

VISUALIZATION SKILLS FOR THE NEW ARCHITECTURAL FORMS

Khaled Nassar, Magda Mostafa, and Amr Rifki

Abstract

The practice of architecture is continuously changing, mirroring the paradigm shifts in the world it builds for. With increasing use of digital technology, we need to ensure that learning and teaching do not shift from the fundamental skill set required of an architect. Architectural problems are unique in their nature, requiring volumetric visualization and problem solving skills, and although many of these skills can be replicated using digital technology, can digital technology replace the cognitive development which occurs through manual problem solving? Over the last three decades we have seen the almost ubiquitous use of computers in the design practice and professional studios with increasingly more complex forms being thought of and turned into buildings. This development obviously raises challenging questions of architectural theory and perplexing issues for those concerned with the future of architectural education and its effect on the design process. But how can this effect be analyzed subjectively remains an open question. Recent research efforts have shown that perception and visualization abilities reflect the quality of a design outcome. Very limited research however exists which attempts to understand or document the spatial analysis and visualization abilities of new generations of architects. This paper reports on a novel scalable test that could be used to investigate the processing and synthesis of visual information related to the new kinds of free form encountered in today's architecture. Unlike

traditional missing views and orthographic projection problems, proposed test can be used to accurately assess freeform visualization. A number of 2-mainfold very high genus surfaces were selected. Physical models of these surfaces are manufactured from a durable thermoplastic material by Fused Deposition Modeling rapid prototyping machines. Students are then asked to position a digital model of the surface to match that of the physical model and vice versa through a number of progressively timed attempts. Results on the average time to success, failure rates, manipulation rate as well as manipulation rate to total time are calculated and analyzed. Statistical analysis of the outcomes was conducted and the results and conclusions of these experiments are presented in this paper along with limitations of the experiments and suggestions for future research. The results should be of interest to architectural educators and architects concerned with the effect of computer technology on the design process, as well as the future of manual skills in our design studios.

Keywords

Design studies, architecture, education, linkographs, entropy, design experiments, pedagogy.

Introduction

One Digital media has revolutionized the creation and manipulation of spatial form in the realm of architecture. Specifically, digital free-form space is now becoming easier to generate as the use of the computer has increased in academia as well as in professional practice. Since computers today are becoming ubiquitous and used in various stages of the design process, the kinds of architecture form, structure, and planning are also becoming increasingly complex. Many free from architectural designs that exist today are either inspired by or fully generated by computers. As such present day digital architecture emphasizes dynamic surface, with its three-dimensional curves, and the interior and exterior continuity of the architectural and urban spaces.

Although shown to be unsurpassed in ability to draft, correlate, coordinate and mass-produce many architectural artifacts (Callieri et al 2006), research has shown that digital media has profound influence on the cognitive development of architects, particularly from the pedagogical standpoint (Boucherenc, C.G. 2006). Such pedagogical research supports the adaptation of manual media in the areas of design cognition and conceptualization. Additionally, and from the realm of practice, manual media has been shown to facilitate and enhance the cognitive design process, preferably, over digital media. Results of such studies “showed that traditional media had advantages over the digital media, such as supporting the perception of visual-spatial features, and organizational relations of the design, production of alternative solutions and better conception of the design problem.” (Bilda & Demarkin 2003).

The concept of design cognition, and indeed

spatial perception and visualization, themselves have begun, however to undergo changes and shifts as a result of the proliferation of digital media. The computer generated virtual world to which we are increasingly exposed, has begun, however to alter how we perceive reality, and consequently space. Beginning with the work of Van de Bogart in 1990 to current studies of this phenomena, the complex relationship between design cognition, conceptualization and spatial perception has been challenged and must be reviewed carefully. Computer-generated virtual worlds have been shown to “catch the attention of the viewers, making them more interested in the narrative and engaged with the visual elements, but does not necessarily enhance their critical awareness” (Neto, P. 2003) Although digital media has begun to develop highly advanced form generative tools that perform spatial manipulations impossible to achieve or even conceive using traditional manual media given that architecture exists in a tangible reality, the role of virtual space through digital media must be appropriately addressed.

