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Towards a Pedagogy of Comparative Visualization in 3D Design Disciplines

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Spatial visualization and interpretation are important skills for designers. However, these skills generally require significant experiential development over the course of years. Visualizations allow the human brain to convey complex spatial concepts in intuitive, navigable and manipulable forms improving learner outcomes and perceptions. But often these visualizations are studied as single modality solutions. Dual modality and multimedia presentation studies show positive improvements in learner outcomes but dual modality is often difficult to compare. This paper presents ongoing research in the use of comparative multimodal visualizations produced with emerging technology solutions in 3D Design classrooms. Presented are previous findings from multimedia design and a methodology to widen the scope of study. The context for this study is a university first year undergraduate course in architectural design. The presupposed outcome is that students become adept at interpretation and mental conversion at a rate greater than they would through more traditional curricular means.

Keywords: Visualization; dual modality; 3D printing; virtual reality; multimedia; architecture;

Introduction

Visualizations and emerging technologies such as 3D printing and virtual reality are providing transformative change to education (Klerkx, Verbert & Duval, 2014). This is evident through technology enhanced teaching and learning (Keppell, Suddaby & Hard, 2011) and increased awareness (Johnson, et al., 2015a) and use (Johnson, et al., 2015b) of emerging media technology in higher education. Although transformative, technology should not diminish the foundational propositions in teaching and learning that, pedagogy is foremost, learning is the construction of knowledge, and collaboration is necessary to derive learning outcomes (Fowler, 2015; Ocepek et al., 2013). Learning is considered to be an active process influenced by prerequisites of the learner (Mayer 2005, 2008). The goal is to move a learner from shallow to deep learning through internal motivation with an intention to understand and environment(s) where students develop a strong personal interest through well-formed learning design.

Visualization is the representation of abstract information and creation of approaches for conveying concepts in intuitive, navigable and manipulable forms including images, videos, virtual environments and physical representations (Höffler, 2010). In the context of this study, that is, 3D modelling, spatial visualization and interpretation are undoubtedly important skills for novice designers to develop (Wu & Chiang, 2013). These skills are involved in visualizing shapes, rotation of objects, and how pieces of a given design solution fit together. The ability to quickly, creatively and effectively interpret 3D spaces and forms from 2D drawings and the inverse, to reduce 3D ideas to 2D representations for communication purposes, is generally regarded as a hallmark of the profession. However, these skills generally require significant experiential development over the course of years and while experienced designers are adept at performing these translations there exists a communication barrier from instructor to learner due to this skills gap.

Prior research in visualization has revealed strengths and weaknesses in the impact of any single modality on learning, and those learners themselves have different styles, needs and capabilities (Fowler, 2015; Höffler, 2010; Klerkx, Verbert & Duval, 2014; Mayer 2005, 2008; Ocepek et al., 2013). The use of multimedia visualizations and multiple modalities as positive learning design support tools are well documented and accepted (Moreno & Mayer, 2007). This research is therefore, not seeking single modality solutions but rather a systematic approach to multimodal modality and interactive presentation and instructions for curriculum designers and learners in courses that rely on visualizations and manipulations. The fundamental question is not whether technology, simulation or

visualization affects learning but how to guide the use of comparative multimodal visualization technology through, media affordances, lesson sequencing, learner perceptions and reflection to inform effective instruction and learning. This paper presents ongoing work on the effect and use of comparative visualization in the teaching and learning of 3d modelling design. Presented is a summary of the author's previous pilot study (Birt & Hovorka, 2014) in the multimedia design discipline and methods to widen the scope of study and subsequent pedagogical approach to transition across disciplines to architectural design.

Comparative visualization in multimedia design

Previous work of the authors (Birt & Hovorka, 2014) explored a pilot study examining the effect of mixed media visualization pedagogy using 3D printing, 3D virtual reality and traditional 2D views on learning outcomes in multimedia 3d modelling design. The learning objectives and resulting objects and their use in the classroom afforded learner centered active engagement through physical and virtual interaction with the visualization technologies. Research measures from each of the weekly learning objectives were achieved through coding and analysis of learner blogs conducted during the 12 week semester. Students were asked to engage in deeper learning by answering questions related to the weekly learning objective and technology visualizations. This included questions on: engagement; cognitive memory; visualization advantages/limitations; contrast between visualization media; how each technology would assist in demonstration of the learning objective to a team of designers; and communication of the learning objective between themselves and the instructor. The direct and reflective comparison between technologies revealed a strong interaction among them for learning. Each visualization technology had positive, negative and mixed perceptions when it came to accessibility; usability; manipulability; navigability; visibility; communication; and creativity. With 3D printing offering positives in haptic feedback and connection between the virtual and physical environment; virtual reality offering real-time external and internal interaction, object scope and scale, improved spatial awareness and defect discovery; and traditional 2D offering high accessibility, ease of use and rapid versioning. The comparisons between delivery modes (visualization technologies) provided much more than different versions of the same material. The engagement with each technology required reinterpretation of the principles upon which the lesson was focused. This provided students a way to "reframe" their own understanding and to "fill in the gaps" they observed using other media. It was suggested that this is particularly applicable to foundational principles where a deep understanding and ability to understand the principle in different contexts is important.

