Assessing the Use of Contact and Non-Contact 3-Dimensional Digitization in Architectural Design Studios

Karim Hadjri
Department of Architectural Engineering, College of Engineering, UAE University, P.O. Box 17555, Al Ain, UAE.
http://www.engg.uaeu.ac.ae/khadjri/Homepage/

Abstract. *This paper presents a recent experience related to the use of 3D digitization and digital modelling. This was done with the aim to bridge the gap between physical and digital models produced by students as part of their design development exercise. The paper examines the use of 3D digitization in architectural design education, by using both contact and non-contact scanning technology. The main aim was to translate physical models using 3-Dimensional digitization in order to create accurate digital copies. Finally, the paper discusses the results of the use of 3D digitisation and the digital modelling process, and assesses the benefit of this technology within an educational setting.*

Keywords. *Digitization; laser scanning; studio; models; modelling.*

Introduction

Advance of technology in the areas of computing meant that architectural teaching processes needed to adapt to the increasing use of modern tools. However, in may schools of architecture, computer technology is not adequately integrated into the curriculum, because first, its introduction means that there is a need for an important change in the way architectural design is taught particularly in studios, and then, the learning outcomes of digital modelling are not known or understood.

Digital technology is allowing architectural students and architects to explore new areas without restraining their imagination in order to produce complex designs. The process by which this is achieved relies primarily on the use of “hybrid” design techniques; i.e. the making of scaled physical models, followed by 3-Dimensional digitization, and then 3D modelling. Traditionally, students produce very accurate scaled physical models, which are very effective design media, as part of their design development, either based on conceptual sketches or final drawings. This is because models are produced at different stages of the design, and can be sketch models or final models.

However, the design relationship between physical models and drawings sometimes lingers or looses its purpose, leaving students with two unconnected components. Usually, students struggle to recreate their designs digitally for primarily representational needs.

A concern arising from a weak Computer Aided Design - CAD - usage in teaching within the Department of Architectural Engineering, UAE University, has encouraged the author to assess the use of 3D digitization in architectural design studios. This is in order to explore ways in creating accurate architectural drawings and digital models from precise physical models. In addition, this experience aims to encourage the use of CAD as a design process by providing new ideas and opportunities rather than a mere representational media. (Manes, 2004)

Undergraduate students at the UAE University do not have a prior knowledge of CAD, and therefore struggle with simple 3D models. It was thus thought that if the physical models can be accurately recreated within a digital environment, then students can concentrate on exploring their design in virtual reality, instead of recreating them. This is why the author has attempted to create facsimile translations of physical models, to examine the ease by which 3D digitization technology can bridge the gap between physical and digital models. This aspect has also been pointed out by Schnabel et al. (2004) in their experiment on 3D Crossover.

The paper first briefly discusses current CAD applications within the architectural profession and educational institutions. It then, explains the architectural design process and introduces 3D digitization, both non-contact and contact. Finally, the educational challenges facing CAD applications and the viability of 3D digitisation in particular are reviewed. The paper explores physical representation, shape grabbing and digital representation and modification, but does not deal with rapid prototyping as explored by Schnabel et al. (2004) and Tamke (2005). This is because the main concern of the study was to effectively translate the analogue design to a digital environment for 3D visualization, design improvement, and representation.

CAD in Architectural Practice and Education

Computer Aided Design - CAD made its appearance a few decades ago thanks to the aerospace and car industry. Recently, there was a proliferation of CAD package providers, which made CAD systems widespread and easily accessible. Nowadays, digital technology is allowing designers to explore new architectural design processes given its ease of use, accuracy and affordability. The introduction of digital tools in the design and construction of buildings has generated mixed feelings amongst designers and scholars alike.

Architectural Practice

Steele (2001) argues that computers have brought about a technological revolution to architecture, but at the same time they have created strong divisions amongst architects and scholars, primarily due to the fact that there is increasing concern that CAD is affecting designers' identities and the expression of their creative work. In addition, some architects have revolutionized the design process by letting the computers lead the way, particularly when it comes to resolving complicated geometries.

