koji žele pratiti određene svjetske trendove u suvremenoj umjetnosti. Primjer su otvaranje Multimedijalnog centra Luka u Puli i svi događaji koji su ondje održani (u posljednjih godinu dana dovoljno je apostrofirati konceptualnu umjetnost Gordane Majnarić, instalacije Pina Ivančića, slike Matilde Brezak, Denisa Sardoza, Fulvija Juričića, itd., izložbe fotografija Đanija Celije, filmske i DVD instalacije Ivana Faktora, koncerte, večeri poezije i drugo).

No, želim skrenuti pažnju na to da je stanje u suvremenoj umjetnosti ipak malko drugačije, pogotovo ako se uputimo dublje u Europu. Evo jedne poredbe. Zavirimo li u sport i borilačke vještine od boksa, karatea, kung-fua, hrvanja, džuda, pa sve do novijeg kick-boksa i konačno vještina koje kombiniraju više tehnika, tj. MMA, K1 i druge borbe, uočavamo da je konačno došlo do kulminacije upravo u ultimate fightu, u kojemu je, neka ne bude zaboravljeno, naš Mirko Filipović trenutno jedan od vodećih boraca.

Jasno je da je to vještina koja od sportaša traži najveću moguću kombinatoriku i poznavanje svih borilačkih vještina. A trendovi su trendovi i oni su ipak zarazni... Odnose se na mentalitet i kulturu življenja jednog vremena i polaze prvenstveno iz ljudskih glava te želim ukazati da se jednaka stvar u biti dešava i u suvremenoj umjetnosti.

Mikrotonalna truba Stephena Altofta

Ono što se u Hrvatskoj trpa pod multimedijalnost usporedivo je s borbama u Saitama Areni u Japanu, ali na način na koji su se takve borbe, pretpostavljam, održavale prije dvadeset godina: možda se tada pod »miješanim tehnikama« smatralo ako bi npr. prvi par bili boksači, pa onda drugi par hrvači, treći karatisti itd.

Naime, ono što se u MMC-u Luka odvija cijele godine - recimo u nizu od 10 događaja – u Londonu ćete doživjeti u jednoj jedinoj noći! Naravno, kod nas je do sada bilo drugačije i uvijek se mogao nazrijeti nekakav prezir prema napretku i izdvajanju iz prosječnosti. »Ne talasaj« - bila bi naša fraza, a onda bi se bez srama kopiralo tuđe (strano) i već viđeno. Četvrto izdanje multimedijskog spektakla »Wild Dog« u Londonu bilo je, jednostavno rečeno: večer ultimate arta!

Predstavljanje 96-mikrotonalnog bellophonea

Wild Dog 4 započeo je, dakle, u izvrsno akustično osiguranom prostoru nekadašnje crkve, a danas kultnog kluba/pub-restauranta The Space. Tony Salinas, Španjolac iz Seville, ujedno znanstvenik-inovator, izumitelj 96-mikrotonalnog bellophonea, održao je predavanje na temu ovog, jedinstvenog u svijetu, mikrotonalnog udaraljkaškog instrumenta.

Inače, u glazbenoj demonstraciji sudjelovali su Lee Ferguson, američki udaraljkaš iz Freiburgu (Njemačka), i moja malenkost iz Lijepe naše. Salinasu je u dodatnoj prezentaciji pomagao prof. Javier Garavaglia, Argentinac, voditelj katedre za elektroakustičnu glazbu pri Metropolitan University London. Uslijedilo je nešto doista fascinantno: prikaz 36 jednominutnih art-filmova grupe umjetnika iz engleskog grada Sheffielda koji sebe nazivaju Host.

Holly Whisker, art performance pečatiranje tijela – prvi je to učinio dr. Donald Bousted (lijevo)

Zašto baš 36 filmova i svi po jednu minutu? Ako umjetnik uistinu ima što za reći, sve će to moći izraziti i u jednoj jedinoj minuti! Nakon toga slijedi solo performans uživo »...the sting of the bee«, koji izvodi oboist extraordinaire Christopher Redgate, za kojeg su skladali najeminentniji suvremeni kompozitori, od Michaela Finissyja do Briana Ferneyhougha (radi se o nekim od najtežih skladbi ikada komponiranih za obou).