Research has addressed this complex relationship and illustrates both pedagogical and professional examples of how this complex relationship can be used to the advantage of the design process. Such examples range from attempts to link both manual and digital media in the design studio (Hadjri, K. 2003) to combining traditional and digital visualization in planning (Al Kodmany, K 1999). More recently hybrid approaches- which capitalize on the palpable, multi-sensory cognitive values of manual media and the complex generative and simulative powers of digital media- have been presented. New representational tools such as rapid prototyping begin to introduce tactility

and palpability to virtual forms (Snoonian & Cuff 2001) and (Séquin, C. 2005). From the e-studio (Al-Qawasmi 2005) to new tectonics (Liu & Lim 2006) and ideation software (Dorta et al 2008), these hybrid techniques seem to be paving the way forward (Snoonian & Cuff 2001).

Yet, there is a lack of understanding of how architects interact with these new surfaces and meshes in the digital space. At a more fundamental level is how well do the new

generation of architects visualize and interact spatially with freeform complex architecture. Therefore, this paper sets out to assess the development of fundamental spatial manipulation and basic perception skills using of the new digital media. A scalable experiment is designed and implemented in order to test the manipulation and perception skills of architectural students in terms of the high genus meshes. The development and the execution of the experiment are presented along with



Figure 1: Sample High Genus Models that were developed and considered for testing. Note that they are all a-symmetric high genus shapes (shapes with high number of handles and holes) as symmetric high genus shapes were excluded from the start. (Source: Authors).

interesting findings and results. The experiment involves designing and manufacturing a physical model of a complex mesh surface and then using the model to test the spatial orientation ability of the students in space. Furthermore the experiment is scalable as it could be conducted with different surface models and test conditions. The results should be of interest to educators, professionals and industry developers.

Developing a Visualization Test

In order to explore how new generations of architects are able to visualize the new free form architecture, we set out to try and develop a rigorous experiment that could not only assess whether new generations have adequate projection and spatial manipulation skills but also understand how these skills are used and distributed among this new generation.

Developing and Manufacturing the Experiment Model

One of the most complicated surface or free form

types that are becoming increasingly used and developed by professional and experimental architects are high-genus surfaces. High genus meshes are among the most exciting new developments in architectural form due to their distinct topology and have already gained fame in the world of sculpting. Some of the most well-known examples of such high-genus sculptures include Bathsheba Grossman's 3D metal printed sculptures [Helman 2006], Brent Collins's saddle sculptures [Sequin 2006], Charles Perry's aluminum and bronze sculptures [Perry 14], Helaman Ferguson's bronze and marble sculptures [Helman 2006, Ferguson et al 1992], Carlo S'equin's 3D printed sculptures [Sequin 2006], and Rinus Roelofs' [Roelofs 2006] and George Hart's [Hart 2006] puzzle like sculptures. These surfaces are also making their way quickly into the design studio and students are experimenting with them in very interesting ways. The genus of a shape refers to its topological structure so that a torus has genus one, as does the surface of a coffee mug with a handle. More details on high-genus surfaces can be found in [17], however three

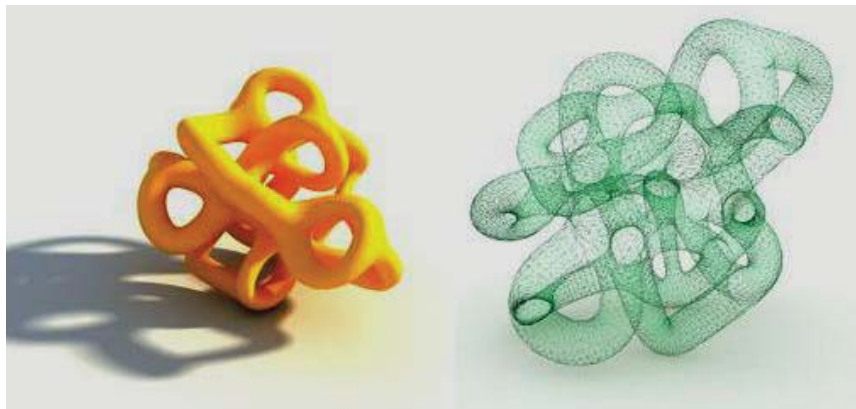


Figure 2: The 3D model of the proposed testing sample. (Source: Authors).

features of these surfaces are important for the visualization exercise developed in this paper; firstly, the high number of holes which makes it difficult to orient the shape. Secondly, the non-orientable property which means that the inside of the model is not distinct from the outside and thirdly, the high number of handles which also created complexity in terms of orientation.