CAD has been used primarily as a tool to enhance design by producing graphically defined concepts, and working drawings. At the same time, architects rely on free-hand sketches and physical cardboard models as important conventional tools that are combined with digital ones during their design process (Szalapaj and Chang, 1999). Although many architectural design offices have used CAD as a drafting tool during much of the 1980's, this did not generate a new architectural language. In fact, it was during the 1990's that

CAD finally started to become an important design tool thanks to architects such as Frank Gehry. Nowadays, architects are using a combination of physical and digital models to develop their design and present their work to clients. (Schnabel et al., 2004:477)

Frank Gehry used CATIA software for the first time in order to produce a smooth and well dimensioned steel structure part of his fish-shaped pavilion for Barcelona (www.ArcSpace.com: 2000a). Peter Eisenman also used computers to design the Aronoff Centre for Design and Art by generating a series of tilted building forms. These two architects had opened the way to a new architecture that was born as a result of the interaction between the architect and the digital media (Jencks 2002: 211; Van Bruggen and Gehry, 1998). He digitises large physical models using mechanical tracking devices, and feeds them into CATIA for analysis and production of working drawings (www.ArcSpace.com: 2000b). This is further illustrated by the fact that his physical models are constantly validated or altered by computer analysis. He does not just use them as a means that enables the design and manufacture of very complex building components. Furthermore, CATIA allowed Gehry to produce detailed drawings that enabled the production of interior steel elements and limestone with minimum wastage. It also allowed the design team to carry out changes and evaluate them immediately in terms of feasibility and costing. The design and construction of the Guggenheim museum in Bilbao demonstrated that the use of CAD has created a new paradigm that "is credible at both the sensual and economic levels". (Jencks, 2002: 251)

Architectural Education

It appears that the use of CAD applications in architectural education had a similar pattern to the one the industry has experienced. That is of being used either as a means to assist the design process, or as an integral part of this one. There is no doubt that most recent graduates are proficient in the use of CAD packages, therefore creating a serious gap between themselves and their predecessors. At the same time, architectural education has failed to produce graduates that are capable of handling practical office matters or even construction problems in a conventional manner. (Steele, 2001: 208)

Worldwide, many schools have adapted their curriculum to include CAD courses, Digital Design Studio and mandatory practical training or year out in practice such as in the United Kingdom and Ireland (Kalisperis and Pehlivanidou-Liakata, 1998; Levine and Wake, 2000). The architectural design process generally follows a methodological approach, and as a result, a variety of teaching means are normally used including model making and computer modelling (Norman, 1998). Students use physical models to express their design intentions, and as communication tools representing form (Kvan and Thilakaratne, 2003:6). Furthermore, architecture students are encouraged to use CAD programs to study and represent their work (Kvan, Wong, and Vera, 2003: 123). The success of this endeavour varies greatly from one place to the other largely due to the availability of advanced CAD facilities, and faculty and students' interest in the field. (Schnabel et al., 2004)

At the United Arab Emirates University, Department of Architectural Engineering, a new course that focuses on the introduction of 3D Digitisation into the design process was introduced in 2001. This was a serious pedagogical challenge in CAD and studio teaching given that CAD had so far been used to complement conventionally produced design projects. In fact, most physical models produced by students display more architectural qualities than the 3D computer models included in the final design submissions. In addition, even with the help of CAD, students seem unaware about the complexity and character of their design problems and how they should be resolved. (Koutamanis, 1998)

Three-Dimensional digitization is helpful in ob-

Figure 1. MicroScribe 3D Digitizer from Immersion

Figure 2. MicroScribe Digitiser, its accessories and the laptop

taining a surface model that will enable digital visualization. This is because it is possible nowadays to develop architecture “entirely on the basis of its surfaceness”. This is why there is a proliferation of expressive skins as architectural forms of extraordinary buildings. However, at some stage architects need to translate their “gravity-less” forms into structural systems and buildable architecture (Klinger, 2001: 242). In fact, this is the main concern of the experience presented in this paper.

