Augmented Reality in architectural studio learning:

How Augmented Reality can be used as an exploratory tool in the design learning journey

David Morton
Department of Architecture & the Built Environment, Northumbria University at Newcastle, Newcastle-upon-Tyne, England UK.
http://www.northumbria.ac.uk/sd/academic/ee/staff/davidmorton
david.e.morton@northumbria.ac.uk

The boundaries of augmented reality in the academic field are now being explored at an ever increasing level. In this paper we present the initial findings of an educational project focusing on the use of augmented reality in the design process of an architectural student. The study seeks to evaluate the use of AR as a tool in the design stages, allowing effective exploration of spatial qualities of design projects undertaken in the studio. The learning process is guided by the exploration and detection of a design idea in both form and function, with the virtual environment providing a dynamic environment (Mantovani, 2001). This is further reflected in the constructivist theory where the learning processes use conceptual models, which are used to create incremental stages that become the platform to attain the next [Winn, 1993]. The additional benefit of augmented reality within the learning journey is the ability of the students to visually explore the architectural forms they are creating in greater depth.

Keywords: *augmented reality, pedagogy, learning journey, exploration*

AIM

Research into the use of augmented reality in the learning environment is relatively emergent in the academic arena. However, the possibilities for exploration of spatial, geometric environments abound. As the pedagogical landscape is now changing in terms of cohort requirements, as a reflection of new societal goals, the pedagogy of 5 years ago has already begun to change. What is expected in today's pedagogic environment is now different, with leaner's requiring change and a deeper learning to their pedagogic journey.

In this paper we present the initial findings of an educational project focusing on the use of augmented reality in the design process of an architectural student. The study seeks to evaluate the use of AR as a tool in the design stages, allowing effective exploration of spatial qualities of design projects undertaken in the studio. The learning process is guided by the exploration and detection of a design idea in both form and function, with the virtual environment providing a dynamic environment (Man-

tovani, 2001). This is further reflected in the constructivist theory where the learning processes use conceptual models, which are used to create incremental stages that become the platform to attain the next [Winn, 1993]. The additional benefit of augmented reality within the learning journey is the ability of the students to visually explore the architectural forms they are creating in greater depth. Traditionally, drawings, sketches were transferred to the 3D format of models. This transfer has allowed the cohort to better understand and comprehend spatial and constructional issues with their designs in a more detailed and clearer manner than traditional learning, via drawings and models. The ability to move seamlessly from sketch idea to augmented model has emphasised a step change in the pedagogical landscape in the architectural studio. The interface of augmented reality allows for faster comprehension of design ideas, the visualisation allowing for intuitive and instructive learning to occur.

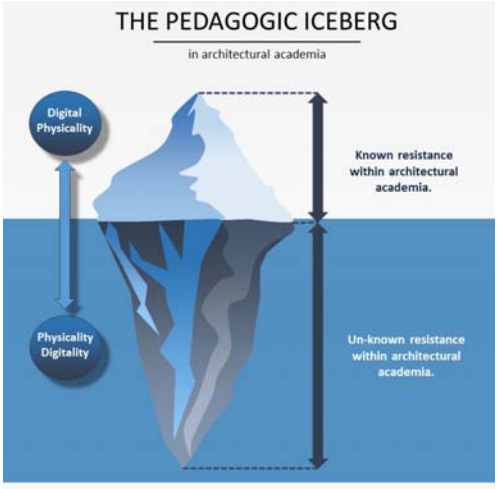

Figure 1
The Pedagogic Iceberg - The Known knows and unknown unknows.

Design thinking and the journey we take towards a solution takes what Cross. refers to as middle path and is primarily concerned with appropriateness, understood as that fragile quality which is achieved when the best of human intentions are realized within the constraints of reality (Cross, 2001). The current dichotomy emerging in studies on the use of visualisation in the design process would suggest there remains confusion as to whether design is thinking or doing? The study attempts to observe and correlate the learning 'loop' of thinking and doing, which forms a critical part of the self learning and reflective feedback that is fundamental to acquiring knowledge. The study assesses the potential, within the architectural studio, to combine thinking and doing into 'design thinking' where the augmented reality models are used to explore and raise questions, that the learning journey may never have anticipated, with the use of augmented reality. The emerging routes of learning and their occurrence in the learning journey are also noted and assessed in relation to the traditional studio based expectations of and the qualitative differences when choosing augmented reality as an exploration tool in the architectural studio environment.

What is Augmented Reality, what is virtual reality?

