Main applicant: Martin Neukom

Title of the Project: **Sound Colour Space – A Virtual Museum**

## 1. Summary of the Research Plan

By investigating the conceptual field *sound*, *tone*, *pitch*, *timbre* in its relation to visual phenomena and geometrical concepts, the project *Sound Colour Space. A Virtual Museum* contributes to an interdisciplinary field of research and aims to explore its adequate modes of representation and communication.

Many scientists and philosophers from antiquity to modern times have studied the relationships between sound, light and geometry. Many of their visualisations on acoustical, optical and perceptual topics speak to the eye and can be studied comparatively. These pictures are interesting because of their diagrammatic structure, in the way they combine text, images and spatial structures on a flat surface and in the way they address topological, philosophical and psychological questions. They often have an aesthetic value of their own. The interdependencies between sound and light, physics and perception seen through the spectacles of geometry, i.e., by using mathematics as a kind of universal meta-language, is a topos of the history of science and philosophy, which can be traced back to Greek antiquity (Pythagoras, Aristoxenos, Aristotle and Euclid) and traced forward to recent discourses in philosophy and aesthetics.

The collection and study of these materials and the attempts to present them as a sequential text lead to the question of adequate forms of representation. Comparative analysis demands an open network approach rather than the application of prefabricated static structures and hierarchical criteria. Since a given picture or graphic can appear in various contexts and with different implications, a distinct network architecture permits forms of content representation free from redundancies in a way that is difficult to achieve in textual form. The structure of such contents can be captured by relational models. Accordingly, we will analyse our collection of scientific illustrations and diagrams (currently about 1000 image files) and present them together with related materials and findings within a dynamical and open online publication. Thereby, the metaphor ‘museum’ is rendered as a place where people and objects meet and interact in various dynamic modes. Visitors to the museum will gain access to the collection of pictures and they will be able to compare and regroup the pictures, read explanations, listen to sound examples, watch animations and interact with audiovisual applications, or they can just follow guided tours. Scientists and scholars can use the museum as a research tool and add to the contents of the underlying database.

The project has a double purpose: To make these specific materials and our own findings available for further study and to contribute to collaborative forms of research and the communication of scientific knowledge, which could otherwise not be properly presented as sequential text. This approach will have a positive impact on other research venues dealing with heterogeneous materials. Since the planned application will be built upon the Media Archive of the Arts developed at the Zurich University of the Arts (ZHdK), the project will contribute to the further development of this online platform as a research tool.

The project establishes a link between the Institute for Computer Music and Sound Technology (ICST) and the Institute for Theory (ith), both part of the ZHdK. It enriches the dialogue between art and science in as much as it makes historical knowledge available and contributes to the current discourse about the fundamental aspects of scientific and artistic practice linked to sound, colour and space.

## 2.1. Current State of Research

There are many excellent studies in every scientific field related to our project. However, there are not so many meta-studies. Historically and up to the 19th century, ‘philosophers’ and mathematicians have usually also studied the physics and psychology of acoustical and optical phenomena (e.g. Pythagoras, Aristotle, Robert Fludd, Descartes, Kepler, Huygens, Newton, de Mairan, Euler, Thomas Young, Goethe, Helmholtz).

### History of the involved sciences

From the rich secondary literature on the history of optics, acoustics and mathematics we eclectically pick just a few:

**Optics**

Olivier Darrigol (2012) is a profound study with many historical illustrations based on careful source reading. Darrigol often draws parallels between the history of acoustics and optics also in articles from 2007, 2009, 2010. Lindberg (1976), on the other hand, focuses on the theories of vision from Al-Kindi to Kepler. Werner Spillmann Farb-Systeme 1611–2007 (Basel 2009) covers colour orders from the 17th century to today. This book contains many high quality reproductions and concise explanations. Also Gage (1995, see below) documents many systems of ordering colour with historical illustrations.

**Acoustics**

Where Patrice Bailhache (2001) focuses on the history of acoustics with respect to music theory, Peter Költzsch (2010) covers the story of acoustics from Antiquity to the 20th century.

**Mathematics**

*The History of Mathematics: Highways and Byways* by Dahan-Dalmedico et al. (2009) originally French (1986) was also translated into German (1994) is easy to read and develops the philosophical backgrounds of mathematical thinking.

### Diagrams

Recently, there is growing interest in the visual means used in historical scientific texts. We give a selection of related studies with some keywords:

Penelope Gouk (1999, see below), Michael Mahoney (2001, ‘sketching science’, 17th C., Christiaan Huygens); Claus Zittel (2009, aesthetic forms in science, Descartes); Bredekamp, Velminsky (2010, “Mathesis & Graphé“, Leonhard Euler, unfolding systems of knowledge); Sybille Krämer (2011b, 2012) is working in the field of ‘diagrammatology’ in order to develop a general theory of diagrams. She also works on Descartes and his diagrams (cf. Section 2.3).

### Unifying Approaches

Jörg Jewansky’s dissertation, *Ist C=Rot? Eine Kultur und Wissenschaftsgeschichte zum Problem der wechselseitigen Beziehung zwischen Ton und Farbe. Von Aristoteles bis Goethe* (1996) carefully develops the cultural history of the mutual relationship between ‘tone’ and ‘colour’ from the Greek Antiquity to Goethe’s time. However, it contains no original pictures.

John Gage, *Colour and culture: practice and meaning from Antiquity to abstraction* (1995) is a rich and inspiring book developing manifold perspectives and containing many images. The colour orders/topologies and the attempts to unite colour and music are of particular interest for our project.

