Space Making – Between the Virtual and the Physical

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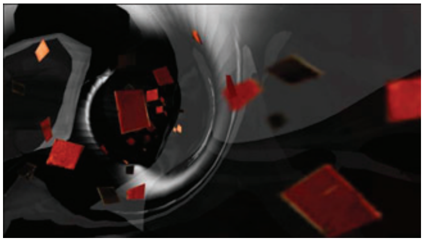
Digital technologies and processes have been used to generate architectural form for over two decades; recent advances in digital technologies have allowed virtual digital environments to be constructed from physical movement. But can a bridge that connects the physical and virtual realms be developed? Can this, currently arbitrary form making be grounded in human activity and subsequently be integrated into real time, space and place? This paper describes the preliminary explorations of research which attempts to address these questions.

1. Introduction

As we move into the 21st century, the limits of modernism with its mantra of 'form follows function' no longer seem relevant. As technology has developed, so has the possibility of space making shifted in parallel with these advances. Layered with an intelligent integration of sensitively selected surfaces, light and textures, numerous possibilities for a new architecture become possible. This paper explores the idea of making spaces that are as yet unrealized, spaces established by a set of rules driven by human motion and interaction, with the ability to mutate as the physical movement requirements of its occupants change.

As architectural tutors in the undergraduate programme at the Mackintosh School of Architecture in Glasgow, we are involved in the design and delivery of programmes that explored the possibility of activity focused architecture. We are also closely connected with the idea of integrating computing into the process of design, as a design tool, and not just a draughting instrument. This research has grown from this practice. The student programme that we have designed, known as 'space making' guides students through a carefully organised series of observations and data collection sessions, requiring them to utilise various mediums in both the observation, collection and communication of information. The drawings and designs that emerge as a result capture spaces and relationships which a traditional design process may not have revealed, and therefore not previously realised by the students. Three areas of research were carefully selected to cover both visual and intellectual areas. Following these preliminary stages involving cubist painting, film making and digital modelling, a further brief requires a 'vessel' to contain the specific activity that had been observed – a building, designed to hold the activity sensitively and appropriately, with the designer having an intimate knowledge of the movement patterns and spatial relationships that had been observed and recorded during the activity's performance (Figure 1). Derived following extensive research, recording, mapping and thorough drawing of a selected activity, an architecture is subsequently born as a result of these studies. The results in some cases have been extraordinary in both the outcome but also in forms and images that emerged from the process.

► Figure 1. Film Space by Aleksandra Dudziak, 2008.



This research was presented at the EAAE Teacher's Conference in Lisbon in 2007 entitled "Teaching and Experimenting with Architectural

Design: Advances in Technology and Changes in Pedagogy" [1].

We were aware of the work of other researchers who were exploring similar processes, in which they also layer in additional steps in order to manipulate and control three-dimensional forms (for example, Paul Coates working with others at University of East London [2]). Whilst this work is alluring, the outcomes were, in our view, driven by a series of arbitrary events and movements. Derix & Ireland's work [3] describes the creation of self-organising maps (SOMs) where relationship with living patterns is made, but does not propose making space from the SOMs. Our question began to emerge: How could these beautiful and intriguing volumes have a direct relationship with specific activities and then be utilised to create architecture within which the activity would be comfortably and appropriately housed? Furthermore, could these volumes be designed to adapt and morph as activity patterns alter? Our hypothesis required these 'envelopes' to be created as a result of human activity. The activity itself would establish the first step of this space-finding process. Once the rules are established, as laid down by the activity, further manipulation would allow adaptation of the volumes skin to occur as the users movement patterns alter over time.

Our aim is to produce spaces born from the movements that they should contain. With this at the forefront in our minds, and reflecting on the current work being done already in this area, a process was designed to pursue our line of enquiry. The first step was to select and record the activity. This was then followed by the collection of essential data that will form the basis for the establishment of the 'movement rules' that will be required to be consolidated for utilization during the proceeding steps. Following this, the data was translated into digital information from which three-dimensional spatial envelopes have been formed. The next step will involve the analysis, and extraction of movement patterns. Patterns observed will then be transferred in to algorithmic formulae and a feedback loop will be established. When the algorithmic process is re applied, manipulations of the envelope will result and an activity specific three-dimensional space will be created. Repetition of the later stages of the process will yield a number of envelopes developed from the same activity but with subtle differences. This array of 3D spaces will establish the parameters of flex for the inhabitation of the activity that the found space will contain.

