AN ARCHITECTURAL APPROACH TO 3D SPATIAL DRUM NOTATION

Jeremy J Ham
RMIT University
jeremy@surfcoastarchitecture.com.au

ABSTRACT

This research has evolved from creative practice focused on inter-disciplinary positioning between the domains of music and architecture. Through engagement in the theories and practice of architectural representation and the computational tools of spatial design, a new form of 3D spatial drum notation is presented. This notation seeks to compliment the capacities of traditional drum notation and overcome issues inherent in a theoretical 'musico-perspectival hinge' between the notation and the meaning of the notation. A representational schema of the spatial drum notation is discussed in the first instance in relation to the development of a lexicon of referent drum patterns and phrases and then in the testing of notation on a multi-layered improvised 'drumscape' composition. The paper culminates in the extension beyond notation into the realm of music spatialization through 3D printing, digital fabrication and Virtual Reality.

1. REPRESENTATIONS OF MUSIC AND ARCHITECTURE

The proposition that the field of architectural representation can inform domain of musical notation draws on creative practice PhD project work in music and architecture. The research draws upon the author's 30 years experience as an improvising drummer, as an architect with around 30 years experience in designing buildings and University educator researching design and representational media. By bringing together these practices in the form of a post-Xenakian integrated 'musico-spatial design practitioner', here is much fertile ground for exploration in both domains, and the space in-between.

This paper represents a first foray into the field of musical notation from a base expertise in architecture. From this position, a founding question arises for this paper directed at a musical notation conference: 'How can the theory and practice of architecture provide new insights into the field of musical notation?' In order to answer this, one must establish an outline of what architects do, and how they represent their creative practice.

In essence, the job of an architect is to transform a functional design brief relating to a site and the needs of people, generate spatial ideas, represent these ideas in the form of a resolved building design and communicate them to people for review; document the design using representational media then facilitate the physical construction of the design into built form on the site.

Central to the process is the use of representational media to form representations of ideas under development to 'achieve situational awareness that allows for meaningful criticism of design [1]'. Representational media constitute *analogue* or *physical* systems (tracing paper, graphite and ink) or *digital* or *virtual* systems (involving scanning, Two Dimensional Computer Aided Design (2D CAD), Three dimensional Computer Aided Design (3D CAD) modelling, animations and rendering). These are used during various stages of the design process to inform design and to communicate ideas separately or in hybrid combinations [2].

Many architectural practices utilise ArchiCAD™ or similar programmes to design buildings through modeling and drawing. Objects (walls, roofs etc.) are generated in plan (Figure 1, top left), edited in 3D (top right), then worked up with notes, lines and fills to form a set of 2D drawings (bottom left and right) for emailing or printing. Drawings and models can be zoomed, rotated, sliced in multiple ways in order to enable comprehensive understandings of the design. The modality of operation, where a spatial object is design in three-dimensions from different planes, is entirely natural for most spatial designers experienced in the use of 3D CAD software such as Revit™, Rhino3D™ and 3D Studio Max™. It is this defining characteristic that forms the basis of this research.

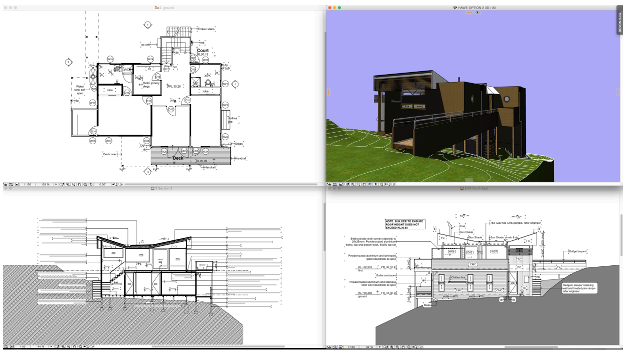

Figure 1. ArchiCAD screen print of a building design showing plan (top left), 3D perspective (top right), sectional drawing (bottom left) and elevation (bottom right).

Pérez-Gómez and Pelletier [3] developed the concept of the ‘perspectival hinge’ relating to how two-dimensional representations in plan, elevation and section form a hinge for understanding (or lack thereof) of the three-dimensional objects they represent. This ‘invisible perspectival hinge is always at work between these common forms of representation and the world to which they refer’, thus acting to limit comprehension in design processes. *Ideas* of buildings are built up between a set of projections (plan, section, elevation, perspective). This idea of the building is then translated into a building, usually by a third party (builders). Thus, it follows that the ideas under development may be limited by the two dimensional nature of the medium of 2D drawing. Working beyond the limitations of the perspectival hinge requires training and experience and is particularly relevant for students of architecture as novice designers [4].

Many lay people cannot read architectural drawings, just as many non-musicians cannot read musical notation. Whereas architects spend years learning the art of representation, the ability to read music is not intrinsic to the playing of music. Novice architectural students often struggle to understand the basics of their own designs, and must work their way through the limitations of this perspectival hinge when working in 2D. Mature practitioners of architecture expertly translate two-dimensional representations into perceptions of the three-dimensional object being represented. Many expert musician practitioners such as Jimi Hendrix, BB King have however navigated their musical world outside of a notation system and perform by memory and ear.

It seems plausible that the two-dimensional and symbolic nature of traditional musical notation acts as a hinge to the understanding of the music that it represents. This ‘musico-perspectival hinge’ is where *ideas* of music are built up through the placement of notes on a stave, which is then translated into a musical performance by trained musicians. Those with sufficient training are able to expertly translate the symbolic conventions into musical events in time, performed on an instrument. For the untrained or those with limited training, the symbolic schema of traditional notation is either meaningless or require significant time and effort to interpret.

The speculative question arises as to the relationship between the spatiality of the instrument (i.e. the issues inherent in the spatial engagement of the musician in making music on the three dimensional musical instrument) and the spatiality of the notation as a means of providing instructions for musicians or in informing the analysis of completed musical works. The playing of a piano, for example, is confined within limited spatial boundaries. The spatiality of the keyboard is intrinsically linear, thus more directly translates into the linearity of traditional musical notation than, say the drum kit.

The spatiality of the drum kit, as a set of 3D instruments (drums and cymbals) positioned in physical space played by the musician with two hands and two feet using drum sticks, is a core consideration in the spatial drum notation described below. For example, the digital drum kit that forms the basis of this research comprises six drum pads, four cymbal pads, a double kick pedal operating a bass drum and a pedal-operated hi-hat positioned within a spatial envelope of approximately 2.0 metres wide x 1.5 metres deep x 1.5 metres high. The kit is played from a pivot point of a drum stool with the snare drum, hi-hat and bass (kick) drum forming the core, with other drums and cymbals played in linear and radial patterns around the instrument (see figure 2).