Three-Dimensional Digitization

Three-Dimensional Digitization is a process that captures the data with a 3D digitizer such as a mechanical tracking device or laser scanning. However, in order to achieve this, there is a need for an accurate physical model.

There is a wide variety of 3D digitisers that range from mechanical tracking devices to laser scanners. Any physical model at a given design stage can be digitised for further development. For the purpose of the new CAD course, developed in 2001, a number of digitisers were reviewed with the aim to select an affordable and useful solution. The mechanical tracking device called MicroScribe was acquired, and later introduced to the design process.

Contact Mechanical Tracking Technology

This uses a mechanical arm that is compact and easy to use. This device digitises contours of physical models using software such as Inscribe to process the data. The 3D computer model can then be transferred to a CAD application such as 3D Studio Max, Form Z or AutoCAD for further modelling. MicroScribe 3D is a tool to measure the location of points in 3-dimensions in space, or on the surface of an object. This equipment tracks the location of the hand-held probe tip. It is a precision mechanical arm with high-tech processor and censors. This equipment is connected to a host computer, and uses a software application interface. (Figures. 1 & 2)

Before digitizing the physical model, a grid or profile curves are drawn onto the surface. This grid represents the mesh forming the surface of the physical model. The grid is used as a 3D reference for the digitisation process. Three-Dimensional Polylines are drawn following the mesh marked on the model. The grid should be accurate and following a logical pattern. Curved lines should have a dense grid to enable an accurate digitisation, and polygons can be digitised using only their corners. As a result a simple mesh is generated, which later is turned into a shaded surface model. Additional profile curves can also be defined on the surface characteristics.

Once the digitization process is complete a 3D model is produced which requires considerable editing. This is due to the fact that mechanical tracking device which has an accuracy of 0.38mm duplicates points if one digitises the same point more than once. These points need to be merged in 3D space. In addition, planes should be smoothed out to match the levels shown on the physical model, particularly the horizontal and vertical lines. This process proved to be a tedious one that students were not able to successfully overcome due to their limited 3D modelling knowledge. This knowledge should be improved to allow students to answer two critical questions: a) 3D modelling of point clouds and surfaces; and b) design analysis and development using digital models.

Non-contact 3D digitization i.e. Laser scanning technology was also tested to assess its suitability, and to establish whether it can capture accurate data from physical models, and whether is can alleviate the amount of 3D modelling involved in editing the point clouds and surfaces. This time the author decided to initially carry out a research project to test the suitability of laser scanning before introducing it to the design studio. The research aimed at establishing whether physical models can be accurately and quickly translated digitally through the use of laser scanning, and whether the 3D modelling process is simpler and quicker than mechanical tracking.

Non-Contact Digitization Technology: Laser Scanning

The development in non-contact recording technology and particularly laser scanning, has enabled professional in many expert fields such as engineering and heritage conservation to accurately document and reproduce reality based models. Advantages of laser scanning are the quick collection of a large number of 3D surface points. It is highly productive and can result in an overwhelming amount of information which needs to be processed in 3D software (McCallum et al., 1998). Thus given that the previous experience of using a 3D digitizer has proved complicated and time consuming and the accuracy is a problem, it is intended to test laser scanning in order to assess its effectiveness within an educational setting.

Three accurate physical models were produced; two solid models made of two different materials, and one using card board and foam. The first model made of wood is based on the London Swiss Re. office tower designed by Norman Foster. The second sketch model was constructed using strong 5mm thick white foam with paper coating. The third model was a simple small sketch model made using solid wood composite. (Figure 3)

A Cyrax HDS2500 scanner system by Leica Geosystems was used. The components of this system include the Laser Scanner, tripod, battery, targets and a laptop computer. In addition, four spherical targets were used for registration purposes. A digital camera was used for capturing the scanning region. (Figure 4)

The scanner software Cyclone 5.1.1 was used for controlling the scanner, and to view and manipulate the 3D data. It is a 3D point cloud processing software; the software interface for the HDS laser scanner series. It is also a tool that aligns point clouds captured from the different scanning positions. It has the ability to align overlapping areas of point clouds even without the use of targets. Captured data can be modelled in this software for export to CAD packages. Editing point clouds in any other CAD software would be extremely complex and time consuming.