This paper describes the photogrammetric method used to construct a 3D spatial envelope from the movements of two actors over a five minute period. It goes on to describe a process where this 3D spatial envelope will be analysed to derive algorithms for the manipulation of the envelope itself. The paper also projects a line of research where a space derived through the process will be built as a responsive research instrument. By utilizing this instrument, use patterns can be recorded. A built architectural space will then be influenced by use patterns, to develop an architecture which is connected to human activity.

2. The process

Currently the project has reached a mid point where the collection of data is complete, the transferral of the moving images into a digital format has been carried out and the realisation of primary spatial envelopes is under way. This paper attempts to explain the process so far and reports on the possible subsequent phases and our expectations for the research.

2.1 The Activity and data collection

The first stage involved the selection of an activity. We were very concerned that the 'everyday' be considered thus providing a very relevant feedback possibility from reality to the virtual and then back to a new reality. We selected cooking and eating, and believe this activity to be reasonably universal in both social and cultural contexts. A script was written and rehearsed to try and recreate a natural performance of the activity of preparing and eating breakfast, and that would also allow us to re run the same activity and achieve similar results. A 'kitchen set' was designed which would contain the performance. Following testing and rehearsal several conditions were established that would have to be adhered to in order to acquire the necessary data that would allow the next step to proceed. The location for the recording was made carefully, not only was sufficient space required around the' set' but the quality of light was also critical. A disused gallery space was procured that gave us both of these conditions – big space and constant north light. An area of 3 m^2 was taped out which set the perimeter of the kitchen. A very skeletal framework for the kitchen set was then designed and constructed. It was important that minimal solid planes were used thus eliminating the possibility of elements of the activity being obscured during filming. Four high-resolution video cameras were located at equal positions from the edge of the kitchen and an accurate survey drawing was made to give exact location relationships between all four cameras and the performance. Standard filming procedures were adopted to allow each of the films from the four cameras to be re played in exact sequence (Figure 2).

► Figure 2. Filming the activity.

2.2 Conclusions on data collection

All went well with this stage of the research although we are aware that despite efforts to maintain flat light, shadows were still evident in the recordings. This has caused an additional layer of work for these to be removed and allow the recordings of the movements of the actors to be as accurate as possible. In retrospect we were also aware that the kitchen set and props utilised to help to recreate a realistic performance caused obstructions. Again, an additional layer of work was required to erase these elements in order to give us a set of clean filmic data that could then be transferred into digital information.

3. Data processing

3.1 Physical to digital

The interaction between the two people was mapped with video recording using four cameras. This information was the transference of the physical into the digital, the goal being to produce a digital 'spatial envelope' of the activity over the course of the event. A camera/computation approach was preferred to motion tracked skeletons, because the goal was to achieve a spatial map as opposed to a motion study. Because motion capture focuses on the movement of the actor's frame, a spatial envelope derived from such a process is additive. Using the photogrammetric method allows for the capture of the *space* of the actor's movements.

A 2D image is derived for each actor at one moment in time for each of the four cameras. These 2D images are projected into a cone of space for each camera. The intersection of these cones creates the 3D shape which each actor occupies in each frame. By placing the shapes for both actors together a 3D 'spatial envelope' of a single moment is generated. Once these individual moments are merged, a 'spatial envelope' of the activity is produced.

The video recorded from each camera was translated into four digital films. From each of the four films, a one minute segment of TIFF images was produced. A variety of processes were used to develop a means of emptying the background information so that 2D shapes of the human actors could be derived. The goal was to convert the colour images into a white-on-black silhouettes, which could be used to create complex curves. In developing the process for isolating the human figure there were two primary goals: flexibility and automation. Each step in the process needed to produce a digital format that would provide multiple options for each of the succeeding steps, while also allowing the process to be automated for processing the four complete films.