In order to break-up binary habits of thinking, triangles play an important role in Penelope Gouk *Music, science, and natural magic in seventeenth-century England* (1999). One is tempted to see in Gouk's approach a ternary logic of science, which had its precursors in neo-platonic world conceptions of the 17th century such as depicted in the *Scala descensionis …* (1662) according to Johann F. Jungius (1558–1617) (see Fig. 1). Consequently, Gouk's book is divided into three parts: geographies, galleries and narratives. The gallery part comes with many eye-catching diagrams. This book inspired the idea of the *Sound Colour Space*-museum of science, as a place where science is done and represented in a non-hierarchical setting.

A recent approach to a unified theory of perception and concept forming is provided by Peter Gärdenfors' *Conceptual spaces – The Geometry of Thought* (2004). This groundbreaking study links physics, perception and cognition by mathematical spaces. Elementary concepts are modelled as convex regions within conceptual domains. According to Gärdenfors there are comparatively strong geometrical relationships within a given conceptual (or perceptual) domain, which can be modelled naturally by Euclidean spaces, e.g., colour perception and colour concepts. Between different domains, however, as between the visual and the auditory, there is less coupling or none at all. Hence, classifying the tone/colour experiences of hearers without pronounced synaesthetic abilities is better modelled by a weak metric as the city-block metric, where distances and angles cannot be defined in the usual way. Gärdenfors also describes procedures to obtain discrete entities from continuous multidimensional data by using tessellation algorithms and he highlights the dependence of such algorithms from the underlying metrics. An interesting point is the question, how essentially two-dimensional neural networks can create one-, two- and three-dimensional percepts and concepts.

## Museums and virtual museums

"A *museum* is a building or institution that houses and cares for a collection of artifacts and other objects of scientific, artistic, or historical importance and makes them available for public viewing through exhibits that may be permanent or temporary." *Virtual museums* emerged in the 1990s. Many of them are closely tied to physically existing museums and provide a quick access to the objects and the archive. The "continuing acceleration in the digitization of information, combined with the increasing capacity of digital information storage, is causing the traditional model of museums (i.e. as static 'collections of collections' of three-dimensional specimens and artefacts) to expand to include virtual exhibits and high-resolution images of their collections for perusal, study, and exploration from any place with Internet." (https://www.princeton.edu/~achaney/tmve/wiki100k/docs/Museum.html )

We conclude this section by mentioning a selection of projects and websites related to aspects of our project.

### Virtual Museum 3D-Software

The Human-Computer Interaction Laboratory at Udine University is developing the tool VEX-CMS for 3D exhibitions and walkthroughs documented in Chittaro et al. (2010, cf. http://hcilab.uniud.it/ )

### Hyperphysics – interaktive physikalische Grundlagen

http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

A website, where the topics are organised as clickable network graph.

### ars auditus

http://www.dasp.uni-wuppertal.de/ars_auditus/index.html

This Website by Martina Kremer focuses on acoustics, hearing and psychoacoustics. The integrated interactive applications must be downloaded first (.exe, Windows only). Then they are run locally.

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Levent, N., Alvaro, P.-L., (ed.) (2014). The Multisensory Museum: Cross-Disciplinary Perspectives on Touch, Sound, Smell, Memory, and Space. Alta Mira Pr, 2014

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## 2.1. Current State of Research

Project manager **Daniel Muzzulini** has been studying the conceptual field ‘sound–colour–space’ for 15 years (Muzzulini 2000, 2001, 2006, 2007, 2011, 2012a, 2015). In the course of collecting material for his doctoral thesis on the notion of timbre he hit upon the diagrams in the *Compendium Musicae* (1618/19, 1650) by René Descartes in 2002.

As a student of mathematics, physics and musicology, he became familiar with the group theoretical approach to music theory of Guerino Mazzola in the late 1970ies (Mazzola 1985). In the years following the diploma at Zurich University, Muzzulini contributed to some of Mazzola’s publications (Mazzola 1985; Mazzola et al. 1989; Mazzola 1990; Mazzola, Muzzulini 1990). The use symmetry transformations to model harmonic and melodic musical processes inspired an extension of Mazzola’s modulation (Muzzulini 1995). From 1992 to 1993 Muzzulini was scientific collaborator in „Computergestützte Behandlung von Intonations-, Agogik- und Dynamikfeldern und deren Logiken als Beitrag zu einer mathematischen Theorie der musikalischen Interpretation“ (Snf-Project Nr. 39422).

His interest in the history of music theory and psychoacoustics intensified during the late 1980s and resulted in the master thesis “Konsonanz und Dissonanz in Musiktheorie und Psychoakustik” at Zurich University (Muzzulini 1991) and in an essay on Leonhard Euler’s ‘gradus suavitatis’ (Muzzulini 1994). In 2006, he took summer courses at Stanford University CCRMA in order to refresh and increase his knowledge in psychoacoustics, digital audio coding and physical modelling.

The concept ‘timbre’ (‘sound colour’ – ‘Klangfarbe’) in its relation to music theory, philosophy, geometry and history of science has been occupying his mind for about 30 years. This research came into fruition in the doctoral thesis *Genealogie der Klangfarbe* (Muzzulini 2006, Zurich University, Prof. E. Lichtenhahn).

More recently, Muzzulini has been studying diagrams from the 17th to the 20th century which correlate perceptual and conceptual features of sound and colour (Muzzulini 2012, 2015).

In a pre-project at the ICST (2013), he studied further primary sources and secondary literature on the history of acoustics, optics and mathematics, and he reviewed his unpublished materials. Currently, the collection of scientific illustrations and diagrams consists of about 1000 image files, addressing the conceptual field *sound – colour – space*.