The Cyrax HDS2500 Laser Scanner was set-up at four selected positions and was manually pointed to the direction of the required scans. Targets were then positioned within the FOV (Field of View) of the scanner just below the model/tripod. The noise within the scanned point clouds were removed either manually, by Intensity or by trimming edges. The different scans were joined together to form a true 3D representation by matching up the name IDs of the scanned targets. The scanned

Figure 3. The three physical models.

point clouds were then directly transferred to the connected laptop and modelled using basic Cyclone modelling tools and later on exported to MicroStation for further modelling.

Actual scanning times took approximately an average of two hours per model, with four scans/ positions approximately 30 minutes per scan per model. The laser scanning process resulted in the capture of dense point clouds for the three models as follows: Model 1 = 2,684,960 points; Model 2 = 2,956,245 points; Model 3 = 3,725,509 points.

Models 2 and 3 proved to be more time consuming in terms of creating an accurate as-built models from their point cloud images. Geometric objects such as lines and shapes needed to be physically drawn into the point cloud images. Unnecessary point clouds or noises partly due to surface reflectivity, range and scale were deleted. It was difficult at times to identify and determine the edges of objects in order to fit and draw the lines or shapes of the point cloud data because of the scale of the models. In addition, true translation of physical objects is almost impossible as reflections and occlusions create errors (Figure 5). (Schnabel et al, 2004:479)

The 3D modelling of the scanned data took

Figure 4. The Hardware and scanning process
1. The Hardware: laser scanner & laptop computer
2. Set up for the 4 spherical targets
3. Scanning of model 1.