A number of very high genus 2-manifold meshes were created to study the visualization skills of students in terms of the new architectural freeform surfaces. In the real world, every object is an orientable 2-manifold surface, which in simple terms means that the object has a well defined interior and exterior. We made sure that the resulting shape is topologically 2-manifold and additionally we avoided self-intersection so that the resulting models are 3D-printer-ready, i.e. they can be printed by using a rapid prototyping machine will be described below. After initially creating a number of various high-genus models (Figure 1) they were compared to select the most suitable surface for the experiment. Criteria for selection included asymmetry, high Gaussian curvature as well as being non-orientable (which means the view from various angles will be different). A positive Gaussian curvature value means the surface is locally either a peak or a valley. A negative value means the surface locally has a saddle points. And a zero value means the surface is flat in at least one direction (ie, both a plane and a cylinder have zero Gaussian curvature). So a model with a high Gaussian curvature appears to be more deformed and freeform. Figure 2 shows the rendered and wireframe mesh of the selected surface.

We used a new software called Topmod that

allows users to interactively create high-genus meshes. The software allows users to develop the model using primarily controls of the high-genus mesh as well as automatic methods, where there is minimal user interaction and the program automatically creates the high-genus mesh. We used the interactive method to create the surface by creating multi-segment curved handles between two different faces, and by "rind modeling", which provides for easy creation of surfaces resembling peeled and punctured rinds.



Figure 3: The Manufactured Rapid Prototyped Model. (Source: Authors).

After settling on the most appropriate high genus surface to use, the model was converted into a stereo-lithography file for rapid prototyping (i.e. 3D printing). We used the Dimension 1200es 3D Printer because it was able to print functional, durable 3D models (whose size was about 10" x 10" x 12"). The printed model would be used by the students latter for evaluation and testing

under real-world conditions. The model was made from a production-grade thermoplastic that is durable enough and also accurate enough to look virtually the same as original CAD model. The model was printed from the bottom up with precisely deposited layers of modeling and support material. To help the students orient the model better the model was printed in two sections with two different colors as shown in Figure 3. After manufacturing, the model supports were snapped off to reveal the final model. Finally the model was cleaned and polished.

Experiment Design

The experiment described below is highly scalable as it could be conducted in different ways. The most basic way is to place the fabricated surface in different positions and then present the test subjects (the students) with the computer model of the fabricated surface. Then the students are asked to modify the computer model to face the same position as the one in the physical fabricated surface. Digital manipulation involves only orbit rotation operations which are easy to use and comprehend.

The use of computer manipulation of the model allows for more accurate measurement of the sequence of events (moves made by students) because the whole experiment can be recorded and analyzed later as described below. There are multiple other testing alternatives which include the reverse process, where students are asked to position the physical printed 3D model to match the position of the digital model. Also the use of animation of the digital model can be used to enhance and test even further the visual reasoning skills of the students. The animations

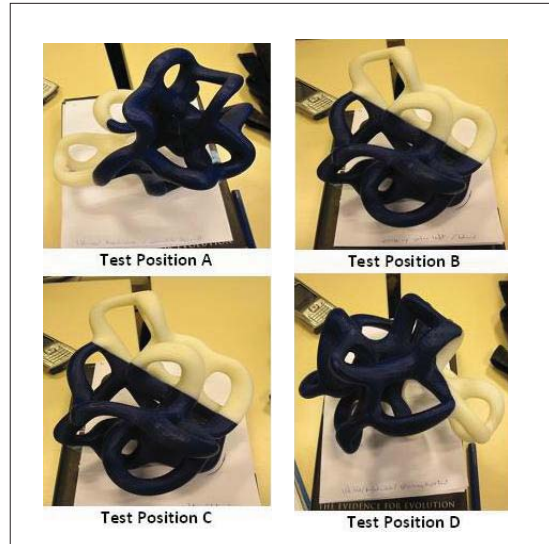


Figure 4: The four test positions considered (note the scale of the model in comparison to the cell phone). (Source: Authors).

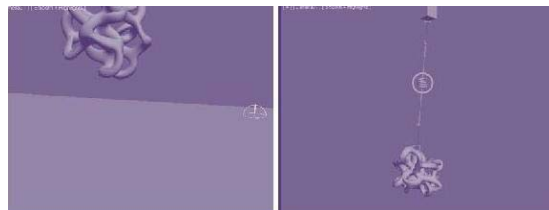


Figure 5: Animated positions of the test model. (Source: Authors).

can be in the form of an object being dropped from a height and landing on one of the natural resting position or being suspended from a spring such as those shown in figure 5. Animating the object significantly enhance the visual reasoning

skills of the students as they are able to grasp the topology of the objects in a more natural way.