During the pre-project it became obvious that a publication and analysis of the collection of images in a book would not live up to the manifold perspectives naturally associated with the topics under consideration. A dynamic network of science is a framework (architecture) that better maps the many and open perspectives belonging to our field of research and its conceptual structure. Such an organisation of knowledge is able to circumvent redundancies in a natural way, rendering the related contents easily accessible to other scientists and interested non-specialists. Thereby, a ‘museum’ (literally: a temple of the muses) turns out to be an adequate metaphor for our method of contemplating, analysing and representing our interdisciplinary field of research. Robert Fludd’s treatise *Templum Musicae* (1617–1622) is a direct forerunner of our virtual museum by making the museum’s architecture a network of knowledge based on scientific and educational visualisations (see Fig. 1, 2 and Section 2.3).

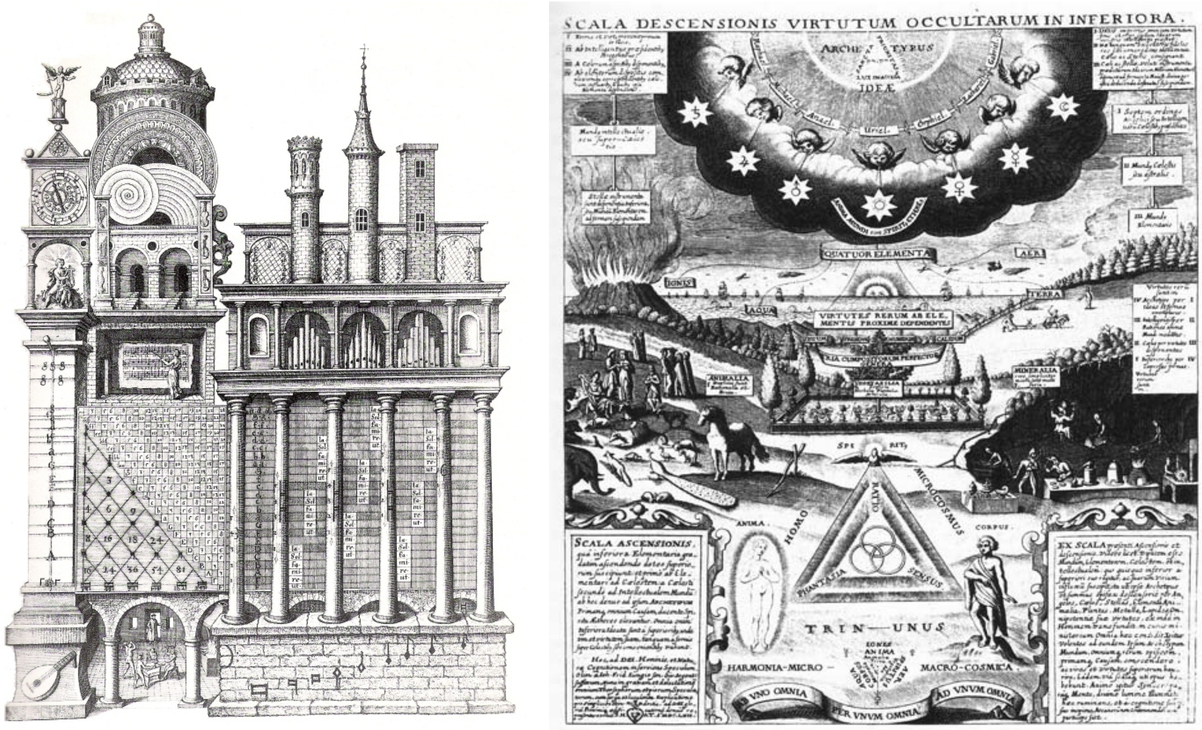


**Fig. 1.** Network conceptions of knowledge. **Left**: Robert Fludd, Templum Musicae (1617–22). **Right**: *Scala descensionis …* (1662) according to Johann F. Jungius (1558–1617)

Co-operation partner **Benjamin Wardhaugh** is an historian of science focusing on the uses of mathematics in seventeenth- and eighteenth-century England with a strong interest in the mathematical theories of music from that period. He shares many scientific interests with the project manager, e.g. he also worked on Descartes's music theoretical diagrams and their reception in England.

## Image-Theory and Visual Thinking

From a theoretical perspective applicant **Dieter Mersch** has contributed to various aspects of semiotics and visual strategies in science. He is head of the Institute for Critical Theory (ith) at the ZHdK, that focuses mainly on fundamental research in aesthetics and art-theory (from every-day aesthetics to image, music, theatre and media arts). From 2004 to 2013, he held a chair in *Media Studies* at the University of Potsdam, where he also supervised the doctoral training group *Visibility and Visualization. Hybrid forms of visual knowledge*. For 15 years he has been concerned with an ‚aesthetics of event‘, developing the framework of a philosophy of performance pertaining to language and art. Another area of interest is what he calls a ‘negative media theory’, the criterion of which is practical reflection in art. In this context he also works on image-theory and visual thinking in contrast to discursive argumentation. Most recently, his interest has been extending towards a general ‘artistic epistemology’. Furthermore, Dieter Mersch works on literature, diagrammatology, mathematical thinking and music with a special focus new music.

## Timbre spaces

Co-operation partner **Christoph Reuter** has been working for about 20 years in the field of timbre research: In 1995 he investigated the attack transients of string and wind instruments with the main result, that the importance of the attack transient for timbre perception has been overestimated so far, and that there is a rule-based interaction between the perception of pitch, formant area and attack transient (*Der Einschwingvorgang nichtperkussiver Musikinstrumente*, 1995a). With the help of the formant principle he was able to prove the concept of timbral blending and partial masking of musical instruments playing together simultaneously and successively (*Die auditive Diskrimination von Orchesterinstrumenten*, Lang 1996a). Based on this concept he wrote a physically and music-psychologically grounded and applicable orchestration treatise, combined with a history of the evolution of the occidental wind musical instruments and their timbres ("Klangfarbe und Instrumentation" 2002). He wrote numerous contributions about timbre, its generation, synthesis (especially pulse forming), analysis and perception. In the last years he has been working particularly in the field of the diverging models of timbre perception (especially timbre spaces and other multidimensional models), typical vibrato, timbre descriptors and neuronal aspects.
The members of ICST have done research on timbre perception of musical instruments, considering characteristics of string instrument sounds that create subtle but perceivable changes in inharmonicity, initial pitch glides, decay profile and vibrato. (Järvelainen, de Poli 2002, Järvelainen, 2003).