The question arises as to the appropriateness of traditional notation to represent drumming. As Stone [5] states: ‘Musical notation, after all, is not an ideal method of communication, utilizing, as it does, visual devices to express aural concepts. But it is all we have’. The mapping of these instrumental engagements into the linear and two-dimensional spatiality of traditional notation would seem to further any theoretical ‘musico-perspectival hinge’ that exists between the notation and the instrument for which the notation exists. Whilst this may not be an issue for simple drum music, the issues with traditional notation for the drum kit are even more pronounced when dealing with complex, polyrhythmic drum patterns or even non-quantized basic 4/4 beat with the subtle slurs that constitute individual style (see Figure 3). Quantization of the MIDI file makes the traditional drum score more readable, however removes information related to the individual stylistic elements of play, for example playing behind and ahead of the meter and the dynamics of drumming.

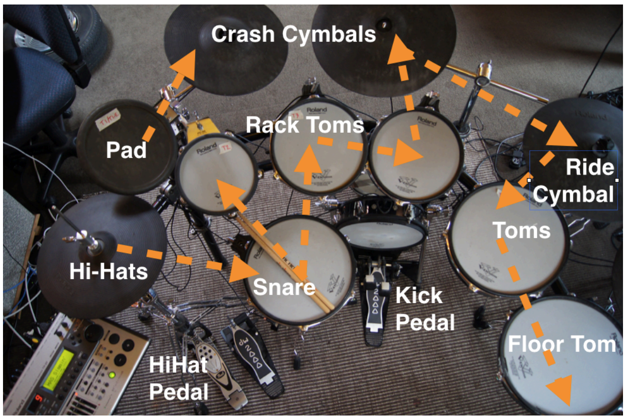

Figure 2. Digital drum kit arrangement, indicating some ideas of directionality and spatiality of play.

Figure 3. MuseScore score of basic 4/4 drum pattern with accents and slurs that constitute individual playing style.

Pérez-Gómez and Pelletier’s perspectival hinge appears to be related to the theory of ‘affordance’ put forward by Gibson [6] that describes the interactions between people, objects and actions. Norman [7] applies this concept to design, with the principal being that affordances should provide users with strong clues to the function of things. Whereas ‘the purpose of using a musical notation may be obvious, the notation’s meaning itself is not always so apparent [8]'. From this foundation, an implementation of a spatial notation for the digital drum kit is outlined that offers an architectural approach to drum notation that may provide affordance to the structure of improvised polyrhythmic drum music.

2. SPATIALIZING NOTATION AND THE "Y-CONDITION"

Performed in real time, music never exists as a whole at any given moment, but rather unfolds in a linear manner over time, and assumes an entity only in retrospect, in the memory of the listener or the performer. However reading a compositional music score is a process closer to perceiving space, as it exists as a whole at any given moment but may be retained by the observer only by a process of observation over time, walking around through, and above it. [9].

Architects invent notation systems to support design processes, to communicate these to others and to make artful representations of speculative ideas [10]. Daniel Leibskind's 'indeterminate spatial diagrams' of his chamber works act as speculative representations 'not regulated to site, scale, orientation, ground and other usual architectural references [11] and as such they constitute diagrammatic forms of art that describe spatiality. Similarly, Bernard Tschumi's 'event notation' and Parc de la Villette fireworks notation 'approach practices that are characteristically non-notated (at least in a temporally precise manner) with a view to codifying and communicating a particular instance of those practices [12]'.

Architect-engineer and composer, Iannis Xenakis provides many examples of where unique notation was invented to provide meaningful representations of design ideas. Xenakis set the standard for musico-spatial design creative practice modalities and the invention of notation systems to support his electroacoustic compositions, polytopes and other creative endeavours. His notation in Pithoprakta, Metastasis and other examples reflected his training as an engineer and mathematician- with lines, vectors, points and other graphical elements directing performers, instruments, sounds and actions. John Cage similarly dismissed conventions of temporal structure, repetition and proportional counting to create indeterminate soundscapes. His notation reflects an approach of 'blurring of unprescribed music, environmental sounds and dismissal of established rules in notation and performance [11]'. Cage's fascination for graphical, non-standard notation systems and random elements is evidenced in his book, with the book itself generated by chance operations [13].

Many notations operate as two-dimensional representations of multi-parameter musical compositions comprising multiple instruments performing complex operations in time and space. Many composers have sought the elusive third dimension in musical notation. Rebelo [12] describes 3D scores as 3D objects to be viewed and interpreted by performers from different directions. This third dimension is still mediated by the 'hinge' of the computer screen interface, however the digital format offers a range of possibilities to develop graphic notation practice by incorporating colour, real time generation, video and interactivity. A summary of approaches of visual notation in the 'visual/sonic representation continuum' is offered by Hope, Vickery [14]'. Vickery's 'rhizomatic' score for 'Sacrificial Zones' engages in the third dimension through a series of layered planes of visual representations of sound. This engagement in the third dimension in musical notation is being explored by many music, performance arts and other creative practitioners as they seek new ways to engage in creative media. It is proposed that architects may have something to offer the music community of practice in this area.

Architects, who have long been fascinated with interdisciplinary connections with music [15], have sought ways of engaging in the 'architecture as frozen music' paradigm. Elizabeth Martin describes the "Y-Condition" as the theoretical intersection between domains where 'there exists a definable membrane through which meaning can move when translating from one to another [16]' The computer has enabled this cross-fertilization whereby the 'reduction of all information to a binary signal, be it a picture, a text, a space or a sound - all data is recorded as a binary sequence allowing computation as defined by programming languages and communication through networks according to transmission protocols' [17]. The principal that 'the byte shall be the sole building material [18]' acts to enable compositional, and therefore notational, opportunities within the spatial dimension.

Mediating this 'y-condition' in between music and architecture computationally requires the 'practiced hand' of the digital craftsperson [19]. Computational processes have been adopted by Ferschin, Lehner [20] the 'Spatial Polyphony' analysis of Bach's fugues by Christensen [21], the shape analysis of Krawczyk [22], the many speculative theoretical, philosophical and computational investigations into 'liquid architecture' of Marcos Novak [23] and the wide range of 'musical sculptures' and music-architecture explorations of Jan Henrik Hansen [24].

My interest lies not in creating a 'frozen music' but enabling ways of 'freezing' the process of music creation in the spatial dimension to create a spatialized notation system to provide meaning to elements of my creative drumming practice.