It is important for this study to ensure that these immersive realities are understood, both augmented reality (AR) and virtual reality (VR) are often taken as the same. Whilst both are considered immersive, it is only virtual reality that is deemed truly 'immersive' as it allows to user to only see and experience the virtual world, with no 'connection' to external stimulus. Whereas, augmented reality allows the user to experience both the 'altered world' and the existing real world environments simultaneously with one 'superimposed' over or within the other. The use of AR in teaching occurred more recently, in 2000, when Shelton and Hedley used the 'tool' of AR in the teaching of their undergraduate students. This teaching included simple rotation of images and shapes that represented the planets and their relationship to the sun. The teaching allowed for the images to be moved and experienced from many differing viewpoints almost simultaneously by the students. This used AR to allow for new levels of learning that were outside of those studied and formalised by

Schon (1983) and Bruner (1961). The learning experience was autodidatic, in that the student using AR learns about their design during their journey without the formal interaction of the studio tutor, in reality the student becomes 'self-taught'. The use of AR within the learning journey that occurs within an academic architectural studio yields a learning that has elements of autodidactism. Where the learning that occurs is self-directed and related towards informal learning and which occurs in a series of successive absorptive and contemplative occurrences. Mantovani (2001), stated that these successions within the learning journey occur through discovery via exploration in a natural manner as an apportion of the process of learning.

Re-abstraction and re-alignment: AR as the new convention for design process

There are few recent academic papers that have continued the exploration and study of creativity in the archietctural academic arena (Neely, D. 2008, - BIM 101 overview - 'From hand drawings to CAD and now BIM', Ambrose, M. A. 2012- 'Agent provocateur - BIM in the design studio', Ibrahim, et al 2010- 'Comparison of CAD and manual sketching tools for teaching architectural design'). The precursor to research into creativity and the creative process were the studies concluded by Finke, Ward and Smith (1992) posit the hypothesis that the creative process is one of a multiple stranded series of processes that together evolve towards a combined phase of 'creative insight and discovery'. Intriguingly these multiple occurrences converge only having moved through a distinct phase termed 'pre-inventive' where the 'structures' of the artefact are brought together from mental representations of the prior creative occurrences.

Interestingly Cross and Dorst (2011), concluded subsequently to Visser (1995), that the creative journey is also a series elements termed activities that also occur in succession and result in a 'novel event'. This novel event could be aligned with the notion of 'creative leap' or eureka moment, when the processes that have occurred prior to that moment allow an alignment or focus to the thought processes that enable the production of the 'artifact' or design solution. However, Cross (2001) and Dorst (2011) do not suggest that the processes or stages to arrive at the artefact have to be part of a cognitive model in order to materialise. In fact they concluded that such events can be random in nature or 'non-routine' and the occurrence of the artefact is merely one activity that is different to all others due to the emergence of a 'considerable or unanticipated' happening. This study uses the hypothesis of Visser (2004) who proposes that design activity is comprised of a series of procedural stages that conclude in the production of what he calls the 'creative artefact'. The use of AR can allow for enhanced reflection of their designs and the ability to create iterative steps that employ progressional advances of multiple layers that are fully implicit and part of the students learning journey.

THE PEDAGOGIC PUSH - PULL: AR INTEGRATION IN THE ARCHITECTURAL STUDIO

It is now understood in academia that the pace of technology in the learning environment is impacting of the differentiation between digital physicality and physical digitality. These previously separate domains are now becoming increasingly integrated and the clear lines between the two are now blurred. There is concern amongst many teaching in architectural studios within academia that this integration will bring with them a new era of exploration within studio design, that of synchronic exploration of building form using both traditional and increasingly digital methods, this goes against the long held traditional norm of non-digital methods of pedagogy in the studio environment.

What was once a dialogue that stemmed from pen to paper to thought and back to pen, in an ordered and responsive learning and design journey. The students within today's architectural studio can utilise the integrated and immersive approaches of Building Information Modelling (BIM) and augmented reality (AR). The student still 'models' their building, its form and spatial expression, however via digital modelling, an immersive exploration can be

experienced. One that allows the embedded data and information about space, structure and materials to be synchronically manipulated in a blended and deeper learning journey.

The augmented models that are used allow for the synergy of both physical and digital modelling and exploration to occur seamlessly. This readily accessible and seamless environment allows for a greater accuracy and finer levels of manipulation to be achieved. There is a new pedagogic classification occurring when we use BIM and AR modelling in architectural teaching, that of 'depth of learning'. The study indicated that when using the BIM model, the cohort were able to explore more 'what if's' in rapid succession which, inturn, enriched the final learning journey and its pedagogic outcomes. Using AR the learning was deeper still; the connection with the model was far more immediate, seeing the model in a real world setting seemed to communication between student to student or student to tutor dialogue (Clayton 2010, Dorst 2011). Both perception and interpretations of the models studied were richer in detail and created a new critique dynamic.