It was noticed that some students are more natural when dealing with the orbit rotational manipulation of the software. When rotating the digital model it was found that Orbit manipulation of the object was much quicker and easier for students than axial rotation and therefore it was chosen.

The timing strategy used in the experiment refers to how much time is given to the students to complete the various sequential exercises. Three different timing strategies could be used; Fixed timing, progressive timing or open timing. The test timing strategy depends on the type of analysis needed and variability in the student spatial and visualization skills. With the fixed timing strategy, the same time is allotted for the various test positions which means allows for assessing differentiating between the students in terms of their abilities but does not give an indication on the distribution of these abilities since results will be binary in nature. Failure rates are hypothesized to be uniformly distributed among the different trials. In progressive timing strategy, less time is given with each attempt. This allows for more detailed analysis on how quickly the students can visualize and learn the form in question as more pressure is put them with each trial. As such it can provide another level of differentiation between the students with better visualization skills and the distribution of the failure rates is hypothesized to be more skewed and sharp. In open timing students are given as much time as they need to solve the problem and hence data could be collected would differentiate between students with poor visualization skills more as they are the ones who will probably remain behind.

Although failure rate data in the open timing strategy would probably not be useful, the distribution of the time to success is hypothesized to be normally distributed.

The following steps for conducting the test are suggested:

1. Students were first told about the exercise and it was mentioned that participation was voluntary. Students were not told any details about the exercise and the actual model was not revealed.
2. Students then were admitted one at a time and were first briefed about the exercise and told that this was a research project and that the results would not affect their grades in anyway. It is important to note however that due to the unique nature of this exercise the students were very excited about it and showed great sense of competition. Although every new student going through the exercise did not know in advance about the specific nature of the exercise, it became very competitive with students asking about the record score so that they can beat it.
3. Students were then given an introduction into orbit navigation of the 3D model to ensure that they felt comfortable navigating the model in 3D space.
4. The timing strategy used was explained to the students. This involves initial calibration of the timing strategy by having 2 or 3 volunteer students take the exercise at the beginning and analyzing their times. For example, in our run we used progressive timing strategy after measuring the amount of time it took 3 random students to complete the exercises.
5. The positions of the model are recorded

in advance (as the exercise protector could easily forget the original positions) and then the first position is shown to the student. It may be necessary sometimes to have the progressive timing strategy start after an initial open time test so that the students get familiar with the interface. Any CAD software can be used, however one that can support real-time rendering and animation is preferred. In our run we used 3D Studio Max.

Number	1st attempt	2nd attempt	3rd attempt	4rth attempt
1	2:17	0:29	1:14	0:48
2	1:07	1:08	X	X
3	1:11	x	1:35	1:48
4	7:47	1:03	0:45	0:25
5	1:03	x	0:09	0:50
6	2:02	1:00	0:18	X
7	13:00	0:20	X	0:57
8	1:55	1:43	X	0:45
9	1:50	1:24	0:08	0:12
10	3:55	0:23	0:54	X
11	1:01	0:41	X	1:02
12	1:20	1:10	1:00	X
13	3:14	2:00	0:46	1:30
14	0:40	0:25	1:00	1:05
15	3:45	2:47	1:00	1:21
16	6:40	2:06	1:37	X
17	1:00	1:20	X	X
18	2:29	2:40	0:50	1:12
19	6:22	1:30	1:15	X

Table 1: Sample results: (Source: Authors).

6. The various positions are then shown to the students while the entire session is being recorded with a screen capture video for further analysis. The various positions can also be photographed and the picture shown to the students. This allows multiple concurrent session of the experiment to take place simultaneously.

7. The results are then calculated from the

recorded videos after all students have completed the exercise. To increase the level of engagement of the students, the current record score can be continuously announced.

Analysis and Results

After conducting the experiment the results were tabulated and analyzed. Table 1 shows sample results of the experiment. The results show the time to successful completion of each student for the 4 different positions, with an “x” indicating failure. In our sample run we used a progressive timing strategy 8 minutes, 2 minutes, 1.5 minutes and 1.25 minutes. The main results calculated are those relating to the time to successful completion and the failure rates (i.e. the number of students who failed to complete test).