3. SPATIAL DRUM NOTATION

Rebelo [12] defines the roles and function of notation for performance, composition, design, choreography, gastronomy and architecture as being for the purposes of documentation, communication, for reflection and in the production of new works. I am interested in spatial notation as a means of exploring this "Y-Condition" and to provide an inter-disciplinary perspective on music and music notation to engage in reflection-on-action [25] and develop understandings of my creative practice as a drummer.

As with Tschumi, Xenakis and many others, I have invented a notation schema to serve a creative practice agenda. In my case this spatial notation system is for the digital drum kit using the Computer Aided Design tools I use in my architectural practice. The spatial notation is primarily directed at my own practice, however in pursuing my own personal notation system it is hoped that insights can be provided for others- with or without similar training in spatial design.

The spatial drum notation is derived from a definition scripted in Grasshopper™ for Rhino3D™, a parametric CAD tool commonly used in complex and innovative spatial design work. The 'ImprovSpace' definition reads time, note, note duration and velocity MIDI data from the digital drum kit and translated into .csv via the Sekaiju app. Using a complex series of parametric operations, data from the .csv spreadsheet is concatenated and sorted into a series of points along a timeline (Figure 4). From this multiple spatial representations such as solids and meshes (spheres, cones, boxes and more complex forms) velocity and note duration data can be represented symbolically. All parameters are user-adjustable using numeric input panels and sliders. A key attribute of the Grasshopper definition is its flexibility, with parameters such as spatial configuration, bar representation and length, line thickness, note representation, velocity, duration, background and colours all able to be adjusted easily depending on specific user requirements and purpose.

The Grasshopper plugin interfaces with the Rhino3D programme, and all representations can be easily 'baked' (i.e.. transformed from flexible objects derived from Grasshopper to solids, meshes etc. editable in Rhino3D), exported to visualization and animation programmes, brought into Virtual Reality environments, 3D printed, laser cut or fabricated using robotic fabrication processes. A defining element of the research is the mediation between notation, representation and fabrication. The same definition in Grasshopper can be adapted, exported or used in conjunction with other applications to achieve multiple outcomes in the musical, spatial and physical domains.

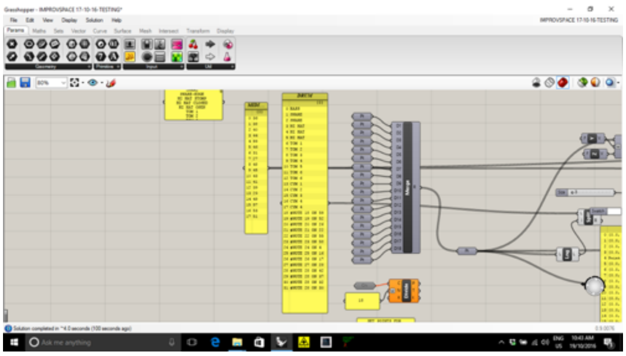

Figure 4. Grasshopper work space showing .csv data being assigned to spatial parameters.

The instrument central to my solo drumming creative practice is a Roland TD20 digital drum kit (see figure 2, above). Although digital, the layout and playing response is very similar to an extended acoustic drum kit. Sounds modeled from real drum kits are enabled in the Digital Audio Workstation through Virtual Instrument applications such as Drumasonic Luxury and BFD3. Virtual instrument software such as BFD stylises the plan form of the drum kit as the basis of their representation of the workspace. This stylised representation recognizes the radial layout that is typical for the drum kit, however the representation is quite literal (Figure 5). The spatial drum notation described below departs from the two-dimensional linearity of traditional notation and the literal representations of the BFD interface to form a symbolic, player-centred representation of the drum kit.

Figure 5. BFD3 virtual instrument interface

The spatial notation schema presented here is the outcome of a design process that attempted to resolve issues inherent in representing the spatiality of the drum kit. The schema stylizes the drum kit in the form of radiating golden section geometric spirals in the X-Y axis (Figure 6), with drum notes represented as events in time along the Z axis. Colour is used as a defining element to enhance the representation of different drums and cymbals. Like all parameters, these are easily changeable. The key to this schema is the practicality of the form as a way of interpreting the drum kit, whilst enabling reading of individual drums from plan and elevation views. The layout is carefully designed to allow the viewing of all drums and cymbals from top, side and bottom planes.

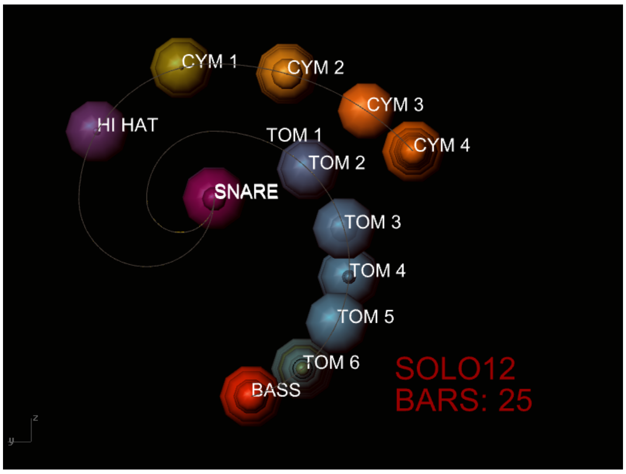

Figure 6. Representational schema for the drum kit with Snare at centre, bass drum at bottom, and hi-hats, cymbals and tom-toms arraying radially.

Whereas traditional notation is designed to be read from one plane only, a key attribute of this spatial drum notation is the capacity to refer to multiple viewpoints in the Rhino3D interface in order to obtain different types of information. The standard Rhino3D interface comprises four viewpoints (plan, two elevations and a 3D perspective or isometric view. Each model view allows the spatial drum notation to be zoomed, panned, rotated and measured by the user to retrieve musical information. As an example, Figure 7 illustrates musical information relating to a drum solo improvisation. This particular improvisation comprises a series of descending roll on tom toms (blue grouped notes) accented by double-kick bass drum notes (red notes) and groupings of hi-hat notes as the timeline progresses. Velocities of drum strikes are represented by the relative diameter of the balls and the time structure is faintly represented as the grid of grey spirals in perspective. Thus, the placement and intensity of notes in the drum solo are given a form and shape within this spatial notation schema and unique elements of style or skill such as rubato can be identified through spatial information contained in this notation.

A second drum improvisation is illustrated in four simultaneous views in the Rhino 3D interface in Figure 8. Each viewpoint provides a different element of this musical information and reading all viewpoints together from the one interface provides a significant body of information that is unavailable in traditional notation. as in architectural representation, certain information can be derived from the plan view (top left), that complements understandings derived from isometric (top right), side elevation (bottom left) and end elevation (bottom right). Through maximizing each view and using zoom, pan and other functions in Rhino 3D, a comprehensive understanding of aspects of drum performance is enabled that is unavailable in other forms of notation.