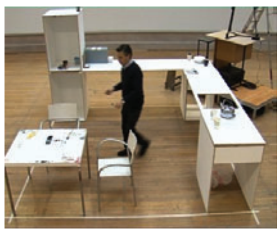
3.2 Figure extraction

The first method of separating the shapes used a compose/difference script written by a member of the team. Although aspects of this method worked, it was deemed too cumbersome for the final process. The process that was settled on used a change mask-composite script, revealing the difference from an image of the scene without the actors, which isolates the human actors from the background. While this removed the background, shadows were still evident (Figure 3).

► Figure 3. Empty set – background.

A sequence of carefully tuned and threshold RGB separation processes were tried (Figure 4).

► Figure 4. Single frame with actor.



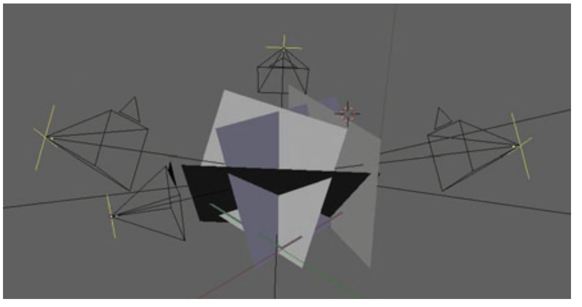
The addition of a threshold component to the process refined the outlines; removing the shadows became the next goal. Using the colour difference between the human actor and the shadows, a single white-on-black silhouette of the human actor was produced (Figure 5).

► Figure 5. White-on-black silhouette.

This filter process is easily varied and is being developed and adjusted as the research progresses. Different command combinations can be devised using this toolkit to reflect particular requirements or visual conditions. A minutes worth of this conversion process for one camera (1500 images) takes approximately 90 minutes on a normal PC.

3.3 Camera set up in digital space

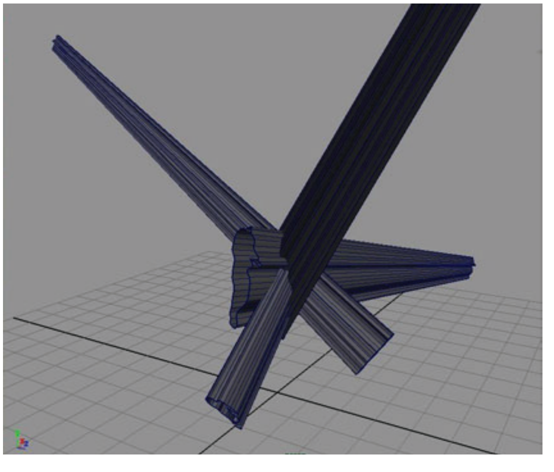
The next step was the acquisition of the camera geometry. A manual model of the scene with its four cameras was constructed in Blender (a free modelling program) to determine numerically the positions of cameras, directions of view and scaling factors for the acquired images. Using the ability to simulate the operation of the cameras in the software while overlaying actual frames from the video in the view ports of the modelled cameras over a skeletal model of the scene, we could create a geometrical simulation of the setup and thereby derive quantities needed for the next stage. It was also determined that the intrinsic distortion of the cameras could be corrected or, within the accuracy of the process, effectively ignored (Figure 6).



◀ Figure 6. Camera setup in Blender.

3.4 Extrusion of silhouettes into forms

The mathematical process targeted by the next stage is illustrated by Figure 7. The silhouettes of the occupants, appropriately scaled and positioned according to the model, are projected from the camera locations into the space and intersected to form an approximation of the shapes of the participants.



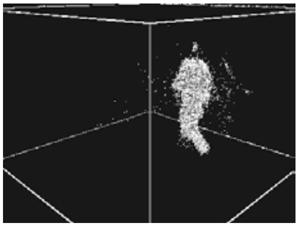
◀ Figure 7. The 'cones of occupation' concept.