Pečatiranje tijela Holly Whisker

Svejedno, čovjek je svjestan da u današnje vrijeme ne može konkurirati samo »lovačkim pričama o legendarnim klasicima« – kako to neki kod nas čine – a potvrđuje to i svojim petominutnim »cirkularnim disanjem«, posebnom tehnikom disanja i sviranja u isto vrijeme u djelu Andriessena »A flower song«, što je bilo uistinu nešto jedinstveno. Slijedila je potom »live art Holly Whisker« koja se pojavila pred publikom, sjela na stolac, posve se skinula te doslovno tako naga sjedila ne mičući se 20-ak minuta, leđima okrenuta prema ljudima koje je unaprijed pozvala da se »posluže« ponuđenim pečatima. Svaki je pečat nosio različitu riječ ili pojam, a publika je bila pozvana postaviti biljeg na dio umjetničnog tijela i tako sudjelovati u performansu, stvarajući međuodnos određenog dijela tijela, tj. njegovoga naziva, i pojma na pečatu. U nastavku duo Contour, koji uz već navedenog Leeja Fergusona čini i trubač Stephen Altoft.

Njegova je specifičnost da svira na mikrotonalnoj trubi koju je sam stvorio u suradnji s Marcusom Stockhausenom (poznatim sinom još poznatijega oca, jednog od gurua suvremene glazbe druge polovice 20. stoljeća). Mikrotonalna truba ima četiri valva, umjesto uobičajena tri, i određeni su dijelovi instrumenta smanjeni, a neki elementi posve skinuti (četvrti je valve vama na slici s desne strane instrumenta, nadodan ispod konvencionalnih tipkovnica).

Slijedila su još dva duža filma – »Passing shadows« Pula Leeja i »Contract with the skin« Paula Henriquea, a zatim opet nešto sasvim drugačije. Moglo bi se nazvati mješavinom kazališne glume, kabarea, sveučilišnog predavanja, stand-up komedije, znanstvenog skupa, live arta, umjetničkog voajerizma i još tko zna čega. Janina Monianska, Engleskinja poljskih i francuskih korijena, profesorica na akademiji za glumu u Amsterdamu održala je posve otkačen performans »o dlakama i kosi« (!)...

Wild Dog u Puli!?

I na samom kraju ove maratonske glazbene večeri - multimedijalno djelo samoga Bousteda »In your dreams«, u izvedbi dua Contour. Djelo uključuje posebno odabrane udaraljkaške instrumente (gudalo za kontrabas kojim se svira po mini disketi, limene kantice, pločicu ružinog drveta skinutu sa skupocjene koncertne marimbe, mikrotonalnu trubu, itd), a uz tu akustičnu živu glazbu idu i dva filma koja se simultano prikazuju na dva platna, te dva ogromna komada stakla koja postaju u isto vrijeme zasebni instrumenti i ogromni zvučnici (!). Na njih je priključen poseban minijaturni transformator »transducer speaker« koji kad se montira na bilo koji element, od čitavog elementa stvara zvučnik. Naravno, sve je to bilo prezentirano u jednoj jedinoj večeri... – dakle, multimedijom, ili ultimate artom, ako hoćete... Eto, nadamo se da će jednog lijepog dana Wild Dog doći i u Pulu.

Ne bi li bilo zanimljivo domaćoj publici prezentirati 96-mikrotonalni bellophone za koji je već jedan priznati skladatelj počeo skladati? Ne bi li bilo cool otvoriti jednu izložbu koja je drugačija od svih izložaba, prisustvovati živom elektroakustičnom performansu, predavanju na tu tematiku, napose diskusijama na temu kojom se bavi i ovaj tekst: multimedij-mixed media art - ultimate art?

Pitam se nije li vrijeme da se konačno oprostimo od 20. stoljeća - jer i 21. je već pomalo prošlost.

Bellophone - 16 elemenata sačinjava tri tona

Fig. A4.2. Performance at the *UK Microfest 2* (2 March 2007).