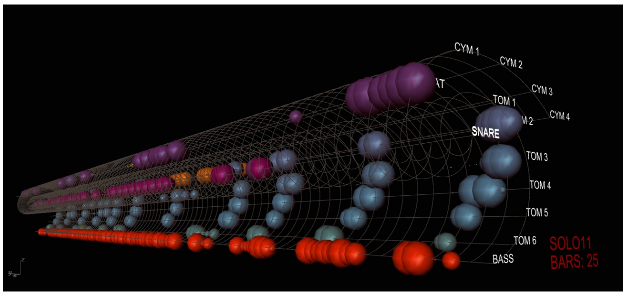

Figure 7. Rhino 3D Representation of a 25 bar drum pattern.

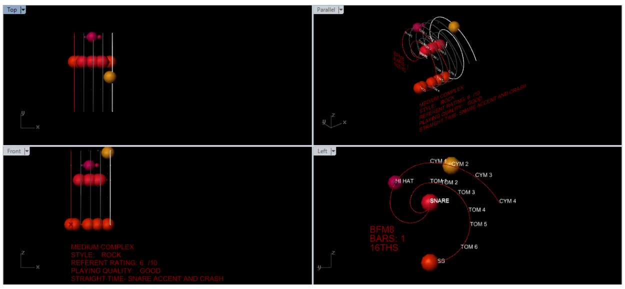

Figure 8. Rhino3D Viewport layout, showing top (plan) view (top left), isometric (top right), side elevation (bottom left) and end elevation (bottom right).

4. DEFINING A LEXICON OF REFERENTS IN 3D SPATIAL NOTATION

'The task of defining improvisation is likely impossible in view of its having no existence outside of its practice (*Brown 2006*)'

Now that the theories and principles of this 3D spatial drum notation have been established, two applications are outlined that are outcomes of creative practice PhD (Architecture and Design) work at RMIT Spatial Information Architecture Laboratory in Australia. A methodology of mass improvisation is used to generate data for the research; to enable reflection on the drumming style developed over thirty years of playing and to form the basis of drum-based compositional works.

The project involved playing a large number of improvisations on the digital drum kit to a basic template of 100 beats-per-minute for one minute, generally at 4/4 time, across three contexts of drumming (playing beats and fills, free form drum solo and playing to a layered guitar track). Playing drums to any template places intrinsic limitation on the outputs and it is recognized that a multitude of different results will be enabled if the tempo, time length or time signature is changed. Given the large body of the author's experience is in the jazz, funk and rock styles this was determined as an appropriate foundation for the research.

Drum improvisations were played on a Roland™ TD20 digital drum kit and recorded in MIDI format on the Reaper™ Digital Audio Workstation (DAW). From the longer one minute, drum solos, beats and tracks, a set of 200 exemplar drum patterns and phrases were extracted in a process of listening, cutting and pasting, and exporting to individual MIDI files. The research draws upon Pressing [26] definition of 'referents' to describe the elements of musical performance that define the player- the 'licks' and 'riffs' that musicians refer to when improvising. These improvisation processes draw parallels with Schon's notion of 'tacit knowing in action [25]'.

A drummer's personal drumming referents are a part of who they are, who their musical identity is. One only has to watch live performances by drummers such as John Bonham to easily identify referent patterns and phrases used, repeated and adapted to different musical situations. The key to this research is to enable a capturing of these referents, using spatial design software to challenge Brown's notion that improvisation has no existence outside of its practice [27].

The author's exemplar set of 200 'referent' drum patterns and phrases were curated, with metadata added in Microsoft Excel™ and Devon Think Pro™ to compliment the sound sample output and spatial notation with identifiers including sample number, a free-word description, complexity of playing, style of music, quality of playing, number of bars, beats per minute and a 'referent rating' that self-evaluated the degree to which they represented the author's individual style. This process has been reported in detail in [28] and [29].

To inform the application of a spatial drum notation, one sample is selected from a much wider body of work (refer figures 9 to 12). Figure 9 provides information about the drums and cymbals used in this sample, including metadata on the sample code and number (SM2) and Number of bars. As all samples for this project were performed at 100 beats per minute, this information is not included, but can be added as required. This information is read directly into Grasshopper from the Excel spreadsheet. In this sample, the snare, bass drum, ride cymbal and Toms 2-6 have been played to produce a pattern described in Figure 10 as 'snare breakout to toms and bell ending'. This high complexity fill was self-evaluated with a "Referent rating" of 8, where 10/10 is where the patterns absolutely represents the author's playing style in the area of 'Rock-Jazz'. The small-diameter spheres on the Bass drum line indicate a series of low-velocity double-kicks whilst the Snare line illustrates a fast set of higher velocity strikes. The sample terminates in a descending Tom Tom roll, with a double strike to the Ride cymbal bell.

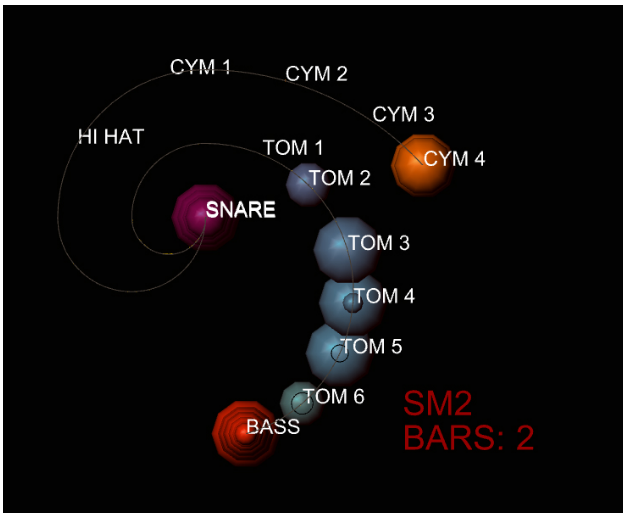

Figure 9. Drum solo Referent No. 2 end view

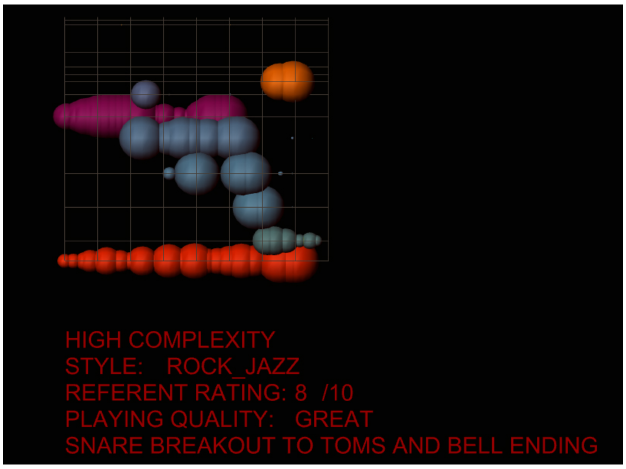

Figure 10. Drum solo Referent No. 2 side view with descriptors on complexity, style, 'referent rating', playing quality and free text.