A program was developed (in C, for the best chance of speedy execution) which generated a 3D 'bitmap' of each camera's 'cone of occupation' for a given frame of video. This bitmap is essentially a simple 3D matrix of 1s and 0s which can be treated algorithmically and combined with other similar bitmaps or sectioned in various ways without using complex modelling software.

3.5 Intersection of forms to construct an envelope

Various intersection operators were used on each set of camera cone bitmaps to cut down the volumes of the other cameras. The favoured approach is to use a 'committee' system which takes the majority (three out of four) occupancy of the three cone bitmaps to identify the actual shape. This seems to minimize the ambiguity caused by furniture obscuring one camera's view while differentiating between multiple volumes. This produces a minimal set of solid shapes: when the shapes from all four cameras were combined a unique 'spatial envelope' of the actors is constructed (Figure 8).

► Figure 8. The intersection of cones of occupation during one moment.



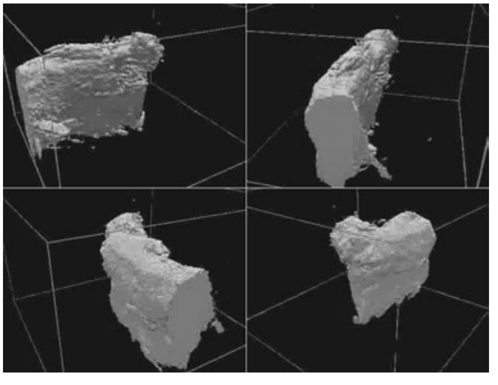
Straightforward filtering processes were then added to the program to remove isolated 'specks' and 'holes' to end with a 'solid' 3d shape.

3.6 Envelope manipulation

The 3D bitmaps are easily combined and manipulated and at the resolutions used (300x300x200: a resolution of 1cm in each axis) such processes are quite manageable, taking seconds rather than hours.

An example of such a combination is shown in Figure 9: four frames from a video showing an integration of four seconds of movement of one participant (the accumulated personal envelopes for 100 frames), viewed by raytracing (within the same bitmap processing program), illuminated by a simple light model and rotated for inspection.

► Figure 9. The envelope of 4 seconds of movement.



4. Pattern analysis

The following stages of the process are still in progress as further analysis and manipulation of the data takes place to move us towards the creation of our three-dimensional activity specific envelope. The generated envelope of the whole event will be analysed to determine patterns of spatial change. As the envelope changes throughout the duration of the event it is predicted that a pattern of density and thinness will emerge. Repetitive motion should create areas of thickness, and movement between locations should result in stretched space, with the cluster and fingers of the spatial map pulsing. This analysis will be done utilising orthogonal drawings and physical models.

4.1 Algorithmic processing

Following the extraction of these repeated movements and analysis, algorithmic formulae will be constructed. The algorithms will then be fed back into the spatial envelope data, and will be run to produce a transformation of the original spatial envelope. The algorithms will be spatial operands that are derived from the patterns of the observed event. The 3D solid of the event will be transformed through an iterative process. Using the structure of the original activity, preparation, consumption and clean up, the iterative process is divided into three distinct phases. Each phase of activity lasts for approximately 1 minute and 40 seconds. Each phase is comprised of different movement patterns and varied rates of repetitive movements. An algorithm based on the pattern of movement from each phase will be written; by using all three algorithms in a process, the 'spatial envelope' of the activity will be transformed and evolved. The repetition of movement in each phase determines the number of iterations that each algorithm will be run on the 'spatial envelope'. The 'preparation' phase algorithm process will be used six times, derived from the movement of each actor from the table to the various stations in the 'kitchen'. The 'consumption' phase algorithm will be used 20 times, to reflect the greater repetition of the actor's movements as they eat. The 'clean up' algorithm will be run 10 times, because the actors move between the table and kitchen stations more times during the 'clean up'.

The new space that results from the process of transforming the 3D solid with the activity based algorithms will be tested with the spatial map of the activity from which it started. This digitally produced enclosure will then be translated back to the physical, to produce a space derived directly from the activity which it is designed to contain. A new 'part physical, part virtual' architecture is born.