Modelling is a key tool in architectural studio teaching, using this method of exploration allows higher order cognitive skills to be used by the cohort, such as spatial, planning and relationship of form. Using AR to explore the model(s) allows for a critical synthesis of these cognitive skills, where interactions with the model create immediate design iterations that move the student forward through the design journey. Levels of detail can be explored simultaneously and in parallel. This studio process should be re-structured to allow for a greater transparency for the cohort to realise that the ability to explore, amend and reflect is a iterative loop that can exist at any point in the design journey. The academic studio should also empower their cohorts with 'tools' such as AR that allow for enhanced reflection of their designs and the ability to create iterative steps that employ progressional advances of multiple layers that are fully implicit and part of the students learning journey. "The discussions at the end of the course clearly indicated to me that the students now consider the development of programs as their own personal expression of an idea, that CAD systems could be used to investigate ideas and not only document deci¬sions already made. They began to understand the feedback their rules created and how it could be used to clarify concepts" (Krawczyk, 1998).

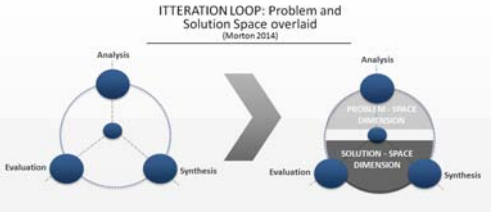

Figure 2
Evolution of the iterative 'loop' with problem and solution space within the iteration.

The base iterative 'loop' shown in Figure 2, has evolved, via the emergence of a digital domain in the studio, to include the concept of problem and solution space proposed by Maher (1996). Maher's concept suggested the idea of movement from problem space to solution space as the learning occurred. This study suggests that utilising AR allows the problem finding - problem solving phases of the design journey to be far more acquiescent, as the exploration of both scale, spatial and structure amongst many other design layers can be viewed and experienced with greater levels of detail at the identical point in time within the journey.

This plurality is conceived of a new construct represented a fundamentally altered medium from the tradi¬tional representation in contemporary practice of architecture. However, this altered approach brings with it many benefits and a richer appreciation of the very design be¬ing formulated within schools around the UK. If AR brings such benefits why is it not fully integrated into the architectural curriculum? As the architectural industry is now approaching full assimilation of design functions and seamless integration for those that use BIM and AR packages, why are we not educating our architectural graduates to stream into such working environments with seamless curricula? As with integration of previous technology in the academic studio, there is current con-

cern and general resistance that the rapidity of transformation in digitial technology will result in an increasing 'gap' between those who teach in the architectural academia and the mastery that such digitiality requires. In order to direct the cohorts towards a greater understanding of the capabilities propositioned by such technology it must first be embraced and embedded. This study demonstrated that the bottom up attitude of using AR and computers in the academic studio first reported by Martinez and Vigo in 1999, it still as challenging today, some 15 years later.

This paper will investigate the reasons behind the complications of AR implementation in curricula by using both an initial forming survey and then structured interviews of current graduates from the Department of Architecture and Built Environment, June 2014. The paper is structured as follows: first, we have an overview of technological change literature will be presented and will introduce the concept of AR in curricula; next, we will describe the how the data is collected and analysed in this study.; then we explain the results of this study; lastly we will conclude the findings.

METHODOLOGY

The ongoing research follows a heuristic approach to evaluation, which consists of an iterative process of analysis, design and re-test phases. This approach has been adopted for this research as there are no current guidelines as to how AR should be tested and what data should be achieved in both type and amount. The cohort were introduced to AR using basic, freely available software from AR Media. This approach was used as it allowed for rudimentary methods of interfacing with their building models. The data was then captured in two stages, seminar sessions were used to review and explore the building model via the use of AR, the findings made by the cohort and the dialogue of these sessions was captured and analysed. The same cohort were also asked to capture their learning journey, finding and how the model was navigated and explored. The study focuses on the use of augmented reality in a collaborative learning context. The studio format for learning architectural subjects within academia is a fundamental influence in the discipline. Cohorts learn both within lectures and also socially, whilst in the studio, by peer to peer learning and conversation and dialogue that become reflections which inturn are embedded into futher design work or learning. Such interactions have been historically studied in this genre by academics and theorists such as Dewy and Schon. This exploratory study has been carried out in a field of research that is still emergent. Although, in the last 3 years there is a notable increase in interest and a growth of research in the application of AR in the learning environment to enhance erudition and scholarship. Particular focus will be given to the use of augmented reality in architectural studio learning. The study is considered as an exploratory review and survey of architectural students currently studying at Northumbria University and completing their architectural design module - BE1341 Virtual Project. This module is studio based and contains a high level of technical challenges (such as continued resistance by the academic studio to digital explorative methods of design and learning by abstraction).