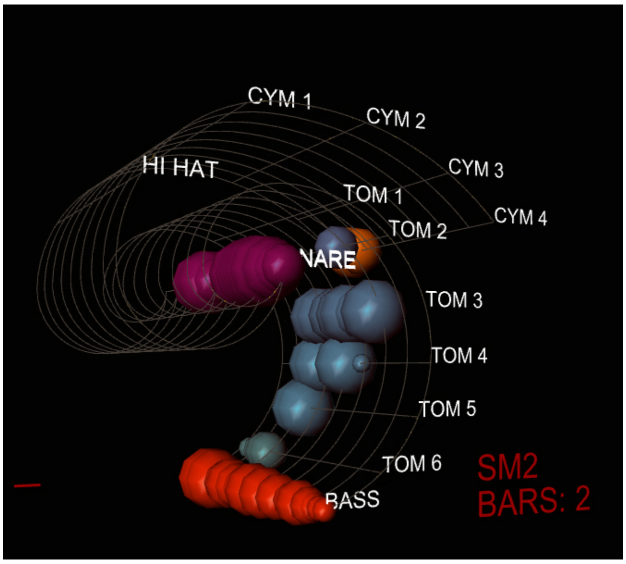

Figure 11. Drum solo Referent No. 2 perspective view

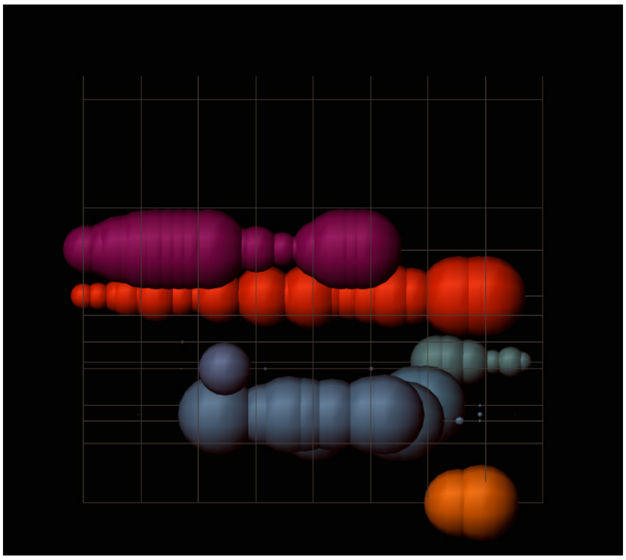

Figure 12. Drum solo Referent No. 2 top (plan) view

As is evident from the four static representations in figures 9-12, a complimentary information set is available from each viewport. Representations in each viewport can be interrogated through zooming, panning, slicing, measuring, animating and other CAD operations. Further, multiple representation options are available to represent the drum events, including using cones (where cone length represents the note duration) and other basic geometries. Sliders in Grasshopper enable quick scrolling through the 200 referents in real-time. It is proposed that this ability to review, analyse and reflect on musical information using multiple spatial representations, colour and through text-based tags significantly overcomes the issues of the musico-spatial perspectival hinge and offers significant affordance for the understanding of the elements of musical drumming style.

These samples, and the metadata schema, provide a large library from which to draw for electronic music composition. The defining characteristic of these samples is the various imperfections, velocity attenuation, microtiming elements and accents that define my style. When looped, sampled and edited using virtual instrument plugins in the Reaper DAW, significant unique compositional opportunities have been made available (see https://soundcloud.com/jjham/). These explorations can occur in both musical and spatial design domains. This initial project has fostered a reflection, using spatial design as the basis, on an established drumming practice. The next stage of the research involves expansions of this practice into diverse domains of music and spatial design. One example is described below.

5. REPRESENTING 'LAYERED RELATIONSHIPS' USING SPATIAL NOTATION

In designing a building, spatial elements (walls, floors, roofs, windows, joinery etc.) are layered on, in and around eachother to form a complete composition in the form of a building. Drawing upon Elizabeth Martin's conception of music and architecture in terms of 'layered relationships [16], the digital drum kit is used to build up a series of improvised layered drum solos to that are layered in, on and around eachother. Whereas for architecture the layering of building elements occurs in space, in this case the layering occurs as drum events in time.

A form of 'spatial polyrhythmic improvisation' is explored on the digital drum kit and represented using 3D spatial drum notation. The principal idea behind this work follows on from view of master drummer Terry Bozzio that the drum kit can be conceived as an orchestra of instruments, rather than a singular instrument itself [30]. By playing with the elements of drumset improvisation identified by Breithaupt [31] (dynamics, tempo, accents, rests, hand to foot distribution and motion) and the 'levers of control' in drum kit practice identified by Bruford [32], the digital drum kit becomes a working tool to enable diverse creative output.

The work also extends the concept of 'drumscapes' coined by David Jones [33] by bringing the drum solo fully into the digital realm. Through sound sampling (including environmental sounds sampled from landscape, the city and buildings), virtual instruments (through Kontakt Massive™, Battery™ and other virtual instrument plugins), spatial polyrhythmic improvisation explores the continuum of music and architecture in both the sonic and spatial dimensions through mixed modalities of improvisation and composition.

'Layered Relationships' is a drum-based composition based on five layers of improvisations from the digital drum kit (see https://soundcloud.com/jjham/). Each layer was recorded on the digital drum kit in the Reaper DAW using a metronome with a visible MIDI piano roll providing visual cues as to the setout of each previously recorded layers. Processed sounds from the Massive synthesizer library were assigned to each layer of drums, with each layer becoming more abstracted and spatial. The compositional intention was thus to build a complex layered drumscape of counterpointed layers of drum improvisations. Although this composition is recorded initially in stereo, research is ongoing in the area of spatial sound, and an adaptation of the spatial notation to incorporate dynamic panning. The five layers of 'Layered Relationships' are illustrated separately in perspective view in Figure 13, below. From this viewpoint, the first few bars of each layer can be viewed providing evidence of the composition of drum selection and relative velocities.