## ‘Modelling the World’ Based on Information Technology

The structure of scientific knowledge in general and the topics of our project in particular can be captured by relational models as used in computer science. Object-oriented and relational data modelling offer means of interpreting ‘the world’ in ways that exceed classical sequential and hierarchical organisations of knowledge by highlighting relational and dynamical aspects of the objects and processes under consideration (cf. Andreas meier, Thomas Wüst, Objektorientierte und objektrelationale Datenbanken, Ein Kompaß für die Praxis, dpunkt.verlag Heidelberg $^{2}$2000, 11–52)

Daniel Muzzulini became involved in data modelling during his after-diploma studies (1997–1998) in Information Technology at the Fachhochschule beider Basel (FHBB). In the following years he worked as a software developer in the field of relational and object-oriented databases and developed standalone and internet database applications, as well as dynamic internet applications in small teams. Furthermore, he created course material for template programmers using a content management system for large websites developed by the Swiss company Day Interactive (now part of Adobe) and ran programming courses in Switzerland and the United States (1999–2000). In 2003, he qualified as an Oracle Database Administrator (OCA 9i).

He lectured programming and databases as well as mathematics and physics at Teko Basel (Höhere Fachschule) and since 2004 he has been teaching mathematics and programming at Kantonsschule Alpenquai, Lucerne, where he is also responsible for the reorganisation of the library of the mathematics department and head of a small team of teachers in developing course material for programming (JavaScript, Processing).

Scientific collaborator **Susanne Schumacher** (M.A.) is an art historian with an expertise in information technologies. She was substantially involved in the conceptualisation of the institutional strategy of archiving at

the Zurich University of the Arts (ZHdK), where she is currently responsible for the product management of the Media Archive of the Arts, an open-source development project initiated by the ZHdK. Presently, she is doing a PhD at ETH Zurich in the field of information technologies and history of art and architecture.
Susanne Schumacher realised a range of hypermedia- and database projects in the field of architecture, art and design. Projects that use information technology to support scientific forms of analysis, presentation or publication:

Media Database (since 2009)
Conceptualisation and realisation of an institutional media database that supports practionars, researchers and lecturers in the arts and design. http://madek.zhdk.ch, http://medienarchiv.zhdk.ch

Index-Browser (2007–2008)
Development of a browsing tool in an image database that uncovers visually thematical releationships of database items. Hochschule für Gestaltung und Kunst Zürich

HyperMedia (2008/2009)
Thematical network of images that displays 2000 years of the history of the orders in architectural theory and practice. http://www.hypercolumn.uzh.ch.
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Translation of the historical rules of the orders into the language of the internet (XML).
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CD-ROM (1997–1999)
A multi media publication to the topic of modern housing development.
Bosch, K., Gleiniger, A., & Schumacher, S. (1999). weisse vernunft – siedlungsbau der 20er jahre. architektur und lebensentwurf im neuen bauen. München [etc.]: Prestel [etc.].

## Databases and internet

For about 15 years and until 2013 the musicologist **Christoph Reuter** was also partner in the internet firm IAMP-Solutions (http://www.iamp-solutions.de/ together with Justyna Hadyniak and Michael Oehler with many years of experience in databases and dynamic website programming (MySQL, PHP, Flash, Perl/CGI etc.).

**Projects** (selection):
www.jiddischkurs.org (Jiddisch-Sprachkurs im Internet, EU-Project Nr. 1999-1501/001-001, EDU-MLCPR)

http://www.oper-um-1800.uni-koeln.de (Die Oper in Italien und Deutschland um 1800, DFG-Projekt)
http://www.schubert-online.at (Schubert-autographs from different libraries, WWTF-project)

**Customers**:
Arnold Schönberg Center Wien, Deutscher Musikrat, Deutsches Musikinformationszentrum, European Music Council (Europäischer Musikrat), Frankfurter Museums-Gesellschaft, Hessische Theaterakademie, Hochschule für Musik und Darstellende Kunst in Frankfurt am Main, Phonogrammarchiv der Österreichischen Akademie der Wissenschaften, Schott Musik International GmbH & Co. KG, WDR Köln, Wiener Urtext Musikverlag GmbH & Co. KG. etc.

Also, scientific collaborator **Philipp Kocher** is well-versed in many programming languages and in web programming (e.g. Kocher 2013b).
The knowledge of our team in this respect will be of great value for the conception and implementation of the planned virtual museum.

## Three-Dimensional Sound Spaces

Main applicant **Martin Neukom** and scientific collaborator **Philipp Kocher** are experienced programmers of audiovisual applications in computer music and experimental psychology. They are also lecturers at the ICST.
During the last years several projects at the ICST have dealt with sound and space. Thereby, innovative techniques and programs for the three-dimensional projection of sound with *Ambisonics* have been developed at the ICST.

**Theoretical and conceptual work**:
Introductions into Ambisonics (Neukom 2003, 2010, 2013, 2014)
Conversion from Ambisonics to 5.1 Surround (Neukom 2006)
Ambisonics Equivalent Panning (Neukom 2007)
SpatDIF, an exchange file format for spatial descriptions of electronic music (Peters et al. 2009, 2013) (Miyama et al. 2013).
**Software**:
Ambisonics Tools for Max (Schacher/Kocher 2006)
Ambisonics UDOs for CSound (Neukom 2014)
Choreographer, a sequenzer software for spatial electroacoustic music (Kocher)
http://www.icst.net/research/projects/choreographer/
**Artistic work**:
Works for the Snf-Projects ISO and ISS, e.g. the realization of works of guest composers using Ambisonics in the Computer Music Studio,
Exhibition and publication *Milieux Sonores: Artistically shaping acoustic virtual environments* (Maeder 2010).