This concert involved two rehearsals of the main work presented, *Autumn* for *conic bellophone* and mixed quintet. Important feedback was obtained from the players while composing and during rehearsal. Working closely with the players was of great importance in knowing what could be expected from each instrument and, to some degree, from their combined sounds. The performance of *Autumn* was followed by the *One row study* for *conic bellophone*, *Improvisatory patterns 2* (*Soleá*), which is now, in 2011, adopted as the overture for a larger work, now in progress. *Autumn* was repeated at the end of the concert.[1]

A4.2 *UK Microfest 2*

The program (Figs. A4.3-5) and a concert review (Fig. A4.6) are documented as follows:

A4.2.1 Programme


UK MicroFest 2

2-4 March, 2007

***river*house**
Manor Road, Walton-on-Thames, Surrey KT12 2PF
www.riverhousebarn.co.uk

Fig. A4.3. *UK Microfest 2* programme (part I).

[1] An emergency stopped the percussionist Petar Curic from attending rehearsal and concert. He was replaced at short notice by Mathew West, who was adept at sight-reading the sliding and microtonal timpani parts.

UK MicroFest 2: Ticket Information

***river*house**
Manor Road, Walton-on-Thames, Surrey KT12 2PF
www.riverhousebarn.co.uk

Ticket Reservations
***river*house box office 01932 253354 (24 hours)**
or
By Post: ***river*house**, Riverhouse Barn, Manor Road,
Walton-on-Thames, Surrey KT12 2PF
By Email: boxoffice@riverhousebarn.co.uk
cheques should be payable to Riverhouse
Visa and Mastercard accepted

for directions and further information about riverhouse:
www.riverhousebarn.co.uk
for accomodation and restaurants in the area:
http://www.elmbridge.gov.uk/tourism/accomodation.htm

***river*house**
***river*house** is an arts venue built around an 18th century barn on the river in Walton-on-Thames. Opened to the public in 1989, it is a performance space, art gallery, craft studio, café-bar and garden with on-site parking. It is close to Walton town centre and within a short walk of the Thames path and a number of attractive riverside pubs. There is plenty of bed and breakfast accommodation, very reasonably priced, nearby. Walton is around 30 mins from London Waterloo and ***river*house** is close to the M25. ***river*house** is approximately 20 mins walk from Walton station; taxis to ***river*house** normally cost less than £5.

What is microtonal music?
The most concise definition of microtonal music is music which uses pitches other than the 12 equally spaced pitches normally heard in western music *or their very close relations* (like the ones used in the temperaments of Baroque music such as *Meantone Temperament*). Such music is not particularly rare. We know that the ancient Greeks used structured intervals as small as a quarter-tone, so do many folk musics from around the world and Indian classical music.

Quarter-tones are by far the most commonly used of these smaller intervals. A quarter-tone is exactly half the size of a semitone, an interval which therefore doesn't exist on the piano but which can be played on all the orchestral instruments with practice. Quarter-tones can also be played on specially adapted instruments such as guitars or brasses with an added fourth, quarter-tone valve.

The expanded palette of sounds which becomes available through microtones is being sought more and more by composers and as well as quarter-tones, in UK MicroFest 2 you can hear many other possibilities realised by performers of exceptional ability.

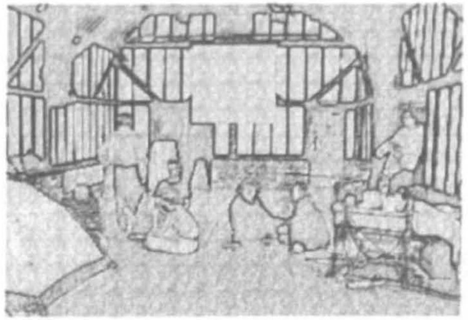
Microtonal music is not concerned with any particular style of music, or any particular musical culture. Indeed, many of the most interesting microtonalists in the 20th century were maverick figures who operated outside the normal music hierarchy. We hope you will come and join us ...