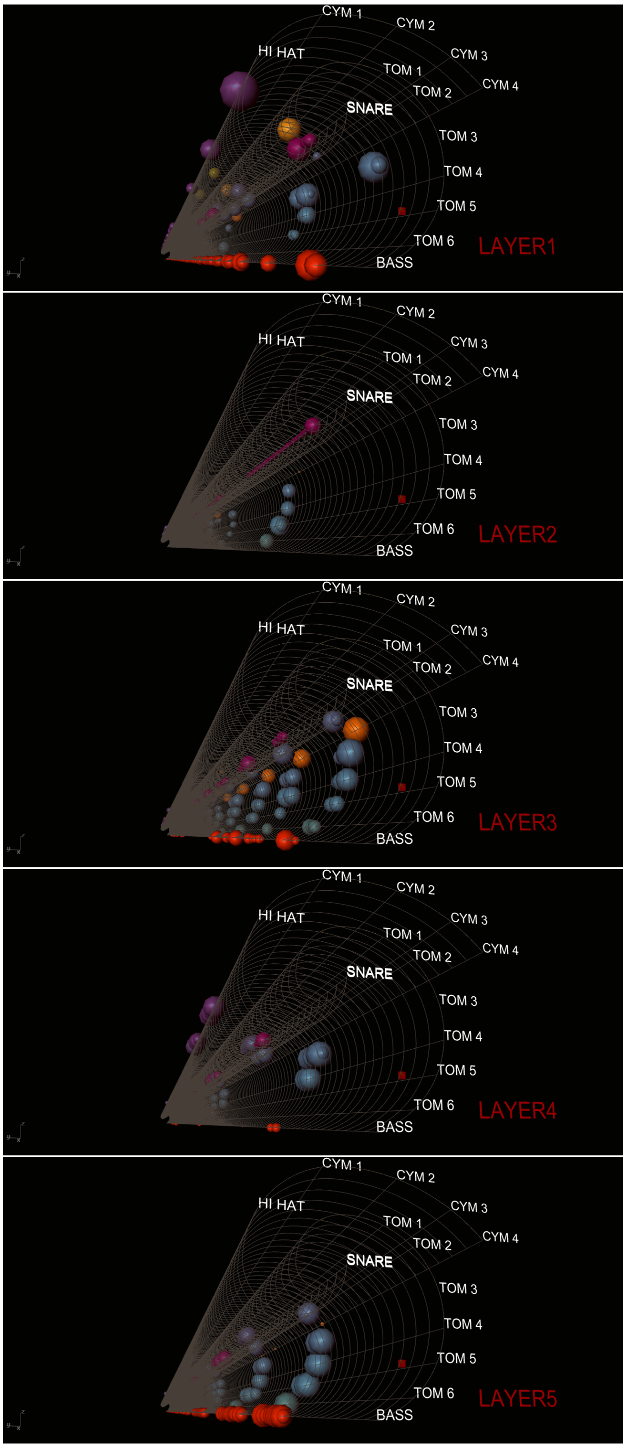

Figure 13. 'Layered Relationships' one point perspective of 5 layers in spatial notation

The layers that constitute a polyrhythmic and multi-layered drum improvisation can be analysed in three dimensions and through multiple viewpoints through spatialized drum notation. Each viewpoint offers different musical information, and all are used to construct complimentary understandings of the composition from a perspective of the notation as three-dimensional spatial elements within a framework of notes and a grid of time.

Referring back to the theory of affordance, spatial notation using CAD tools is particularly helpful in revealing the relationships between layers by using CAD layers to place musical events on. Figures 14 and 15, below illustrate all five layers (represented by different colours) from two different perspectival viewpoints. It is important to note that model views are not static, but can be dynamically panned in and around drum events in time and space. This immersion into, around and through the spatial notation provides opportunities to reveal the detailed interactions between layers, relative velocities, slurs and accents and timing relative to the meter.

Returning to the principles of orthographic projection, 'multiviews' of plan, elevation and section 'help us accurately examine geometric configurations, spatial relationships, and the scale and proportion of a design' for pictorial depth expression, 'single view drawings termed paralines and perspectives are needed [34]. In orthographic representation, certain information is provided on one projection that is complemented by other projections. Together, these projections provide a spatial information set that offers a comprehensive definition of the object under review.

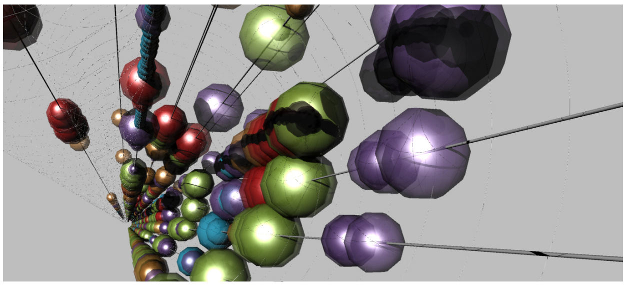

Figure 14. 'Layered Relationships' composition immersive view

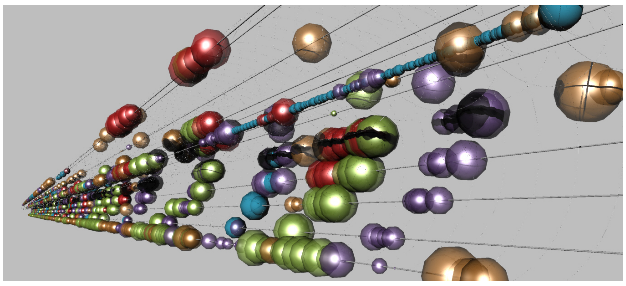

Figure 15. 'Layered Relationships' composition immersive view

6. FROM SPATIAL DRUMS NOTATION TO SPATIALIZATION

Within an integrated 'Musico-Spatial Design' creative practice, opportunities abound for the extension of enquiries beyond the area of spatial notation into the spatialization of drum-based music. The capacity exists to a represent digital drumming improvisations, referent patterns or improvised compositions as notation, 3D spatialization, in Virtual Reality, Augmented Reality and as 3D printed objects and through digital fabrication. Whereas the spatial notation described above utilizes a basic stylization of drum notation, speculative explorations take the creative practice research into more abstract and diverse realms.

Figures 16 and 17 illustrate two different ways of abstracting the composition 'Layered Relationships'. Figure 16 draws on the 'massing representations' used in the field of urban design where clusters of data are brought together to form a representation of the mass of, in this case, drum events in time. By representing in this manner, one can determine the drums most used along the timeline of the composition/ improvisation. In this case, the dominance of use of the snare, bass drum and hi-hats is evidenced by the solid continuous block along the timeline. These clustered representations remove velocity information and thus enable a focus on larger-grained compositional aspects.