## Interactive Audiovisual Programs

For their courses in acoustics, psychoacoustics, sound synthesis, signal transformations and computer-based composition, Philippe Kocher and Martin Neukom have developed many interactive applications. These were published in *Signale, Systeme und Klangsynthese* (Neukom 2003) and in its updated and translated English edition *Signals, Systems and Sound Synthesis* (Neukom 2013), containing hundreds of interactive Mathematica programs, Max-Patches, Processing programs and Csound examples, and in *Versuch einer Anleitung zum reduzierten Hören* (Kocher 2013a) with online material (Kocher 2013b).
In the near future the ICST is strongly interested in publishing more web-based interactive material with educational aims.

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## 2.3. Detailed Research Plan

In the following, we will focus on a small sample network of diagrams in order to give an impression of the nested structure of our field of research. Then we will delineate our field of research by giving a topology of the involved topics and sciences. To conclude this section, we will address the technical and conceptual means needed to create the virtual museum as an online platform.

Robert Fludd's Temple of Music (1617–1622) is a kind of virtual museum. Fludd takes the temple's architecture as a metaphor for science, where all topics related to music have their own place. Within the main text of the treatise, the different parts of the temple are fully developed and "curated" – sometimes by adding extra pictures, sometimes by using "tree sentences" and sometimes in ordinary Latin language. This creates a network of science. Shapes and solids with a rotational symmetry as circles, double cones and spheres play an important part in Fludd's visualisations (see Fig. 2). The circle, "the perfect shape" is present in each topic he studied – from the colours of urine to divine numbers.

**Fig. 2: A Network of diagrams around Robert Fludd's Temple of Music.**

A: Robert Fludd (1617–22, Plate 4.1., 191): Septet of Binary Durations (1, 2, 4, 8, 16, 32, 64, 128)
B: Robert Fludd (1617–22, Plate 6.5, 232): Circular Diatonic Transposition Scheme
C: Robert Fludd (1617–22, Plate 6.8, 236): Fretting scheme of the bandora
D: Robert Fludd (1617–22, Plate 4.3, 204): Matrix of binary and ternary durations
E: René Descartes, Compendium Musicae (1650 [1618/1619]): Matrix of Zarlino's 'Senario'
F: Robert Fludd, Templum Musicae (1617–22, Plate 1.1., 161): A network of music theory
G: Jost Bürgi, Arithmetische und Geometrische Progress Tabeln... (1620): Circular anti-log table
H: Isaac Newton (ms. 1664/1665): Tuning problem with five diatonic scales
I: William Brouncker (1653): The hexachord system according to Descartes with disproportioned angles.
J: Thomas Salmon, Vindication of an Essay (1672): The Cycle of an Octave / The Circulation of Octaves
K: William Oughtred (1632): Circular slide rule
L: René Descartes (1650 [1618/1619]): The diatonic scale in just tuning
M: Isaac Newton, Opticks (1704): Colour circle and pitch classes
N: Robert Fludd, Medicina Catholica I (1626): Colorum Annulus: colour circle (black – blue – green – red – orange – yellow – white [– black])