The specific objective of this study was to establish those challenges and the potential benefits of using augmented reality within the learning journey of the cohort studying this module. The study included a questionnaire to the 45 students studying the Virtual Project module. The final submitted number of questionnaires totalled 41. The survey contained 10 questions relating to the use of augmented reality and how this was used within the learning journey of the student(s). Three questions gathered information on the development of the design and what was learnt at key stage of its development using traditional methods and AR within the studio environment. The subsequent four questions related to the use of augmented reality, the software, it ease of use or adoption as part of the learning, exploratory process of the students journey through the project. The concluding questions related the use

and perceived benefits of augmented reality within this learning journey. Focusing on the proficiency of the students to visually explore the architectural forms they created as the output for the module. The questions were generated to allow for identification of the types of inferences that would best inform a process of change in the future pedagogic format of learning and delivery within the architectural studio.

The cohort has an average of 2-3 years' experience of the design process and have used various design software packages prior to commencing on this degree course. So far, the results have indicated some robust themes that occur across the data. Therefore, although the results are partial, they can inform future study in this area of pedagogy.

AUGMENTED REALITY: CATALYST FOR RETHINKING DESIGN EDUCATION

The study of design activity has grown progressively over the last 30 years. During this period a rather small number of studies have been undertaken. The early pedagogic studies of Bruner (1961) and Schon (1983) set the grounding for more digitally focused studies by Cross (2001), followed by Winn (1993) with a marked increase in studies and research by Ambrose (2009), Clayton (2010), Ozener (2010), Farias (2010) and more recently Decker (2013). These studies were often small in scale and remain untested, as their findings were not verified in repeat studies. AR allows the problem finding - problem solving phases of the design journey to be far more acquiescent, as the exploration of both scale, spatial and structure amongst many other design layers can be viewed and experienced with greater levels of detail at the identical point in time within the journey. Cross (1999), concluded that within design cognition there are distinct phases of 'finding' and 'solving'. These activities included significant problem structuring and problem solving (Cross, 1999) cycles. Cross formulated three cognitive phases from his early studies; (1) Formulation, (2) generation and (3) process. These phases allow for an identification of design as a process in the context of academia.

AUGMENTED REALITY AND ITS INTEGRATION: EXPLORING THE UNBUILT

The process being observed in this study is the process of design, the creativity that drives the progression and the activities that are involved. Creativity itself is often stated as an event of singular occurrence. However the 'creative leap' is often debated in academic theories and academic research as a manifestation of a series of smaller events that culminate in the 'leap'. This point in the learning journey is acknowledged as a significant observation point of the journey, where the idea becomes clear and better understood. Such activity is known as 'design cognition' with pioneering studies undertaken by Eastman (1969). The design output from the academic studio can take on many forms, varying at different stages of the learning journey.

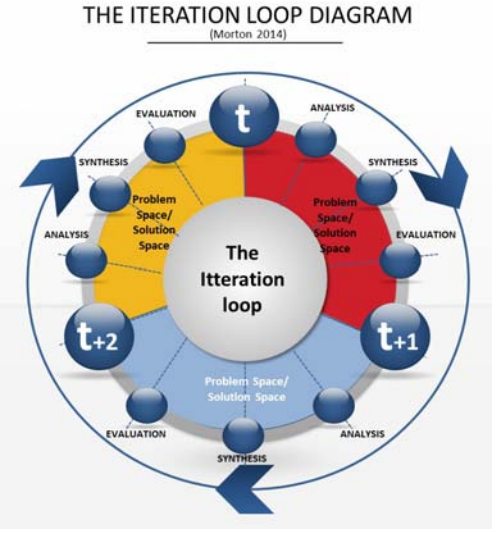

Figure 3
Mutliple Iterations occurring within learning journey evolution.

These variations are often due to a need to communicate rapidly and effectively which in turn allows for interaction from others (namely the tutor in this context) externalizing the thoughts of the architectural student. This need to switch from design journey to what is essentially 'presentation' of the idea(s)

is a quick side step, the question is, using AR, could this side step become a forward moving process. This is not to state that discussions with the tutor are not a forward movement in the design journey. Simply that, the need to 'produce' in order to communicate an evolution seems somewhat unnecessary. AR and other technology available to the cohorts of today's architectural academic studios have a chance to update this process.