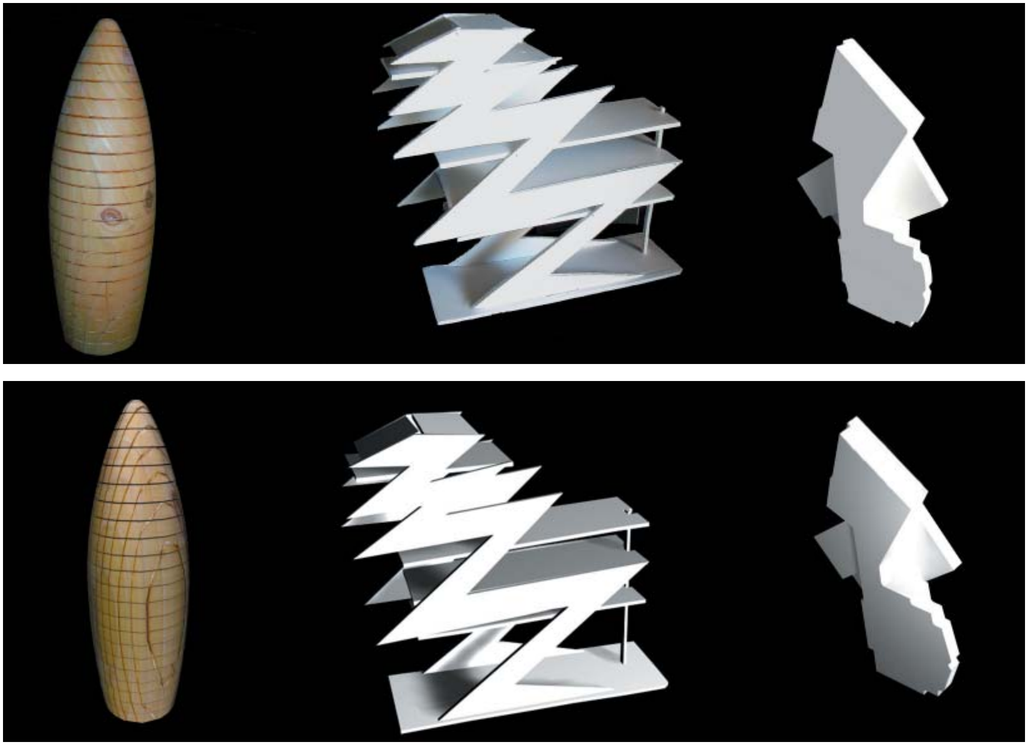

Figure 5. Comparison of 3D models

Physical models
Digital models

approximately six times longer than the scanning process. The 3D modelling process also comes with its complications and problems associated with the software or the level of detail required. Depending on the complexity of the scanned object, 3D modelling can be time-consuming. The fact that a large amount of point clouds are generated in a few hours, offers many opportunities for 3D modelling. This is why this technology is an extraordinary tool that can speed the design process and allow architects to express their ideas efficiently, and explore them within a digital environment.

Lessons learnt from these teaching and research experiments would improve the form finding and physical modelling through the use of laser scanning-friendly materials that will minimize errors. The scale of the model is also an important variable, as larger models yield fewer errors. A next step would be to let students use this technology and explore design limitations by moving back and forth from analogue to digital. Another research direction would be to attempt the production of architectural drawings from surface models produced by the scanning process, using Parametric Building Modelers such as Revit or ArchiCAD.

Conclusion

This paper presented a teaching and research experience related to the use of 3D digitization in architecture. The principal aim was to improve the design process by bridging the gap between physical and digital models. The reason behind this is that students generally produce accurate physical models, but are not able to recreate them digitally with the same precision. Knowing that the advantages of CAD applications in architecture vary from the speed and accuracy of production of technical drawings to Virtual Reality, their use and application have been diverse. While some architects use them to merely produce technical drawings, others rely heavily on their use in order to create buildings that are very difficult if not impossible to develop manually. At the same time, most architects use physical models as part of their design process. Those who utilise them exclusively resort to 3D digitization in order to develop the design, resolve structural problems and produce working drawings. Three-Dimensional Digitization allows the production of accurate digital copies of physical models. It is a very useful tool that helps recreate complex physical models.

Given that there is a widening gap between physical models and their digital counterparts, the experience presented here aims at minimizing a noticeable shortcoming in the teaching of architectural design. Students should be able to produce complex buildings and easily display them using accurate physical models. Then, they can digitise them in order to develop the design further by producing digital models, which later can be used to build accurate final physical models using 3D printers, CNC or laser cutters.

The product of mechanical tracking requires considerable editing, which is time-consuming and necessitates expert knowledge in 3D modelling. Laser scanning process, on the other hand, is simple, fast and very accurate. This in fact is easier that with contact digitizer due to the development of 3D editing software such as Cyclone. This software has enabled to quickly edit the captured point clouds.

From the architectural design point of view, this technology is an extraordinary tool that can speed up the design process and allow architectural students to efficiently express their design ideas, and visualize them very quickly. The success of contact 3D digitization relied heavily on the 3D modelling expertise of students. This is because 3D modelling is more problematic than the actual digitization process. This is due to the fact that knowledge of CAD applications is up to the students and their interest in the field, as it is not properly addressed by the curriculum.

The next stage would be to introduce this technology to the design process, and to involve students in the physical modelling, scanning and digital modelling. Possible applications of this technology could incorporate 3D crossovers, moving back and forth between the physical and digital to explore the design limits. In addition, the possibility of generating architectural drawings from the digitized models is an attractive way forward. VR applications can also be explored further as this can greatly enhance the design proposals. (Schnabel et al, 2004)

Acknowledgements

The author wishes to thank the Research Affairs at the UAE University for their financial support of research grant no. 01-03-7-11/04 in 2004, and the UAE University Academic Affairs Department (DVCAA) for supporting the development of the CAD course and for purchasing the digitizer in 2001.