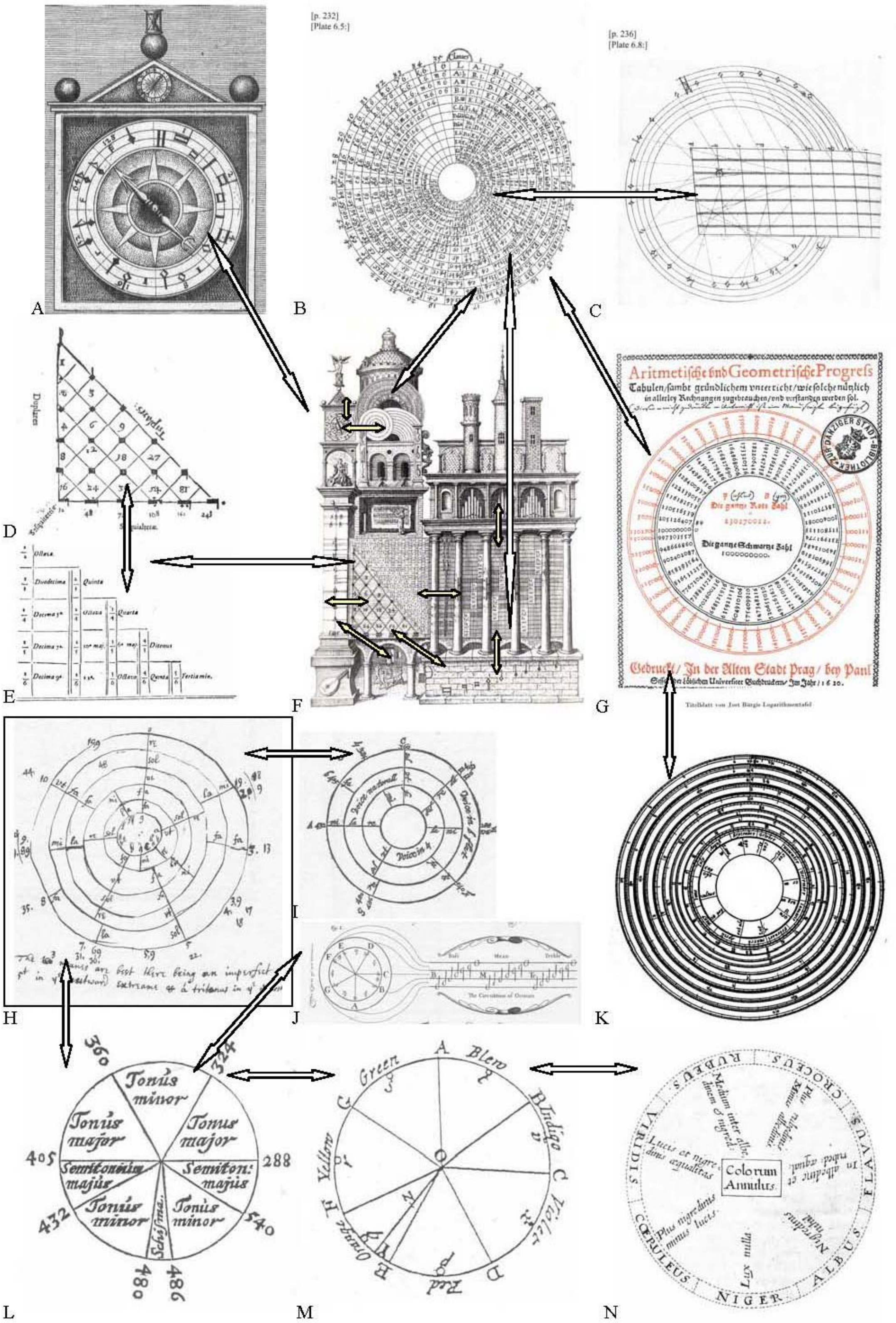


**Fig. 2**. A network of diagrams.

## Bürgi – Descartes – Newton: Logarithms and Circles in Music Theory

From a musician’s point of view, it could be argued that using small integer proportions, as in Pythagorean music theory, is genuine logarithmic thinking, if a one-to-one relationship between integer ratios of sound frequencies and musical interval size as a quasi-geometrical property is stated. Western (diastematic) music notations developed during the Middle Ages and the early Renaissance map the pitch/time domain to a two-dimensional geometric plane by formally identifying both time and pitch with number lines. In occidental culture, this mapping has created frozen metaphors (cf. Goodman 1976). The pitch dimension of this mapping is a logarithmic transformation. The mapping of the time domain is, at least locally, a similarity transformation (dilation) between ‘physical time’ and ‘mathematical time’ as expressed in musical scores (cf. Goodmann 1976; Mazzola 1990; Mazzola, Muzzulini 1990; Neukom 2010b).

The use of the circle for representing numbers and their relationships provides interesting insights into the history of science. In the late 16th century, the Swiss clock-maker Jost Bürgi (1552–1632) and the Scottish mathematician John Napier (1550–1617) independently invented logarithms in order to simplify the time-consuming multiplications and divisions of numbers with many digits. This was achieved by creating a fine-grained and accurate two-way look-up table, which then allowed performing the “complexity switch” mechanically and within no time.

Bürgi’s circular ‘anti-log table’ (1620) visualised the new calculation technique with a circular arrangement (see Fig. 2.G, cf. Voellmy 1948). Descartes used similar circular pitch diagrams in the ‘Compendium Musicae’, which was written 1618/1619 but only published posthumously 1650 (see. Fig. 2.L, cf. Muzzulini 2012).

Musicians “feel” that a frequency ratio of 5 : 4 of two sounds belongs to same sized musical intervals irrespective of the underlying frequencies. Also the similarity of tones forming an octave is felt naturally. Descartes’ tying together the ends of the octave may be seen as an ingenious didactical trick, as a deep insight into perceptual universals and logarithms, as a glimpse of group theory or any combination of these aspects.

## Descartes’ Tone System and its Reception by Newton

Initially, the well-known octave similarity as a perception phenomenon led Descartes to a circular arrangements of pitch classes. He then combined three such circular arrangements to a system of rings in order to illustrate the inherent ambiguities of a hexachord-based tuning system in just intonation. Eventually, he speculated that infinitely many ambiguities would arise if one would continue to apply the procedure to more hexachords in the same manner (cf. Muzzulini 2012). Newton generalised this approach to five diatonic scales in the major keys B-flat, F, C, G and D in the 1660s. This shows that he must have been familiar with Descartes’ pitch class circle (see Fig. 2.H, cf. Gouk 1999, 140). The early English edition of Descartes’ *Compendium* (1653) has disproportioned sectors, so that equal intervals do not correspond to equal angles. The person who made the drawings had no feeling for logarithms (see Fig. 2.I, cf. Wardhaugh 2008, 2008b, 2013).

## Newton’s Colour Theory

In 1704 Newton developed a circular colour order, which he depicted in a diagram almost identical to Descartes’ circular pitch order. By surpassing Descartes’ diagrams, he gave the inner points of the circle a psychophysical meaning as well (see Fig. 2.M): The distance from the centre of the circle measures the saturation, whereas the angular position marks the hue of a colour impression. By applying a centre of gravity construction, he could predict the hue of mixed sunlight from its components. In this context he also rightfully conjectured that a white light impression could be produced by mixing two diametrically opposed spectral components. Actually, the geometrical construction of mixed colours in Newton’s colour disk takes place in a three-dimensional setting, where the third dimension is tied to the intensity of light.

Newton's colour theory is formulated for light particles, where the spectral primary colours are coded in the mass or density of the particles. He postulated the existence of seven primary colour particles (i.e. colour prototypes), which he placed on the circumference of a circle. Possibly, this very close analogy to music theory prevented Newton from developing a proper three-component additive (or a two-polarities based) perceptual theory of colour vision, which is implicitly indicated in his choice of a two-dimensional topology.