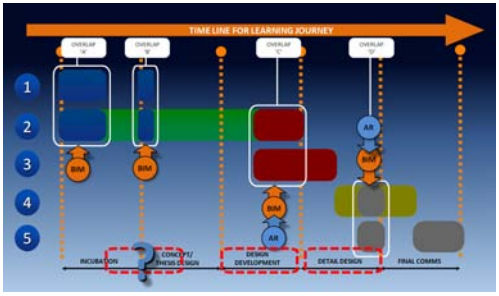

Figure 4
Occurance of AR in the learning Journey, overlaid onto the Schon's Design Process of Problem Setting and Problem Solving

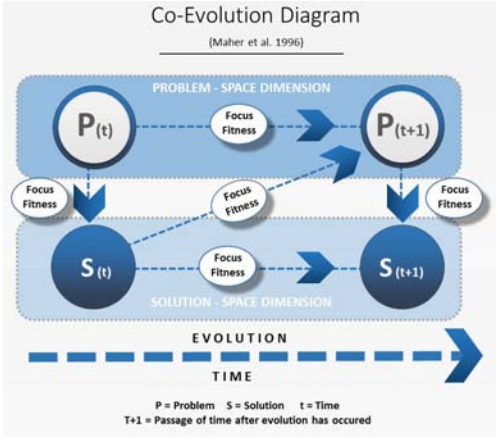

Figure 5
The Co-Evolution Diagram of Maher et al (1996) (Image: D.Morton)

FINDINGS FROM STUDY : CONJECTURES AND REFUTATIONS IN A DIGITAL CONTEXT

Finding 1: Developmental theory of cognition and the act of seeing moving seeing. The study demonstrated a pedagogic journey undertaken by the cohort using AR that reflects a problem finding - problem solving structure. With 73% of the cohort using AR in the exploration of their designs to formulate solutions for spatial or structural relationships.

The findings would suggest that the use of AR allowed these students to confront complex tasks within their design and manage the complexity by seeing the relationships of their intentions at both a macro and micro scale. The resultant design change could then be assessed and accepted or assessed and rejected, so the 'task' could be managed at the smaller scale, but with a clear understanding of what the implication of that would be for the overall scheme. The finding replicates the relationships found between talking and drawing in studies of architectural cohorts by Schon and Wiggins (2006). In this study the act of 'seeing - moving - seeing', is sublimated by AR into a series of small iteration cycles that contain the same analysis, synthesis and evaluation stages.

The cognitive steps taken in 58% of the cohort studied follow a linear progression similar to Piaget's constructing operational thinking findings (1979). However, although the progression is linear using AR, the progression is a series of parallel linear progressions. The student creates abstract concepts and articulated intuitive progressions from which they begin creating constructs that arch between these parallels. The learning route is not autonomous but in fact manifold in its pedagogic structure. The arches or leaps between the parallel learning seem to form the reflective abstraction. The leaps from linear routes create an extensive mapping of formalisation of conceptualisation and transformation of the design. Such constructs of abstraction and reconstructs can be found in studies of Piaget (1979). In these studies the journey of learning in also linear, however the journey is a series of successive stages, the findings of which have been critised for being resolute.

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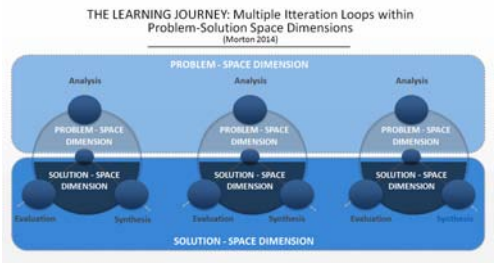

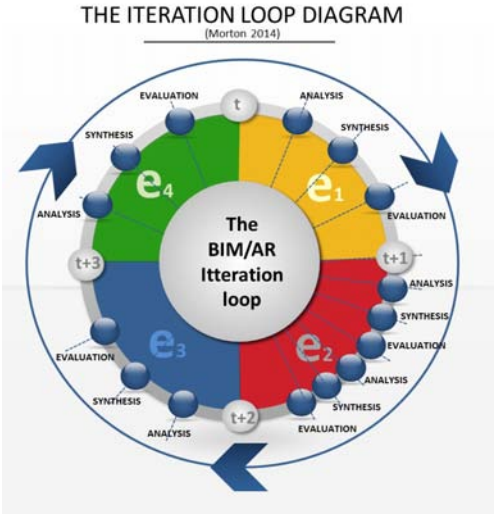

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Occurrence of Manifold Evolution Phases

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Finding 2: Parallel learning streams: Interactive cyclical learning journeys. The results suggest that as the design journey evolves there is a formation of concept(s). The formation of these concepts are generated from the interactive nature of exploration of the model in AR. The study findings indicate the process as being highly interactive, mirroring studies of Vygotsky (1978). The study indicated that 68% of the cohort confirmed that the process of using AR allowed their exploration to be a series of adaptive and evolutionary stages, as the 'what if's' were explored. A higher figure of 81% stated that their design journeys were dialectic in formation arriving at a final concept formation.