References

ArcSpace.com: 2000a, Frank O. Gehry, The Architect's Studio: Vila Olimpica Fish Sculpture. http://www.arcspace.com/gehry_new/.

ArcSpace.com: 2000b, Frank O. Gehry, The Architect's Studio: Guggenheim Museum Bilbao. CATIA Computer Program. http://www.arcspace.com/gehry_new/catia/catia.htm/.

Jencks, C.: 2002, The New Paradigm in Architecture: The Language of Post-Modernism. Yale University Press, New Haven.

Kalisperis, L.N. & Pehlivanidou-Liakata, A.: 1998, Architectural Design Studio: Digital and Traditional, EAAE/eCAADe Computers in Design Studio Teaching, International Workshop Proceedings / ISBN 09523687-7-3, Anne-Catrin Schultz (ed), Leuven (Belgium) 13-14 November, pp. 73-81.

Klinger, K.R.: 2001, Making Digital Architecture: Historical, Formal, and Structural Implications of Computer Controlled Fabrication and Expressive Form. eCAADe: Architectural Information Management, Helsinki, Finland, 29-31 August, pp. 239-244.

Koutamanis, A.: 1998, Designing with the Computer: the Influence of Design Practice and Research, EAAE/eCAADe Computers in Design Studio Teaching, International Workshop Proceedings / ISBN 09523687-7-3, Anne-Catrin Schultz (ed), Leuven (Belgium) 13-14 November, pp. 91-97.

Kvan, T. & Thilakaratne, R.: 2003, Models in the design conversation: Architecture vs. Engineering, in Clare, N., Kaji-O'Grady S., and Wollan S. eds., Design + Research: Project Based Research in Architecture, The Association of Architecture Schools of Australasia, Melbourne.

Kvan, T., Wong, J.T.H. & Vera A.H.: 2003, The contribution of structural activities to successful design. International Journal of Computer Applications in technology, 16 (2/3), pp. 122-126.

Levine, S.L. & Wake, W.K.: 2000, Hybrid Teaching: Design Studios in Virtual Space, Paper presented to National Conference on Liberal Arts and the Education of Artists, SVA, New York, 20 October.

Manes, S.: 2004, Architectural Representation Software: a Design Tool, International Journal of Architectural Computing, 2 (03), September, pp. 403-422.

McCallum, B.C. et al; 1998, "A feasibility study of hand-held laser surface scanning". In Pairman, D. (editor) Image & Vision Computing, New Zealand, Lower Hutt, August, pp. 103-108.

Norman, R.:1998, Teaching Computation for Design, EAAE/eCAADe Computers in Design Studio Teaching, International Workshop Proceedings / ISBN 09523687-7-3, Anne-Catrin Schultz (ed), Leuven (Belgium) 13-14 November, pp. 115-122.

Shnabel, M.A. et al: 2004, 3D Crossover: exploring objects digitalise. International Journal of Architectural Computing, MultiScience, 2 (4), ISSN 14780771, pp. 475-490.

Steele, J.: 2001, Architecture and Computers: action and reaction in the digital design revolution. Watson-Guptill Publications, New York.

Szalapaj, P.J., & Chang, D.C., 1999. "Computer Architectural Presentation: From Physical Models in Space to Virtual Models in Cyberspace", International Journal of Design Sciences and Technology, 7 (1), pp. 41-54, Zreik, K., Vasquez, G. and Branki, C. (eds.), Paris, France, EuropIA productions, March.

Tamke, M.: 2005, Crossing the Media: An Experiment in the Digital Analogue Borderland. Proceedings of the Tenth Conference on Computer-Aided-Architectural Design Research in Asia (CAADRIA), Anand Bhatt (ed.), 28-30 April, New Delhi, India, pp. 364-374.

Van Bruggen C. & Gehry F.: 1998, Frank O. Gehry: Guggenheim Museum Bilbao. New York: Guggenheim Museum Publications.