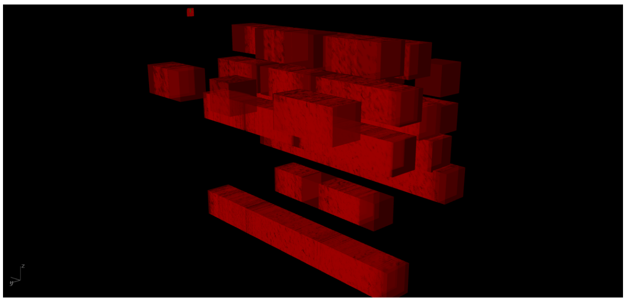

Figure 16. Compacted block representation of 'Layered Relationships'

Extending the abstraction of musical data further, Figure 17 illustrates a lofted representation of the first layer of 'Layered Relationships' and a composite image of all layers (Figure 18). This model was built by setting out drum notes in 3D space (X-Y plane) and velocities in the Z axis. This creates a set of data points in three-dimensional space where a mesh surface can be draped to create a complex curved lofted mesh. As a 3D object, this representation can be exported into different modeling formats for virtual reality, augmented reality, 3D printing and digital fabrication.

Figure 17. Lofted spatial representation of Layer 1 of 'Layered Relationships'

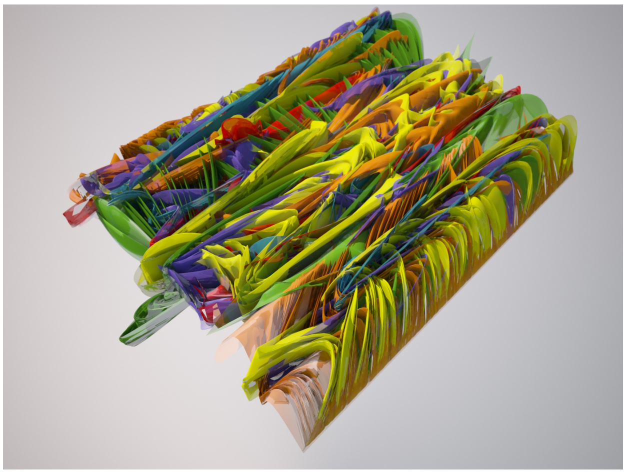

Figure 18. Lofted spatial representation of all layers of 'Layered Relationships'

3D printing potentially extends the affordance of understanding the elements of digital drumming by bringing the notation into being a real object. 3D printed notation allows haptic and physical engagement that overcomes the limitations of the computer screen interface. Although, the concept of 3D printed scores has been explored by Tess [35] to facilitate music reading for sight-impaired people, these 3D printed scores appear to simply operate as a braille form of traditional notation, with raised notes be read by touch. The procedure to build a quality 3D printed score is time-consuming. Drum improvisations and scores written in MIDI are 'baked' in Rhino3D, then exported to Meshmixer and ReplicatorG, then printed with a 3D printer.

Figure 19, below, illustrates an early stage prototype 3D model of a 2-bar drum referent. Longer scores can be built by cutting up a larger model and gluing together. Further potential is enabled by the use of laser cutters or Computer Numerically Controlled (CNC) routers build large scale 2D or 3D musical scores. Work in this area is at the early stages, and ongoing.

Figure 19. 3D printed score of a drum solo referent.

Virtual Reality offers another way in which to afford insights into spatial notation to explore the complexities of polyrhythmic drumming. Working with the University of Stuttgart High Performance Computing Centre Virtual Reality 5-sided CAVE (Cave Automated Virtual Environment), we have conducted early experiments into ways of achieving immersion in spatial notation. VRML models derived from Rhino3D can be 'walked through' using a headset and directional pointer, thus providing a full spatial experience of the score (Figure 19). This overcomes the interface limitations of interrogating spatial notation through the computer screen.

The aim to 3D VR musical notation is noted by Hmeljak [36] to be 'the most intuitive representation of music', and should include 'an appropriate use of symbology and geometry…(and) the use of colours and colour mapping'. We have tested both static 3D VR notation and dynamic 3D VR notation. Whereas static notation is derived from a 'baked' rendered CAD model, the dynamic notation is generated directly from MIDI drum files and, potentially, can be generated through live play in the CAVE. Dynamic notation animates velocities by sending notes into a gravity-simulated virtual environment.

Initial review of this early research work suggests that static notation is a more effective way of enabling reflective understandings of creative practice. Baking and freezing metaphors render the dynamic act of creation into a static object, enabling deeper levels of review and reflection. The dynamic VR system, however, holds much potential for creative practice centred on the spatial design domain. Through our early experiments in Virtual Reality, we affirm the potential uses of the system cited by Hmeljak [36] for computer-aided music analysis, music composition and music education. It is evident that further potential uses are available of CAVE-based drumming in the areas of collaborative CAVE-to-CAVE performance, engagement for non-musicians and exploring an integrated musico-spatial design creative practice wherein the musician-architect is able to create space at the same time as creating music.

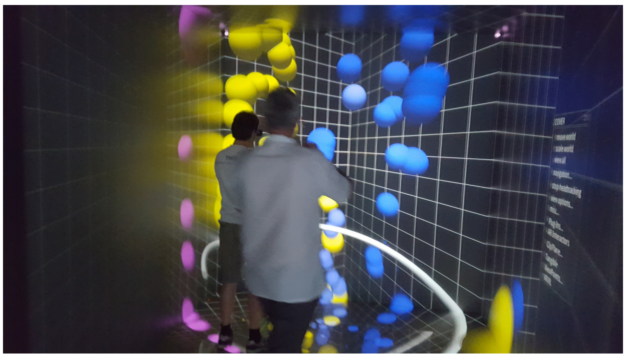

Figure 20. Dynamic VR inside the CAVE.

7. CONCLUSIONS AND FUTURE RESEARCH

This research presents a framework for spatializing drum notation founded on the principles and theories of architectural representation using the tools of architectural practice. The creative research project work presented here: the reflection on a lexicon of referent drum patterns and phrases; a multi-layered 'drumscape' composition and extension beyond notation into abstracted representations, 3D printed scores and into Virtual Reality environments are intended to demonstrate the potential of that the domains of architecture and spatial design can bring to that of musical notation.

Clearly, this research offers potentials that compliment or extend traditional notation and the area of 3D notation. The point of interest is how this spatial notation system affords insights into the complexities of polyrhythmic playing, and enables a spatial mapping and representation of the elements of individual drummer's musical styles. The focus of this paper has been the author's reflective and compositional work and the development of a system primarily intended for internal use. If a theoretical 'musico-perspectival hinge' indeed exists and notation that is limited to two dimensions offers less affordance of musical knowledge, this spatial notation system may provide the basis for many further explorations.