Artistic Director: Donald Bousted
Promoter: Microtonal Projects Ltd (a not-for-profit company limited by guarantee) www.microtonalprojects.co.uk

Microtonal Projects Ltd gratefully acknowledges financial support from the PRS Foundation and RVW Trust and generous support from London Metropolitan University and Kingston University

UK MicroFest 2

2-4 March, 2007



***river*house**
Manor Road, Walton-on-Thames, Surrey KT12 2PF
www.riverhousebarn.co.uk

(Walton is only half an hour from London Waterloo)

Tickets available from:
***river*house box office 01932 253354 (24 hours)**

Artistic Director: Donald Bousted
Promoter: Microtonal Projects Ltd (a not-for-profit company limited by guarantee)
www.microtonalprojects.co.uk

Microtonal Projects Ltd gratefully acknowledges financial support from the PRS Foundation and RVW Trust and generous support from London Metropolitan University and Kingston University

Ticket for all events: £40 (full price), concessions £25, students £10
Conference Meal: £20 per head excluding alcoholic drinks at Khoa Sarn Thai Restaurant
(to reserve, email: info@microtonalprojects.co.uk before 22.02.07, cheques payable to 'Microtonal Projects Ltd' and sent to 75 Canbury Avenue, Kingston upon Thames, Surrey KT2 6JR, UK or, if you are coming from abroad, give the money in cash to one of our staff at the festival)

Local Accommodation (Elmbridge Borough Council Website):
http://www.elmbridge.gov.uk/tourism/accomodation.htm

Fig. A4.4. *UK Microfest 2* programme (part II).

Friday 2nd March, 2007

Session 1 *(Price: £8, concessions £5, students with card £2):*

6.30pm-7.30pm welcome and overview followed by discussion with musical interludes by *Wim Hoogewerf* (guitar)
Neil Haverstick: Mysteries for 19-tet guitar (UK premiere)
Ivor Darreg: Two preludes for 19-tet guitar: Prelude for Guitar in E Minor; Prelude Nr. 2 for 19-tet guitar (probable UK premiere)

8.00pm concert: *Neil Heyde cello, Chris Redgate oboe, Paul Archbold and David Gorton live electronics*
Fabrice Fitch: Per Serafino Calbarsi II: Le Songe de Panurge (Neil Heyde cello)
Paul Archbold: Penumbra (Neil Heyde cello, Paul Archbold live electronics) (World Premiere)
Roger Redgate: Ausgangspunkte (Chris Redgate, oboe)
Fabrice Fitch: Trois Filigrammes (Chris Redgate, oboe)
David Gorton: Erinnerungsspiel (Chris Redgate oboe, David Gorton live electronics)
Jonathan Harvey: Advaya (Neil Heyde cello, Paul Archbold keyboard/live electronics)

Saturday 3rd March, 2007

Session 2 *(Price: £8, concessions £5, students with card £2):*

10.30am *Donald Bousted* introduces 'The Microtonal Trumpet', a project between *Donald Bousted* and *Stephen Altoft*

11.00am concert: *Stephen Altoft, microtonal trumpets*
Jean Philippe Calvin: Flux II (UK Premiere)
Oded Ben-Tal: Still-Life with live electronics (World Premiere)
Donald Bousted: Yasser describes his Polemic (and adds some footnotes) for 19-div trpt (World Premiere)
Donald Bousted: 4, Eighth-tone studies (from 24 Microtonal Studies) (World Premiere)
Chris Bryan: Dialogue for 19tone trumpet and computer (World Premiere)
Donald Bousted and Gary O'Connor: Slide for quarter-tone trpt and film with accompanying text
(finish c.12.30)

Session 3 *(Price: £8, concessions £5, students with card £2):*

2.00pm Music in 96 divisions: *Lewis Jones*, conductor; *Guido Arbonelli*, bass clarinet; *Alan Tomlinson*, trombone; *Stephen Altoft*, trumpet; *Petar Curic*, timpani; *Lee Ferguson*, conic bellophone; *tbc*, cello; *Wim Hoogewerf*, guitar
J.A. Martin Salinas: Autumn for conic bellophone (96ET), percussion and mixed quartet (24 division) (World Premiere)
J.A. Martin Salinas: Studies for the conic bellophone (World Premiere)
Pascale Criton: La ritournelle et le galop (1996) for quarter tone guitar in 1/16th tone tuning (UK Premiere)
J.A. Martin Salinas: Soleá for 96 division guitar and conic bellophone (World Premiere)
(finish c. 3.30pm)