5. Further development of research

5.1 A responsive architecture

Another goal of this research is to find a methodology for implementing a 'responsive architecture' that is based on human action. There are numerous proposals for architecture which will respond to various demands being made on it. One proposal is for an architecture that can respond to changing structural demands such as wind loads [4]. Other proposals suggest that a building enclosure could change in response to fluctuations in light levels and direction to maximize thermal performance [5]. This work also shares the goals of the Kinetic Design Group at MIT, for an architecture that is adaptable to changing needs. While these forms of response are welcome and provide significant improvements over static solutions, this research proposes another form of response – a dialogue between the user and the space they occupy.

The research begins by seeking to find in the motion of the users, the spatial occupation of a specific activity. From this starting point a spatial envelope is derived. This spatial envelope will be transformed algorithmically to account for the passage of time in relationship to movement patterns. Our speculations propose that the use of the Event Based Digital Morphogenesis that we are developing, along with embedded computing, robotic technologies, flexible structures and building fabrics can create a feedback loop between the user and the architecture. It is hoped that this loop can derive architectural enclosure that is shaped to human activity and specific desires.

6. Conclusion

This could be an architecture of use and delight. By taking into consideration the possibilities of both long term and immediate response, this architecture would provide practical and qualitative benefit. An architecture which could remember spatial use patterns and adapt to improve the provision for users would have obvious benefits. If a small kitchen is used by a single user, the space would change to suit this use pattern; if another user becomes part of the pattern, revisions in the configuration would help accommodate the interaction between the two users, and so on. This reformulation of space would be gradual and automated in response to the occupants use patterns over time. This long term or use memory is one possible benefit of use-based responsive architecture. Added to this is the opportunity for users to make qualitative changes to the building fabric. Users could modify light and privacy by changing the size and location of apertures on an immediate basis. While these short term local changes could also become part of the feedback data base for use in the long term evolution of the architecture, the objective would be to provide qualitative control over the architectural space.

The possibility of this type of architecture is not beyond the grasp of current technologies and building materials. The use of digital technologies in the manufacture of sophisticated forms will allow the production of spaces generated with Event Based Digital Morphogenesis. New thinking in structural engineering is providing models for structures that can move (such as Muscle by Kas Oosterhuis and Ole Bouman [6]). Sensor technologies can provide information and the methods for user input to direct changes in spatial envelopes. Robot technology and embedded computing can effect the changes that the sensors and users demand; making an architecture that is interactive, dynamic and organically related to those using it.

6. References

1. Crotch, J. and Mantho, R., Media, Technology and Teaching, in: Spirdonidis, C. and Voyatzaki, M. eds., *Teaching and Experimenting with Architectural Design: Advances in Technology and Changes in Pedagogy*, EAAE Transactions on Architectural Education (35), 2007.
2. Coates, P. S., Teaching Architecture through Algorithms – the First 15 years, in: Spirdonidis, C. and Voyatzaki, M. eds., *Teaching and Experimenting with Architectural Design: Advances in Technology and Changes in Pedagogy*, EAAE Transactions on Architectural Education (35), 2007.
3. Ireland, T. and Derix, C., The poly-dimensionality of living, in: *Proceedings of the 2006 eCAADe Conference*, Volos, Greece, 2006.
4. Sterk, T., Using Actuated Tensegrity Structures to Produce a Responsive Architecture, in: *Connecting Crossroads of Digital Discourse*, Proceedings of the 2003 ACADIA Conference, Indianapolis, 2003.
5. Fox, M., *Sustainable Applications of Intelligent Kinetic Systems: Responsive Skylights*, in: Kronenburg R., Limm J. and Yunn Chii W., eds., *Transportable Environments 2*, SPON Press, London, 2002.
6. Oosterhuis, K. and Bouman, O., Muscle, in: Ibeling, H., ed., *The Artifical Landscape*, NAi Publishers, Rotterdam, 2000.

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