## From Newton's Colour Circle to Tri-Chromate Vision

Circular colour orders inspired by Newton's arrangement of the primaries were adopted by painters in the early 18th century (e.g. Boutet 1708, cf. Gage 1995, 162; Spillmann 2009, 18–19). This topology was investigated by Maxwell and Helmholtz in the second half of the 19th century via additive light mixing. They based their work on Thomas Young's tri-chromate theory of vision (1800, cf. Pesic 2013) and they turned the circle into a "horse shoe"… Newton's topology (Fig. 2.M) is actually a convex heptagon and not a circle, since colour mixtures of colour impressions represented as points are always positioned on the connecting line segments of their constituents. The purple line introduced as a cut into the circular disk topology by Helmholtz (cf. Muzzulini 2012, 706) is compatible with Newton's ideas: Newton merely used more physical elementary particles than psychological colour prototypes.

## Sound Colour Space: A Map

The diagram depicted in Figure 3 summarizes the network of the central notions, the involved branches of sciences and techniques characterizing our field of research.

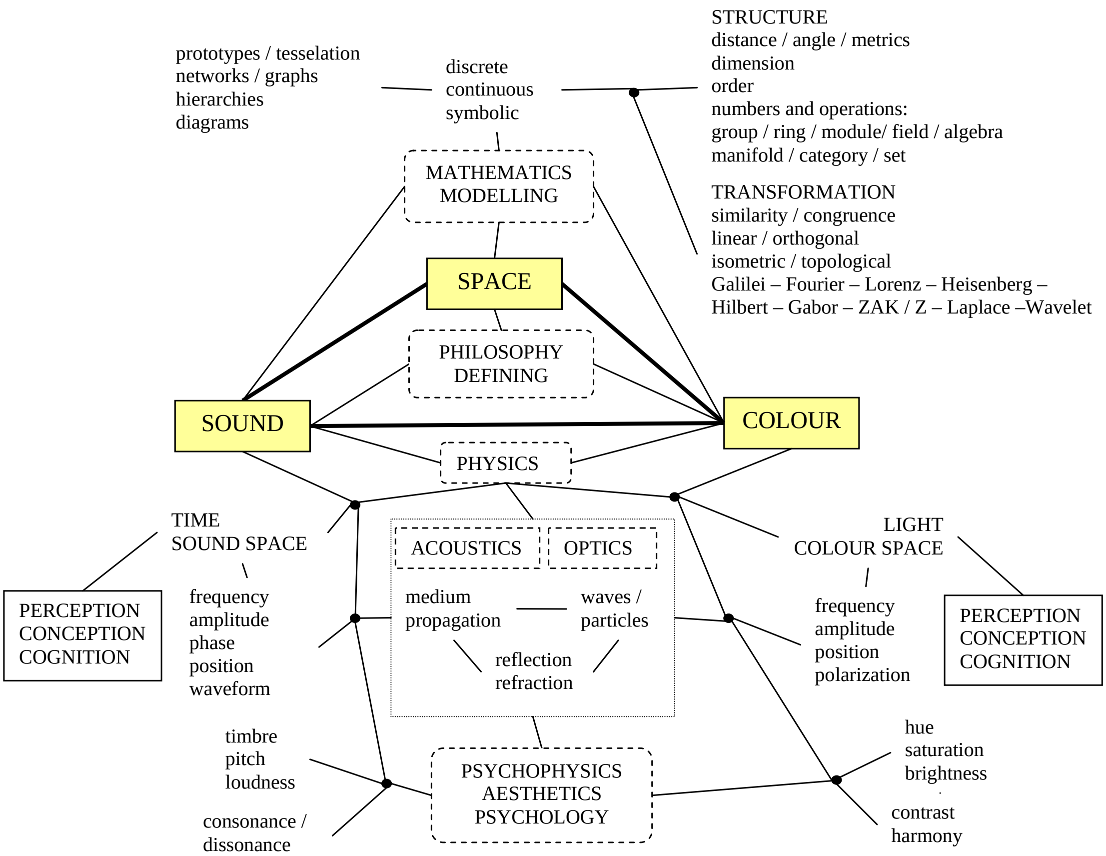


**Fig. 3**: An approach to the conceptual field of sound, colour and space.

## Creating the Virtual Museum as an Online Platform

We are planning to construct a “living” virtual museum and research database where users interact in various roles with respect to the displayed objects and related materials. Modern means of presentation will be applied, which include audiovisual animations and applications. The museum will offer public exhibitions, guided and individual tours. New content will be added collaboratively to the collection and administrated not only during the project but also after its completion and publication as an internet platform.

## Media Database and Content Management System

The objects of the collection and their metadata will be stored in the media archive developed at the ZHdK. The logics of the museum communicating with the media archive will be realised within a content management system, where structure, content and design can be separated completely, so that the programmers, curators and designers can work to a wide extent independently.

The linking of the basic objects with manifold contents of different format (text, graphics, animations, sound files, interactive audiovisual applications, hyperlink lists, etc.) and the realisation of the museum as an interactive application demand extensions or interfaces that must be developed for the project, if possible on the basis of existing tools.
The realisation of the centre as a walk-in application is an optional part of the project. We think of the possibility of a layout-switch defined by the visitors of the Website. The museum software should be easy to adapt for mobile devices.
The centre’s main language will be English. Written source material comes in many western European languages (Latin, Italian, French, Spanish, English, German). Translations into English, German or both will be given where appropriate and available.

Also, interactive applications, which cannot be stored in the media archive, will be included into the internet application. Basically, there are two ways to achieve this. Either the content management system communicates with an application server, so that no installation on web-clients visiting the site is, or the applications will be run via the client. The balance between server-sided and client-sided embedded applications will depend on the software decision (cf. Section 2.4).

We conclude this section by listing some possible embedded applications providing useful information related to selected objects and themes of the museum.