Session 4 *(Free)*

4.00-5.00pm *James Wyness* talks about his microtonal music

Session 5 *(Price: £8, concessions £5, students with card £2)*

6.00pm *Lawrence Casserley* (electronics) and *Simon Desorgher* (flute) lecture-recital
Simon Desorgher: Concert Studies, Turbulence (excerpt)
Lawrence Casserley: PanHarmonic, Transformations III (excerpt); The Monk's Prayer; Improvisations for flute and computer

(finish c. 8.00pm)

8.30pm ***Conference Meal: £20 per head excluding alcoholic drinks at Khoa Sarn Thai Restaurant*** *(approx 7 mins walk from **river**house at 26 Bridge Street, Walton)*
(to reserve, email: info@microtonalprojects.co.uk before 22.02.07, cheques payable to 'Microtonal Projects Ltd' and sent to 75 Canbury Avenue, Kingston upon Thames, Surrey KT2 6JR, UK or, if you are coming from abroad, give the money in cash to one of our staff at the festival)

Sunday 4th March, 2007

Session 6 *(Price: £8, concessions £5, students with card £2)*

10.30am *Jeff Herriott* (USA) introduces his music

11.00am *Guido Arbonelli* (It) clarinet and bass clarinet
Carey Nutman: Clarinet Vision for clt and tape (UK Premiere)
Jeff Herriott: Instances for clt and tape (UK Premiere)
Eric Chasalow: In a Manner of Speaking for bass clt and tape (UK Premiere)
Mauro Porro: Ipse for clt and tape (UK Premiere)
Jeff Herriott: Design for bass clt and tape (UK Premiere)
Bruno Strobl:Gate of Gate for bass clt and tape (UK Premiere)
Luigi Ceccarelli:Birds for bass clt and tape (UK Premiere)
(finish c.12.30pm)

Session 7 *(Price: £8, concessions £5, students with card £2)*

1.30pm talk: *Aaron Hunt* 'For the Future of Music' - bringing microtonality into the mainstream
Aaron Hunt, Director and founder of **H-Pi instruments** presents a multimedia lecture with instrument demonstrations

2.30pm concert: *Wim Hoogewerf*, guitar
Julian Carrillo: Excerpts from the Suite ("Impromtu", 1931) for quarter tone guitar: Preludio (Recitativo); Lentamente "Bajo las frondas de ahuehuetes milenarios en Chapultepec" (probable UK premiere)
Dick Visser (1926): Quintierens (1998) for quarter tone guitar (7'): Allegro ma non troppo; Larghetto; Prestissimo (UK premiere)
Joseph Pehrson (1950): Just in Time (1999) in 11-limit Just Intonation for guitar with moveable frets (UK premiere)

Session 8 *(Price: £8, concessions £5, students with card £2)*

3.30pm Concert: *Trio Scordatura* (*Alfrun Schmid*, voice; *Elisabeth Smalt*, viola, Adapted Viola; *Bob Gilmore*, keyboard, electronica):
Alvin Lucier Voice (from Still and Moving Lines of Silence in Families of Hyperbolas);
Tristan Murail C'est un jardin secret...;
Horatiu Radulescu Intimate Rituals XI (UK premiere);
François-Bernard Mâche Kubatum;
James Tenney Harmonium no.2;
John Fonville Songs of Sappho;
Christopher Fox Time Enough (World premiere);
Harry Partch Two Psalms
(finish c.5pm)

END OF UKM2

***river**house* cafe will be open for lunches, snacks and refreshments throughout UK MicroFest 2

PRSFoundation for new music

Fig. A4.5. *UK Microfest 2* Programme (part III).