Figure 6
Mahers Concept of Problem- Solution Space, blended with the continuous overlay of AR: Creating a series of 'itteration loops' that becomes cycles of assimilation and accommodation.

Figure 7
The AR influenced Iteration Loop : Occurrence of Manifold Evolution Phases.

The interactive cycles indicated in the findings of this study show distinct alignment with Piaget's theory of cognitive development, when using AR in the design journey. Piaget's theory focused on two processes, which were titled 'assimilation' and 'accommodation'. Assimilation is a building element of learning. From a series of these 'blocks' we assemble our own unique and personal relationship to how we understand the world around us. These learning blocks are then used by us to add to and incorporate our understanding of the world and enhance our existing knowledge. These associative connections then build upon one another to deepen our knowledge base. The process of accommodation, according to Piaget, is the process by which the new experience or knowledge gained changes or replaces the existing in your schema. These two processes are organised in our knowledge as 'schemas'. These schemas can be thought of as sections in a library. The schemas allow us to readily access and categorise the knowledge acquired from assimilation and accommodation.

In the results of this study, 72% of the cohort agreed that use of the VR model allowed for better perception of the developing building. In particular, the spatial interrogation and structure were recognised in terms of their attributes. A room was no longer simply a space of three dimensions. These elements of the design were queried in terms of their location on plan, the relationship to section and how all of these constituents were recognised in terms of impact of the final design. During the exploration of the model in AR, the assimilation and accommodation processes are in continuous 'loop' as the design is created by abstraction. In the study the cohort, used the AR to test 'what if's' in a series of assimilation processes. Many of these did not result in overall amendments to their designs, but were part of the learning journey. The occasions where these tests of the design resulted in amended their design or part of the design, this is in effect modifying the schema of the model (in Piagets terminology) and from this the new information is created and added the overall knowledge of the model and the learning experience, accommodation took place. After 8 weeks of designing their projects for BE1341, the cohort showed no defined 'pattern' to the timing of accommodation in their learning journeys. However, their was a considerable increased in general accommodation in the earlier stages of 67% of the cohort in the study.

Finding 3: The act of abstraction and concept development. According to Arnheim (1998), the process of abstraction in the design journey in part of what is termed 'productive thinking'. He believed that the abstraction of a design is significant in understanding the underlying concepts that are within a form or object. The observations of this study indicate that as the cohort explored and moved around their designs in AR, the immersive environment allowed for informed levels of abstraction. These encompassed relationships of form and spatial qualities that could be readily experienced by the AR environment. The significance of these discoveries where that they indicated an assimilation underlying characteristics of the model elements being investigated. The unifying route of investigation parallels the idea of true abstraction in Arnheims 'productive thinking' theory.

Finding 4: The AR stages of design exploration: From metaphoric to metonymic.. The use of AR in the design journey allows, as discussed in previous findings of this study, for exploration by abstraction. The understanding of exploration in the metaphoric and metonymic forms have been observed and analysed for over 50 years. In 1968, Arnheim first considered the concept of visual reasoning in architectural design. Three decades later, in 1995 and 1999, Goldschmidt continued these observations into reasoning and visual relationships of design elements. More recently Oxman (2002) continued the enquiry into design discourse, with research indicating that domain knowledge can be employed in virtual design, within the architectural context of design. Oxman has established that digital media has made significant impact on design processes and meth-

ods of pedagogic discovery. Oxman's latest paper 'The Digital in Architecture' is the culmination of her research and applies new definitions to theoretical and methodological structures to the field of digital methods of design. The current proposition of her studies is the idea of morphogenesis. This incorporates both form finding and parametric design as part of the exploratory process of using processes such as AR in design exploration.

This study observed iterative methods of design learning and abstraction that work based around the students using the AR to explore and augment forms, and adapting elements from previous iterations of their designs. These gradual analogous relationships to form abstraction replicate the morphogenesis that occurs in nature. However, these are more digital in their development.

Finding 5: Exploration of design using AR: From analogous connections to functional variation.. The exploration of the building as its component parts is a route that has been historic in architectural pedagogy as the process of 'partii'. This process defines the building form as a syntax of elements that form the whole. The partii is both explicit and implicit in the buildings final form. That is, a completed building design could be formally analysed and 'deconstructed' to functional, spatial and structural elements. The partii not only encompasses all of these elements but also includes the interrelationship of these without design conjecture.