Project rationale

In 3D architectural design as in 3D multimedia design, as spatial and geometric ideas become increasingly complex the industry standard 2D representations tend to convey less information about a design and how it is to be interpreted. Figure 1 illustrates this by showing: (a) 2d orthographic elevation drawing of a geometrically complex structure, (b) virtual 3D model perspective and, (c) the physical building.

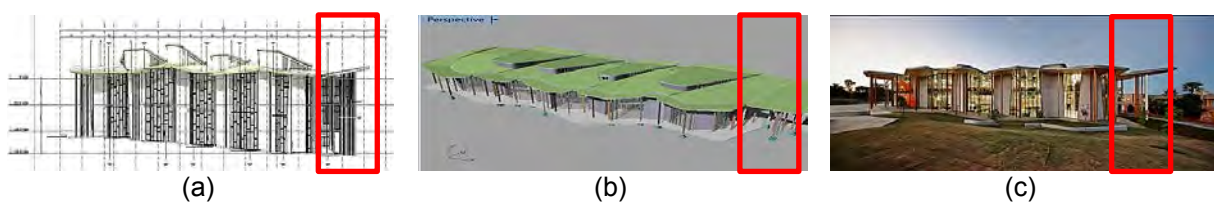


Figure 1: A geometrically complex structure shown in 2D, virtual 3D and physical 3D

While the 2D representation is useful in showing a simplified general arrangement of the building elements, many 2D drawings are required to fully illustrate the complexities and form of the design. In particular the region marked in Figure 1 (a) is not readily discernable from this projected vantage point as can be seen in Figure 1 (c). The virtual 3d model, while it serves to inform a more complete view of the tectonics and geometric characteristics, contains little to no data about physical assembly, nor does it facilitate a piecemeal selection of information about the structure which is the goal of the 2D projections. The physical building shown in Figure 1 (c) provides haptic feedback and navigation but lacks internal transition within the geometry and ways to view the structure in its entirety. These differences in utility and comprehensibility therefore necessitate the need for trainee designers to

develop the skills to quickly and effortlessly switch back and forth between various media both cognitively and physically.

Visualizations can assist in teaching, learning and skills acquisition because the human brain is wired to 'see' and comprehend relationships between images faster and more efficiently than text or numbers (Höffler, 2010). Additionally, visualizations allow people to move between concrete reality, which means objects they can see and touch, to ideas and creations of objects and solutions that do not exist yet. Visualisation can enhance students' conceptualisation, manipulation, application and retention of knowledge and skills provided they follow specific learning design (Mayer 2005, 2008; Moreno & Mayer, 2007). In part, visualizations must prime the learner's perception - *why do learners care?*, draw on prior knowledge, avoid working memory overload through specific learning objectives, provide multiple presentation modalities, move learners from shallow to deeper learning and allow learners the opportunity to apply and build their own mental models (Hwang & Hu, 2013). Meta-analytic studies of 2D and 3D visualization show positive improvements in learning outcomes among low and high spatial learners (Höffler, 2010). However, there are many challenges to visualizing learning objectives including choosing between 2D and 3D interfaces, physical or virtual navigation, interaction methods, selecting an appropriate level of detail and availability of the visualization media.

To assist with these challenges, technologies such as 3D modelling, game engines, 3D printing and VR are becoming available for use commercially and thus able to be incorporated into the classroom. The 2015 NMC Higher Education Horizon Report (Johnson, et al., 2015a) and Technology Outlook for Australian Tertiary Education Report (Johnson, et al., 2015b) specifically highlight these technologies as key educational technologies. VR technologies are mature, but the uptake in education has been hindered by cost, expertise and capability. This is now changing with the recent wave of low cost immersive 3D VR technology by vendors such as Oculus Rift™ (<http://www.oculusvr.com/>) and powerful interactive game engines such as Unity3D™ (<http://unity3d.com/>). However, there still remains an innate lack of physical haptic feedback that one gains through physical media manipulation (Fowler, 2015). In this way, 3D printing offers a way to bridge the gap between the virtual and the real. 3D printing has seen an explosion in the past five years due to low cost fused deposition modeling (FDM) systems by makers such as MakerBot™ (<http://www.makerbot.com/>). 3D printing at its basic level uses an additive manufacturing process to build objects up in layers using plastic polymer. Although the process is slow, 3D printing creates direct links between a virtual 3D based model and the formation of an accurate, scaled, physical representation from that model (Loy, 2014). This direct linking of object making to computer modeling changes the relationship of the learner to the making of the object and subsequent use, that is, it creates and enables a haptic feedback loop for learners.