A4.2.2 *SEAMUS Newsletter* Review (8 April 2007)

2007, April, Issue 2, page 8 SEAMUS Newsletter

MICROFEST UK 2

A report from London

http://www.donaldbousted.pwp.blueyonder.co.uk/ukmicrofest.htm

By Jacob Barton

I had the exciting opportunity this past March to travel to London and attend Microfest UK 2, a weekend festival for microtonal music. I say 'exciting' because I was, and remain excited about microtonal music, perhaps in a naïve way. When I first discovered the writings of Harry Partch and Ivor Darreg in 2003, I decided that the idea of tuning differently in itself was delicious, even irresistible; finding equally delicious music has since been an awkward and perilous journey! Until microtones are more commonplace in all sorts of music, festivals such as this one are rare delicacies.

Microtonality in Western music is usually defined as the use of any tuning besides the ubiquitous 12-tone equal temperament, and while such alternate tunings are slowly becoming more widely used (with no small help due to developments within the electronic music making community), interest in the development of tuning as a consciously independent parameter of music (X.J. Scott has called this "intentional microtonality") remains on the fringe yet, even in the UK. At the eight events I saw an average of 30 people in attendance, most of them involved in the festival in some way.

That's not to say that microtonality is only listenable by microtonalists; I have played this music to folks of all stripes and witnessed mostly positive reactions. However, when we present music as having this particular (often very subtle) quality, we run the risk of making our listening obsessed with this quality. Of course, it is with my obsessed ear-brain that I offer this report.

Virtuosity was well represented at this event. Oboist Christopher Redgate, clarinetist Guido Arbonelli, and cellist Neil Heyde stood out as exceptionally adept performers; here, microtonality served gesture in spiny quarter-tone passages and timbral trills, and electronic accompaniment was common. Lawrence Casserly used live electronics with flutist/panpiper Simon Desorgher to brilliant effect, and Trio Scordatura played a concert in exquisitely accurate just intonation.

Then there were some who took the "micro" further than others. Aaron Hunt of Illinois presented his Tonal Plexus keyboard, which has 205 button-like keys per octave, as well as a related notation program and a box for live-retuning MIDI synthesizers – see <www.h-pi.com> for more details. J. A. Martin Salinas presented his 96-tone conic bellophone, a wonderful new type of tuneful percussion, and guitarist Wim Hoogewerf kept up by stringing his quarter-tone guitar with 6 low E strings. (Hoogewerf also plays a guitar with moveable split frets – what more could one ask for?) The music of Jeff Herriott (Wisconsin) and Pascale Criton (Paris) made much out of very small intervals – the line between timbre and pitch blurs.

The music which made use of new *structures* of pitch excited me most; I guess it's a feeling of *nativeness*, of feeling completely at home in a completely alien tuning that I'm after. The music for 19-division trumpet seemed to do this the best. The trumpet, which is actually a non-permanent alteration to a normal trumpet, is the result of a project between festival director Donald Bousted and trumpeter Stephen Altoft (www.microtonaltrumpet.com).

All in all, the festival lived up to my initial excitement. As microtonality is only a technique and not limited by style, the festival was an interesting intersection between worlds, including the electronic and acoustic worlds. Alternate tunings might be trivially simple to program on a computer, but they are still quite a pain to produce on acoustic instruments, and as long as people still like acoustic instruments, events like this one will be rare. My hope is that acoustic instruments will actually evolve, such that they can continue to challenge the imaginations of all composers.

Fig. A4.6. *SEAMUS Newsletter* Review (8 April 2007).

A4.3 Lecture demonstration at the EPSRC Musical Acoustic Network *Symposium* (5 March 2007, London Metropolitan University)

This event followed the UK Microfest 2 concert directly. Percussionist Lee Ferguson demonstrated the *conic bellophone*, showing a wide range of beaters and techniques. He also played the *One row study*, and demonstrated several glissando exercises in unison with the Sixteenthtone Guitar, played by Wim Hoogewerf (see DVD2-tk 12). These short demonstrations illustrate an array of techniques for the *conic bellophone*, and an example of how the 96-et can be used with other instruments to achieve simultaneous microdiscrete sliding pitch movements, in this case parallel glissandi played on a guitar with 6 low E strings and fretted in quartertones, playing 4-string arpeggios (strings 4 to 1), the open tunings of the 4 strings ascending in sixteenths of a tone, this making possible a microdiscrete ascending glissando progression. In this case Wim Hoogewerf used a bottleneck held in diagonal position, which he slid progressively at a fixed speed to match the fret on which the strings were stopped. The reverse process was performed for descending pitch and a combination of both for playing zig-zag exercises, all in unison with the *conic bellophone*.