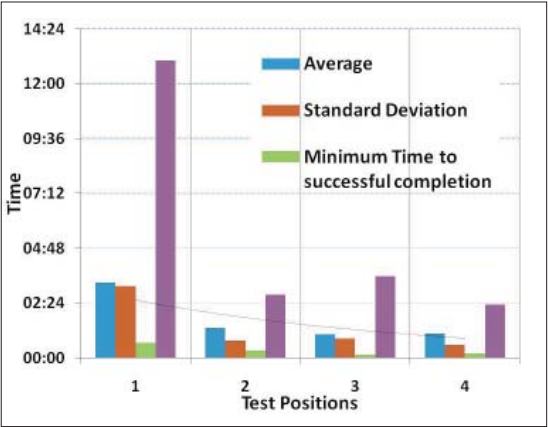


Figure 6: Correct and wrong results versus test number (1 to 4) as well as overall correct and wrong percentages. (Source: Authors).

Figure 6 shows the summary scores versus the

various sequential test positions. The average time to successful completion decreased from 3:17 minutes in trial one to 1:04 in trial 4. This is expected as students become more familiar with the model. It is interesting to note however that while minimum time decreased from 0:40 in the first trial to 0:12 in the last trial the maximum time taken remained fairly unchanged over the last three attempts. This can be explained if we look at the various strategies employed by the students during the experiment. Some students were moving too rapidly while others took their time. Some focused on a specific loop and tried to find that loop. They were able to differentiate between the various loops in the model and their relationship to other loops. Therefore the main orientation guide or aid used was the ability to focus on one specific portion of the model and its relationship to the entire model. As such they used an “anchor” to orient the model so that they could achieve the orientation they wanted. Other students reported that they were relating the view of the model to the resting position. The model had exactly 12 different resting positions, all of which were three-point resting positions, while the model had about 24 loops. Still more students used the loops as a visual anchor. They were able to differentiate between the various loops in the model and their relationship to other loops.

If we look at the variability in the students' performance versus the number of position attempts, we find that the variability of the average time to successful completion as measured by the standard deviation significantly decreased. During the first attempt the standard deviation value was 3:08 (96%) which reached 0:35 (55%) at the last attempt. This is further demonstrated by the distribution of the average

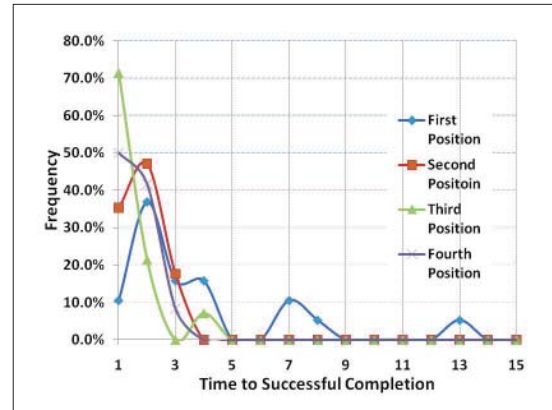


Figure 7: Distribution of Correct Timing overall and by test number (1 to 4). (Source: Authors).

time to completion as shown in figure 7 above. During the first attempt the success time was more evenly distributed when compared with the last trial. This fact along with the decrease standard deviation indicated a very interesting issue. As students become more familiar with the model they seem to improve their spatial understanding of the model and as such as they take less time to complete the exercise but even more importantly, their performance seems to converge, i.e. so that after more trials most students would achieve more or less the same success time. But is this true for all students?

Figure 8 shows the failure rate versus the average time to successful completion. What is evident here is that although the time to successful completion is significantly reduced, the failure rate increases. Although this could be partially attributed to the progressive timing strategy, it also indicates that some students are more able to visualize freeform spatially than others. In

essence the good get better and the bad get worse. This duality can be also explained by the fact that some students who initially fail end up giving up at the end.

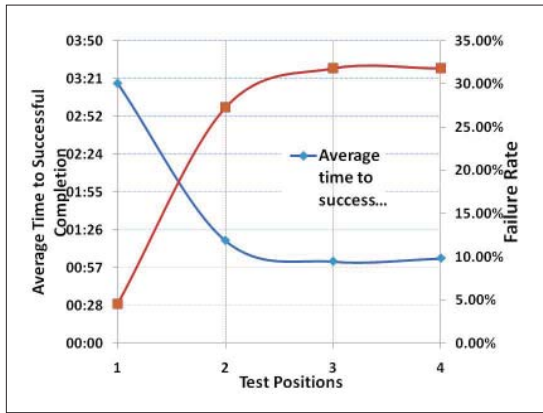


Figure 8: Number of manipulations to correct solution versus test number (1 to 4) as well as overall correct and wrong percentages. (Source: Authors).