- Brightness and octaves (use cepstrum technique to analyse FFT data). Visualising Castel/Telemann sound colour mapping, parallelised with FFT waterfall plots. Real time application. Auralizing colour topologies.
- Timbre spaces as audiovisual interactive installations. Walk-in timbre spaces?
- Simulation of Helmholtz’s vowel timbre experiments (phase and timbre).
- Ohm/Seebeck-dispute: sound and waveform (experiments; physical modelling, 3D-printing of Seebeck’s and Koenig’s sirens)
- 3D-print historical synthesizers (Helmholtz, Koenig) and speaking machines (Kempelen, Kratzenstein)

- Visualise vowel-topologies and relate them to the formant theory of musical instrument
- Consonance dissonance in just intonation and equal temperament tuning systems (North, Sauveur, Euler, Rameau, Helmholtz)
- Pitch models, adaptive tunings (Wille, Sethares) real-time visualisations: Euler-grid, Vogel's-grid, Noll's curved pitch space, Mazzola's Moebius strips
- Mazzola's modulation model – musical modulation modelled as symmetry transformations (quanta) as 3D-animations.

## 2.4. Time Schedule and Milestones

| Team | | | Content | | | Implementation museum | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | % | SRs | CM | App | Mdl | Cslt | Des | Impl | Doc |
| Applicants | Martin Neukom | | | x | x | | | | | |
| | Dieter Mersch (ith) | | x | x | | | | | | |
| Project manager | Daniel Muzzulini | 50 | x | x | | x | | x | x | x |
| WiMa | Philipp Kocher | 10 | | x | x | | | x | | x |
| | Raimund Vogtenhuber | 30 | | (x) | (x) | | | x | x | x |
| | Susanne Schumacher (MIZ) | 5 | | | | | x | | | |
| | n.n. | 10 | | | | | | | x | |
| TeMa | Christine Kaufmann | 30 | | | | | | x | x | x |
| Co-operation partners | Christoph Reuter (A) | | x | x | | x | x | | | |
| | Benjamin Wardhaugh(GB) | | x | x | | | | | | |

| | |
|---|---|
| % | average employment over the duration of the project |
| SRs | Scientific research (history of science, theory of diagrams |
| CM | Content manager: adding and editing scientific content |
| App | Application programming |
| Mdl | Data modelling |
| Cslt | Consulting, choice of software and architecture |
| Des | Design GUI, corporate design |
| Impl | Implementation, Content Management System (CMS) |
| Doc | Documentation Applications, CMS |

| Time | What? | Result | Who? |
|---|---|---|---|
| 1.00 – 1.06 | Software decision | Report (application-server architecture) | DMz, SSch, ChR |
| 1.00 – 1.06 | Data modelling | Object relational model of institutions, people, content | DMz, ChR |
| 1.00 – 2.03 | Scientific research | Classified secondary material | DMz, DMe, ChR, BWa |
| 1.00 – 2.03 | Application programming | Audiovisual applications | PhK, MNe, RaV |
| 1.06 – 1.12 | Implementation CMS, Interface Media Archive | Prototype Science Centre | DMz, RaV, ChK, Ph, n.n |
| 2.00 – 2.06 | Design User interface | Working Science Centre | ChK, RaV |
| 2.06 – 2.09 | Content management | Uploaded contents / Snapshot / Online | DMz, ChR, BWa |
| 2.06 – 2.12 | Documentation | Documentation project / Online Help | DMz, RaV, ChK, MN |

BWa: Benjamin Wardhaugh | ChK: Christine Kaufmann | ChR: Christoph Reuter
DMe: Dieter Mersch | DMz: Daniel Muzzulini | MNe: Martin Neukom
PhK: Philipp Kocher | RaV: Raimund Vogtenhuber | SSch: Susanne Schumacher

**Software Decision**

Since interactive applications will be made available through the internet a careful evaluation of the used software tools and technologies will decide on how much time will be spent on in house programming. This is a field of rapidly changing technologies and “standards” and it makes sense to come to a final decision within six months. By then one of the tools under consideration might be at least in the beta stadium.

**Data Modelling**

Mapping the inner structure of the museum, its contents and agents, by data modelling will be crucial for the proper functionality and its future extensions.

**Scientific Research**

Research on scientific topics will end after 15 months. By that time the items to be displayed and the related background information must be ready, i.e., given in a conventional format (image files and text files).

**Application Programming**

The interactive programs to be run on the platform must be ready and documented after 15 months as well.

**Implementation CMS/Templates**

After the software decision, the implementation of the content management system’s specific functionality pertaining to the museum can start. This involves programming the interface to the underlying media database and template programming.

**Design User Interface**

The ‘corporate identity’ will be shaped by designers in collaboration with internet programmers (style sheets).

**Content**

The upload of the content, which turns the museum into a dynamic internet platform, will be terminated by a snapshot and its publication in the web.

**Documentation**

The technical documentation of the museum and the documentation of the project will be completed in the last six months of the project.

## 2.5. Relevance of the Research

Creating a museum as a net platform is an ongoing project. It is expected that the flexible way of representing, storing and linking scientific knowledge will stimulate research and the production of conventional scientific texts in the related fields of research.

Educators/teachers will benefit from the attractive presentation of complex scientific material.

The *Sound Colour Space* museum uses state-of-the-art multimedia technology and will be source of inspiration for scientists, artists and composers.

Facing the vast increase in data accessible all over the world, we assume that unifying approaches will gain more influence in the future. It is not a coincidence that an interdisciplinary archiving project at Basel University won the Basel City science price of the year 2013 (www.medienmitteilungen.bs.ch/showmm.htm?url=2013-09-17-rrbs-004 ).

The project will refresh old links between natural sciences and humanities and the collaboration with other European Scientists working on similar topics as cooperation partners Christoph Reuter and Benjamin Wardhaugh opens perspectives for future and collaborative research.