The use of AR to generate elements of the partii and abstract multiple elements to explore relationships of function and aesthetics was also replicated in the journeys of 79% of those students studied. However, the remaining 21% of the cohort studied did not include this governing principle in their design journey. This set of journeys contained analysis of the design thought, abstraction and representation that occurred in parallel but without any perceivable singular linear progression. The design partii was conceived simultaneously and processed in a seemingly complex interactive cognition that may well be investigated in a future study. These analogous connections in the abstraction of the learning journey contained the spatial, functional and structural elements. However, as they were perceived simultaneously, the design elements were globally conceptualised.

Finding 6: Learning and the acquisition of architectural syntax.. The research results Indicate that the use of AR in the learning journey created the paradigm of increased conviction in design decisions during iterative abstraction of design ideas. When questioned in the studio during the study, the cohort stated that the use of AR allowed them to understand the design in a clearer and more accurate manner. The decisions they made during iterative design changes contained both scale, form and function, they were not merely sketched ideas, but something more concrete. Although the iterations were conceptual in abstraction they contained a syntax that was real world. The predicted outcome of these iterations was therefore to some extent known, giving the cohort a high level of knowledge transmission to their design than approximated outputs in non digital format, such as sketching.

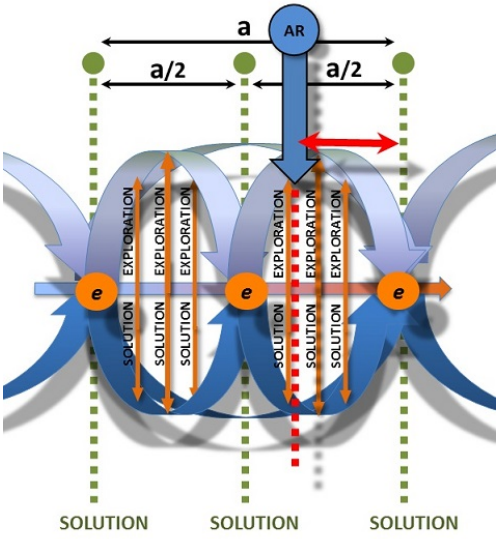

Figure 8
The impact of AR in the solution-exploration cycle of the learning journey.

Finding 7: Conjectures and refutations: The re-emergence of Poppers Method in AR.. The mode of abstraction that emerged from this study aligns itself with the method Popper suggested (1953) in that the use of AR in the learning journey allowed the cohort studied to explore their design theories whether they were singular or multiple in nature (ie. Exploration of a design element such as spatial or structural, or combination of these or more elements), this allowed them to be tested or exposed to refutation as part of the generation of ideas from the design process itself.

However, as conjecture requires a reliance on the prior concept of knowledge for its intelligibility. As knowledge is based on the premise that it is an idea proffered without proof, many iterative steps in the design journey could be conceived as comprising this key component. The abstraction that occurs within the learning journey at various stages (these were unfixed and varied in occurrence) allowing the cohort to have prior concept of knowledge within their design. The iterative abstraction allows conjecture to become a concrete knowledge of the design at any particular point in time. The study findings suggests that for 39% of the cohort expressed that the use of AR allowed for a series of visual operations in the design process that did not rely on them fully understanding the 'architecture' in precise detail, but allow for clarification of a design element.

RESULTS & CONCLUSION

Christiaans studied industrial design students with the study focused on the search for creativity in design (Christiaans 1992). The research presented in this paper develops this work with students further, by extending a similar research methodology into studies of the architectural studio context and the learning journeys that occur within.

This study has indicated a simple but influential system for supporting the existing learning journey in the architectural studio. Students are allowed effective exploration of spatial qualities of design projects undertaken in the studio. The whole is then greater than the sum of its parts so the investigative focus is on the exploration of individuals using technology in settings (Crook 1994). The findings correspondingly indicate a similar model to that proposed by Maher et al, which is based upon a both a problem and solution space that occupy a 'co-evolution' space when the cohort use augmented reality to visualise a design iteration (Maher et al, 1996). These elements co-exist and efficiently allow a more effective interchange in the design process.

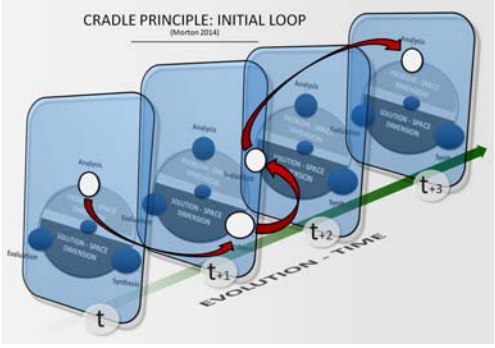

Figure 9
The Cradle Principle: Initial Loop: Problem Finding - Abstraction.