Project Methodology: Translating to architectural design

The purpose of this study is to translate the previous findings and pedagogy of comparative visualization use in the classroom to additional disciplines in the hopes to (i) gain insight into spatial visualization skills in trainee students and (ii) form a body of knowledge to allow for future expansion to new skills and disciplines. The selected discipline for this proposed pilot study is in architectural design. This discipline was selected primarily because it is an accredited design discipline with coinciding learning outcomes with the first study in multimedia design. In line with the original pilot study the first research question is: RQ1: "How do learners perceive the comparative capabilities of visualization media to support learning?" and the second research question is: RQ2: "Do learner's preferences for visualization technologies change with task or over time?" To answer these questions students will be given a series of eight dual coded comparative weekly media learning objectives highlighted in Table 1.

Table 1: 3D modelling learning objectives and applied media conditions in architectural design

Learning Objective	Applied Media		
	2D	VR	Phys
Introduce the basic theoretical paradigms of 3d modelling	Y	Y	Y
Demonstrate applied knowledge of 3d primitive construction and manipulation	Y		Y
Demonstrate applied knowledge of curves and NURBS surfaces	Y		Y
Demonstrate an understanding of 3d modelling as it relates to the human scale	Y	Y	

Demonstrate the ability to construct complex surfaces		Y	Y
Demonstrate an understanding of 3d modelling as it applies to architecture	Y		Y
Demonstrate the ability to manage complex scenes with a high number of models	Y		Y
Demonstrate applied knowledge of presenting a complex scene and ability to reflect and synthesize the course material	Y	Y	Y

It must be noted that although the word *Demonstrate* is used in Table 1, in the studied domain of architecture this refers to higher order skills of analyse, evaluate and create as highlighted by Blooms taxonomy and deeper learning. Through weekly learner blogs students will be asked a series of questions in line with the previous study and translation to deeper learning. The theme of the questions include: engagement; cognitive memory; visualization advantages/limitations; contrast between visualization media; how each technology would assist in demonstration of the learning objective to a team of designers; and communication of the learning objective between themselves and the instructor. These question themes and learning objectives have been formed in relation to the specific learning designs highlighted by Mayer (2005, 2008); Moreno & Mayer, (2007); Hwang & Hu, (2013) and others. The outcomes from the learner blogs will be analyzed using a thematic analysis through NVIVO™ (<http://www.qsrinternational.com>) and correlated against student outcomes. Over the course of the eight exercises students compare various forms of media including 2D, 3D print, built environments and 3D VR, culminating in comparison and *demonstration* (creation, evaluation and analysis) of all three. These exercises are intended to provide practical concept conveyance and higher order thinking. An illustrative example of the complex scene learning objective is provided in Figure 2. The scene represents an interactive VR visualization and simulated lighting cycle of a physical built environment on the learner's campus highlighting complex shapes, surfaces, lighting and human scale.

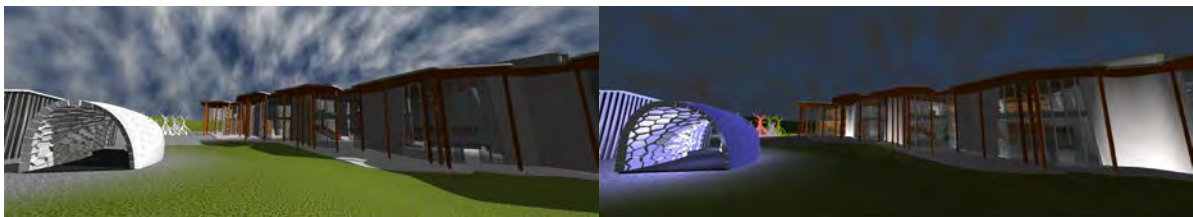


Figure 2: A geometrically complex scene in VR of a physical built environment on the learner's campus

Expected Outcomes and Future Project Direction

The presupposed outcome of this study is that students become adept at 3D interpretation and mental conversion between 3D and 2D at a rate greater than they would through more traditional curricular means. More specifically as highlighted in Birt & Hovorka (2014) it would indicate that students would initially prefer the higher dimensional media as a means of rationalization and exploration due to the ease and familiarity permitted by them, but by the end of the study the students would be more adept at interpreting the lower dimensional media and thus prefer them for their convenience and availability. A future outcome of this study is to gain insight into the effectiveness of wholly 3D and VR representations of the built environment that can potentially help move the design industry toward working in higher dimensions. Additionally, the outcomes from this study and the previous work will look to extend the pedagogy and design to new skills and disciplines framing a body knowledge to develop a guideline of comparative visualization use in the classroom.

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