One of the results that could analyze is the timing of each digital manipulation (rotations). Since a video of each trial for each student was recorded, it is easy to segment the time of the video to determine the number of the rotations made until success as well as the time between each of the rotation and the next. From these two values the following rates could be calculated:

Manipulation rate = Number of Manipulation / Total Success Time (in seconds) (1)

The manipulation rate represents the average speed at which the students make their manipulations and is important to assess how

students interact with the digital model. Students with a high manipulation rate tend to either have a high trial and error approach (if their time to successful completion is high) or tend to have a crisper visual understanding if their time to completion is relatively small. Figure 9 shows a recorded sequence of manipulations during three different trials.

Therefore, it is important to calculate another important measure which is the ratio of manipulation rate to total time as:

Ratio of (Manipulation rate) to total time = Manipulation rate / Time to successful Completion

This value is critical in differentiating between the students. Students with a high manipulation rate and long time to success are basically on a trial and error mode and have not definite strategy. On the other hands students with a low manipulation rate and a low time to successful completion are methodological and efficient in reaching the correct position. There are two other permutations, i.e. students with a high manipulation rate but and a large time to completion, which could indicate luck, or students with a low manipulation rate and a large time to completion, which could indicate a different visualization process where more time is taken to comprehend and synthesis the model in each move. It is important to note that another measure that could also be important is the Manipulation rate change (first derivative of the manipulation rate). This is important to study the behavior of the students with time as it gives an indication on the change in their manipulation rate and could be related to panic and failure.

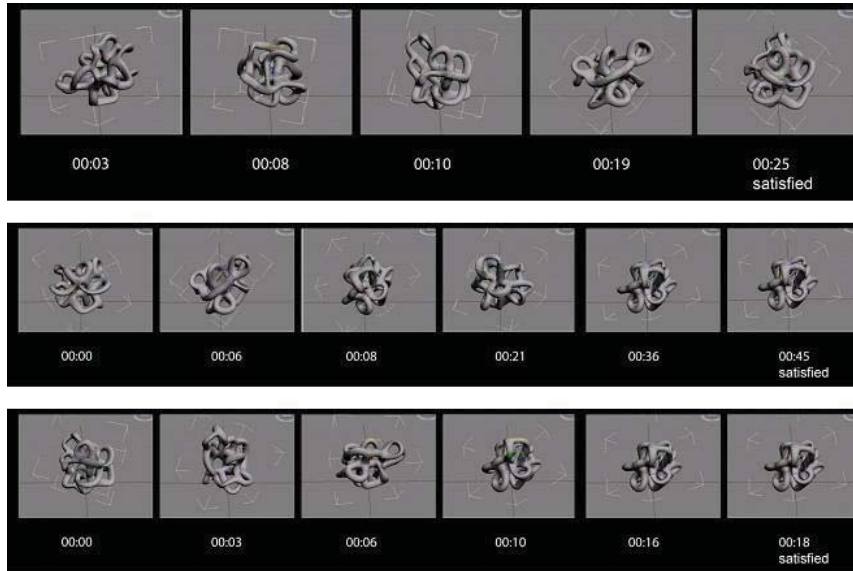


Figure 9: Recorded sequence of manipulations for three attempts. The last two are of the same position. (Source: Authors).

Conclusions and Recommendations for Future Work

This paper presented an experiment that could be used to investigate the processing and synthesis of visual information related to the new kinds of free form encountered in today's architecture. The effect of introducing computer-aided drafting and design tools to new students of architecture and the impact on the quality of their spatial thinking abilities is addressed. In particular this paper seeks to address whether the early introduction of computers enriches the ability of freshman and sophomore architecture students in terms of their ability to solve design problems requiring spatial arrangements, or handicaps it. Statistical

analysis of the outcomes was conducted and the results and conclusions of these experiments are presented in this paper.

Future extensions include assessing the performance of the students based on the courses they have taken or other background aspects. Also future extensions include studying the manipulation rate more accurately from video recordings and comparing two-way test where the users have to orient the physical object from the computer model as well as using augmented reality systems for the comparison. Furthermore, one other extension the authors are working on includes assessing the visualization skills and design skills. Experimental data from protocol studies of a number of student

designers solving similar design problems would be analyzed. The verbalization of the students during the design session was segmented and coded to produce linkographs. Entropy of the linkographs was calculated and analyzed in relation to the design outcomes. Previous research has indicated that design outcome is more related to the rate of change of entropy than to the entropy alone and consequently the change of entropy over time of these linkographs was focused on along with the various measures described above.

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