An open discussion with the audience produced pertinent feedback about the instrument. One comment concerned the stability and safety of the stands, if the instrument should be presented in an exhibition space where children would be allowed to play it.

Appendix Five

Appendix Five: Personal communication .

– E-mail from Milton García –

Re: Some questions about Julián Carrillo 5:15 AM

"Milton" miltoncgarcia@gmail.com

To: "Martin Salinas" <martinsalinas@japan.com>

Milton C. García

Barcelona, Spain

12-SEPT-2013

Dear José Antonio Martín Salinas,

Thanks for your interest in the work of Julián Carrillo. I am more than happy to answer your questions in very simple words.

(1) What was the foundation behind Julián Carrillo's music theories?

The work of Carrillo is built on three pillars: simplification of the notation system, enrichment of sound, and purification of the intervals.

(2) Did you have personal contact with David Espejo and Oscar Vargas?

I did have personal contact with David Espejo in several occasions before his death in 2007. I did not have personal contact with Oscar Vargas. Also I had discussions several times with Jimena Giménez Cacho. She took lessons and classes with David Espejo before his death.

(3) What was their main contribution to the work of Julián Carrillo.

David Espejo and Oscar Vargas were late students of Julián Carrillo, and were asked by Carrillo to complete his work concerning the purification of intervals. This was an aspect of Carrillo's theoretical foundation that was compromised by the use of equal temperaments. David Espejo first formulated a tuning 100 notes per octave (101 tones when including the octave). The tuning starts from harmonic 100 as a root (ratio 100/100), and employs each single harmonic above (ratios 101/100, 102/100, ... 199/100) up to harmonic 200 (ratio 200/100), an octave above the root. The two-digit numerical notation used by Carrillo is preserved with this tuning system, and in this case instead of using from 00 to 95 to reach 96 notes, it employs from 00 to 99 to reach 100 notes.

Concerning Oscar Vargas, I know that he built *Microintervallic Harps* using David Espejo's 100-notes-per-octave tuning (101 notes per row, since the octave of the starting note on the left is repeated on the right end). These harps were built covering 3, and up to 9 octaves. To give you an idea, the *Microintervallic Harp* covering nine octaves has 901 different frequencies, with 8 of them repeated, consequently includes 909 tones. This harp places strings at both sides of the box and one string has several bridges to include different frequencies in different sections (still the same note in different octave), since it relies on several bridges precisely placed for that purpose. I have seen these Harps and played them myself.

I hope that this answers your questions. Please get in touch if you need more detailed information.

We have already placed some information about your research at the '*Julián Carrillo y el sonido trece*' homepage (sonido13.tripod.com) and hope that you keep updating us with your future progress promoting and seeding the work of Carrillo.

Kind regards,

Milton

>El 09/09/2013, a las 04:21 p.m., "Martin Salinas" <martinsalinas@japan.com> escribió:

>

>Dear Milton García,

>

>I am research student at the London Metropolitan University. Part of my
>research analyses the work of Julián Carrillo and proposes new ideas stemming
>from his work.

>

>First of all, I would like to congratulate you for your amazing project titled '*Julián*
>*Carrillo y el Sonido 13*'. As director of this organisation I would like you to report on
>Julián Carrillo and two of his pupils by answering the following questions:

>

>(1) What was the foundation behind Julián Carrillo's music theories?
>(2) Did you have personal contact with David Espejo and Oscar Vargas?
>(3) What was their main contribution to the work of Julián Carrillo?

>

>Sincerely,

>

>José Antonio Martín Salinas
>1-12-19 Terugaoka. Yata.
>Higashisumiyoshiku.
>Osaka.
>JAPAN 5460021