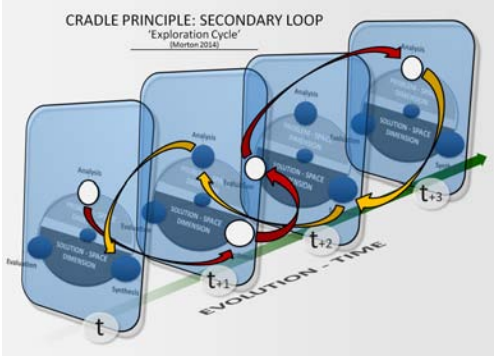

Figure 10
The Cradle Principle: Secondary Loop - Exploration Cycle.

The results indicate that when using augmented reality in the academic architectural studio context it becomes a new foundation from which to view the possible design decisions and from which to explore new iterations. The use of augmented reality in facilitating both pedagogic and didactic learning in the use and application of this exploratory tool

within the architectural studio. This in-turn enables the cohort to more effectively explore design possibilities and the impacts of these design decisions visually and more coherently. The learning experience is more located in the exploration arena of the students learning, the 'what if's' are more effectively navigated towards a deeper understanding of the design that would otherwise be difficult to obtain in the more traditional methods within the studio. The author plans to create a template from this module that could be used as shared resource.

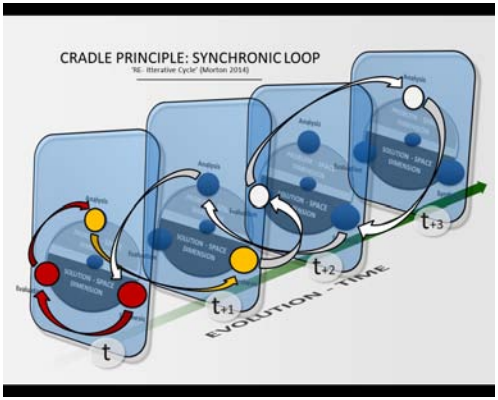

Figure 11
The Cradle Principle: Synchronic Loop - Exploration Cycle using digital tools.

FINAL THOUGHTS: AR IN THE ACADEMIC STUDIO

It is now understood in academia that the pace of technology in the learning environment is impacting of the differentiation between digital physicality and physical digitality. These previously separate domains are now becoming increasing integrated and the clear lines between the two are now blurred. There is concern amongst many in architectural studios within academia that this integration will bring with them a new era of exploration within studio design, that of synchronic exploration of building form using both traditional and increasingly digital methods.

What was once a dialogue that stemmed from pen to paper to thought and back to pen, in an ordered and responsive learning and design journey. The students within today's architectural studio can utilise the integrated and immersive approaches of Building Information Modelling (BIM) and augmented reality (AR). The student still 'models' their building, its form and spatial expression, however via digital modelling, an immersive exploration can be experienced. One that allows the embedded data and information about space, structure and materials to be synchronically manipulated in a blended and deeper learning journey. The augmented models that are used allow for the synergy of both physical and digital modelling and exploration to occur seamlessly. This readily accessible and seamless environment allows for a greater accuracy and finer levels of manipulation to be achieved.

There is a new pedagogic classification occurring when we use BIM and AR modelling in architectural teaching... that of depth of learning. When using the BIM model, the cohort were able to explore more 'what if's' in rapid succession which enriched the final learning journey and its pedagogic outcomes. Using AR the learning was deeper still; the connection with the model was far more immediate, seeing the model in a real world setting seemed to enhance communication between student to student or student to tutor dialogue. Both perception and interpretations of the models studied were richer in detail and created a new critique dynamic.

Modelling is a key tool in architectural studio teaching, using them allows higher order cognitive skills to be used by the cohort, such as spatial, planning and relationship of form. Using AR to explore the model(s) allows for a critical synthesis of these cognitive skills, where interactions with the model create immediate design iterations that move the student forward through their design journey.

LIMITATIONS

The study was programmed to evolve over an 8 week duration, with the final results programmed being captured after this time. The analysis of the findings thus far from the study data, indicating the value of

augmented reality as an exploration tool within the learning journey of an architectural student. There are high levels of practical value in the findings thus far, with findings indicating the pedagogic advantages for application of the augmented reality 'tools' and how the pedagogic interface of augmented reality allows for increased comprehension of design ideas. In turn how the visualisation allows for intuitive and instructive learning to occur. During this study the availability of free augmented reality software increased 240%. The advances in better interoperability will also be a potential future study as augmented reality systems within the studio may become ever more feasible and translate into pedagogic efficacy.

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