One such exploration that will be reported in future research is the use of spatial notation to compare the improvisation of different drummers improvising over the same 'template'. A reversal of the Grasshopper definition is underway that will allow the exploration of composition using spatial notational, with resultant output in MIDI format. These are just some of the fertile areas available for exploration within an integrated musico-spatial design creative practice.

Acknowledgments

This research is supported by an Australian Government Postgraduate Research Scholarship. The author would like to acknowledge Daniel Prohasky and Awnili Shabnam for their fine work on the Grasshopper script and Uwe Woessner and Joachim Kieferle for their work inside the CAVE.

8. REFERENCES

1. L. Kalisperis and A. Pehlivanidou-Liakata. *Computers in Design Studio Teaching'*. in *EAAE-eCAADe International Workshop Architectural Design Studio: Digital and Traditional*. 1998.
2. J. Bermudez and K. King, *Media interaction and design process: Establishing a knowledge base.* Automation in Construction, 2000. **9**(1): p. 37-56.
3. A. Pérez-Gómez and L. Pelletier, *Architectural Representation and the Perspective Hinge. Cambridge, Massachusetts & London*. 1997, The MIT Press.
4. J. J. Ham, *On Representation and Construction in a Tectonic Design Studio*, in *School of Architecture and Building*. 2004, Deakin University: Geelong, Australia.
5. K. Stone,, *Music notation in the twentieth century: a practical guidebook*. 1980: WW Norton.
6. J. Gibson, *The Theory of Affordances in the Ecological Approach to Visual Perceptual*. 1979, Houghton Mifflin.
7. D. Norman, *The design of everyday things: Revised and expanded edition*. 2013: Basic books.
8. N. Weinberg, *Guidelines for Drumset Notation.* Percussive Notes, 1994: p. 15.
9. M. Muecke and M.S. Zach, *Essays on the Intersection of Music and Architecture*. Vol. 1. 2007: Lulu. com.
10. N. Goodman, *Languages of art: An approach to a theory of symbols*. 1968: Hackett publishing.
11. C. MacNaughtan, *Indeterminate notation and sound in the space of architecture.* The Journal of Architecture, 2006. **11**(3): p. 335-344.
12. P. Rebelo, *Notating the unpredictable.* Contemporary Music Review, 2010. **29**(1): p. 17-27.
13. J. Cage, *Notations*. 1969, New York: Something Else Press.
14. C. Hope, L. Vickery, A. Wyatt and S. James, *The Decibel scoreplayer–a digital tool for reading graphic notation*. in *International conference on technologies for music notation and representation (TENOR 2015). IRCAM, Paris*. 2015.
15. R. Wittkower, *Architectural principles in the age of humanism*. 1971: WW Norton & Company.
16. E. Martin, *Pamphlet Architecture 16: Architecture as a translation of music*. 1994: Princeton Architectural Press.
17. Lab-au.com. *The shape of sound*. 2015 [accessed 24th April 2015]; Available from: http://lab-au.com/theory/article_soundscapes/.
18. A. J. Levy, *Real and Virtual Spaces Generated By Music.* International Journal of Architectural Computing, 2003. **1**(3): p. 375-391.
19. M. McCullough, *Abstracting craft: The practiced digital hand*. 1998: MIT press.
20. P. Ferschin, D. Lehner, and Y. Oka, *Translating music into architecture*, in *The third International Mathematics and Design Conference M&D2001: digital, hand, eye, ear, mind*. 2001, Mathematics & Design Association: Deakin University Geelong, Australia.
21. P. Christensen and M. A. Schnabel, *Spatial Polyphony: Virtual Architecture Generated from the Music of J.S. Bach*, in *CAADRIA 2008 [Proceedings of the 13th International Conference on Computer Aided Architectural Design Research in Asia]* 2008: Chiang Mai (Thailand). p. 501-509.
22. R. J. Krawczyk, *Exploring the Visualization of Music*. in *Proceedings of Bridges 2012: Mathematics, Music, Art, Architecture, Culture*. 2012. Tessellations Publishing.
23. M. Novak, *Liquid Architectures in Cyberspace (1991).* Multimedia: From Wagner to Virtual Reality, 2002: p. 272.
24. J. H. Hansen, *Musical Sculptures*, 2012: [accessed 24th April 2015];

https://www.youtube.com/watch?v=uxYHlZQSADQ&t=71.

25. D. Schön, *The reflective practitioner: How professionals think in action*. Vol. 5126. 1983: Basic books.
26. J. Pressing, *Improvisation: methods and models.* John A. Sloboda (Hg.): Generative processes in music, Oxford, 1987: p. 129-178.
27. D. Brown, *Noise orders : jazz, improvisation, and architecture*. 2006, Minneapolis: University of Minnesota Press. 159 p.
28. J.J. Ham and D. Prohasky, *Developing a parametric spatial framework for digital drumming*, in *13th Sound and Music Computing Conference*, R.G.a.G. Hajdu, Editor. 2016, Zentrum für Mikrotonale Musik und Multimediale Komposition, Hochschule für Musik und Theater Hamburg Germany. p. 197-202.
29. J. Ham, M. A. Schnabel, L. Harvey and D. Prohasky, *'Starting with Nothing' and 'Ending up with Something' - Musical Improvisation and Parametric Spatial Design Improvisation*, in *Complexity & Simplicity - Proceedings of the 34th eCAADe Conference, A.* Herneoja, Editor. 2016: University of Oulu, Oulu, Finland. p. 377-386
30. D. Zulaica, *Terry Bozzio: An Interview From The Vault Part I*. 2013 [accessed 2015 29th March]; Available from: http://www.drummagazine.com/features/post/terry-bozzio-interview-from-the-vault-part-i/.
31. R. Breithaupt, *Musical Considerations for Drumset Improvisation.* Percussive Notes, 1987. **26**(1): p. 15-16.
32. W. Bruford, *Making it Work: Creative music performance and the Western kit drummer*, in *School of Arts, Faculty of Arts and Social Sciences* 2015, University of Surrey: Surrey UK.
33. D. Jones, *Drumscapes Solo Concert recorded at Melbourne Recital Centre*. 2013, Independent Release: Melbourne.
34. R. Yee, *Architectural drawing: a visual compendium of types and methods*. 2012: John Wiley & Sons.
35. P. Tess. *3D printed Tactile Stave Notation helps visually impaired to better read music notations*. 2015 Nov 9, 2015 [accessed 2016 30th September 2016]; Available from: http://www.3ders.org/articles/20151109-3d-printed-music-notation-system-for-the-visually-impaired.html.
36. D. Hmeljak, *3D Musical Notation-Providing Multiple Visual Cues For Musical Analysis*, in *Unknown*. Unknown.