Developing Digital Literacy in Construction Management Education: A Design Thinking Led Approach

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Abstract: Alongside the digital innovations in AEC (Architectural, Engineering and Construction) practice, are calls for a new type of digital literacy, including a new information-based literacy informed by creativity, critical analysis and the theoretical and practical knowledge of the construction profession. This paper explores the role of design thinking and the promotion of abductive problem situations when developing digital literacies in construction education. The impacts of advanced digital modelling technologies on construction management practices and education are investigated before an examination of design thinking, the role of abductive reasoning and the rise of normative models of design thinking workflows. The paper then explores the role that design thinking can play in the development of new digital literacies in contemporary construction studies. A three-part framework for the implementation of a design thinking approach to construction is presented. The paper closes with a discussion of the importance of models of design thinking for learning and knowledge production, emphasising how construction management education can benefit from them.

Keywords: Construction management education, design thinking, digital literacy, building information modelling.

1. Introduction

Construction project management educators have advocated the need for flexible curriculums capable of addressing the growing complexity of practice whilst maintaining core professional knowledge (Thomas & Mengel, 2008). The use of digital technologies for project management forms part of this growing complexity as it has quickly moved beyond electronic document management (EDM) systems and project-based extra-nets to the application of Building Information Modelling (BIM) for virtual construction prototyping (Taylor & Bernstein, 2009; Becerik-Gerber & Kensek, 2010), adding another layer of complexity to the discipline.

BIM is now routinely utilised for construction management purposes, providing contractors with the ability to model, simulate, analyse and visualise both the product and process of construction (Eastman *et al.,* 2008). Whilst BIM technologies and practices are aimed at managing construction complexity, their integration with traditional AEC (Architectural, Engineering and Construction) practices – forming a hybrid of traditional and digital ways of working (see Harty & Whyte, 2010) – has in turn added a layer of complexity to the contemporary construction manager's knowledge and skills base. To address the rise of digital construction management a different approach to education is required. The claim of this paper is that an approach led by design thinking, and the promotion of abductive problem situations can inform a new view of digital construction education.

In developing an approach to digital construction management education, we explore BIM-supported education and Design Thinking processes that promote innovation. The paper is organised as follows. Section 2 discusses the impacts of advanced digital modelling technologies on construction management practices and education. Section 3 examines design thinking research, the role of abductive reasoning and the rise of normative models of design thinking developed for education. Section 4 explores the role that design thinking can play in the development of new digital literacies in contemporary construction studies. Section 5 then presents the coupling of design thinking and BIM-supported construction management education, presenting a framework for the implementation of a design thinking-led approach to digital construction education, which introduces creativity and innovation. The paper closes with a discussion of the importance of models of design thinking for learning and knowledge production, emphasising how construction management education can benefit.

2. Impact of Digital Construction Practices on Education

A number of factors are driving the need to rethink construction education, including, increases in project management complexity (Winter *et al.,* 2006), the paradigm shift in construction practices owing to the BIM methodology (Holness, 2008), the need for multidisciplinary problem-based learning (PBL) (Chapman, 2007), and wholesale differences of upcoming generations of students in terms of their social practices, learning styles, and even cognition, due to their early and constant engagement with digital technologies (Palfrey & Gasser, 2008).

A growing number of educational programs are responding to the rapid changes that are occurring. Recently, new theories and approaches have been proposed, including multidisciplinary digital collaboration (Plume & Mitchell, 2007), value-based approaches (Jupp *et al.,* 2010), systems theory (Boyd, 2011), and critical thinking (Allison & Pan 2011). What many of these approaches have in common is their desire to address the need for an interdisciplinary approach to creativity.

For the construction management profession, the paradigm shift surrounding the BIM methodology means that it is not only possible to model, simulate and analyse the building *product* but also the construction *process (*Holness, 2008*)*. To varying degrees, construction programs have updated their curricula so as to incorporate digital technologies and more collaborative digital PBL environments. As academic infrastructures are being reconfigured to accommodate BIM in the classroom, a number of noteworthy international initiatives are emerging. These range from the design of individual courses as instructors experiment with digital technologies in PBL-based construction education, (see e.g., University of New South Wales – Plume & Mitchell 2007, and Stanford University – Peterson *et al.,* 2011); to program-level implementations, (see e.g., Salford University – Arayici *et al*., 2011, and the University of Technology, Sydney – Forsythe *et al.,* 2013).

However, these previous endeavours to develop digital construction education have tended to manifest in teaching software and the underling capacities of visual learning. Many education offerings tend to associate the recent changes in AEC practice solely with technical skills development, such as model authoring, information capture and retrieval and computational programming abilities. In this way, the focus on technology eclipses the role of 'thinking through making', and overlooks the circularity of making and reflecting, i.e., reflection in action (Schön, 1983). The introduction of the BIM methodology to the construction classroom should enable educators and students to change from thinking about problems to making solutions to them so as to learn a new *thinking through making*.

Further, many construction management educators champion similar skills development to those advocated by the design science and business management communities, such as exposure to abductive problem situations, critical thinking, collaboration, and multi-modality. However, construction management educators seldom associate these abilities with design. The authors posit that some measure of the breadth of design thinking should be considered – the underlying rationale being: to expose students to methods and processes that encourage innovation and creativity in the application of BIM to construction problems; the aim being to extend learning beyond the development of technical competencies. From this perspective, design thinking offers an alternative and appropriate framework for the PBL situations surrounding virtual construction prototyping.

3. What is Design Thinking?

The term design thinking has two definitions: firstly as an approach to design reasoning, and secondly as a human-centred, open problem solving process. As an approach to reasoning, design thinking has been investigated for the past three decades by the design science community in their research of the practices of designers. Design reasoning reflects an abductive problem situation, yet as Dorst (2010) highlights it does not imply one way of reasoning, but rather a mix of different kinds of solution focused thinking (abduction). This includes analytical problem solving (induction and deduction) as well as activities that involve the framing and reframing (Schön, 1984) of the problem situation in a co-evolution process (Maher & Poon, 1996). This conceptualisation of design thinking is rooted in research undertaken by Lawson (2004; 2006) and Cross (2007a, 2007b) on how designers approach problems and develop solution concepts (Lindberg *et al*. 2010a). According to Dorst (2010) design thinking identifies abductive problem situations and 'ways of knowing' that can be applied throughout different levels of a problem. Fundamental to this, is how the professional practices surrounding problem framing and reframing then consist of a sustained effort to create considered and original approaches to the issues of a field of knowledge (Dorst, 2010). The embedding of this layer of design thinking into the construction management profession should create an environment in which the pursuit of novelty and progress becomes a part of overall practice.

Recently, this understanding of design thinking has been reinterpreted into normative guidelines for creative problem solving in general. This reinterpretation aims to improve decision making when dealing with abstract problems and managing complex systems or processes. Aspects of the discourse on design thinking have therefore been 'professionalised' into methods and processes for use in fields outside design, resulting in the 'branded' form of 'Design Thinking'. Consequently, 'Design Thinking' is distinguished by a normative approach to investigating ill-defined problems, acquiring information, analysing knowledge, and positing solutions. Design Thinking has most recently been applied to various disciplines and fields of innovation (see, e.g., Brown, 2008; Drews, 2009; Dunne & Martin, 2006; Martin, 2009; Plattner *et al.,* 2009). It has had increasing purchase in the Business and Management communities (e.g., Martin, 2009). However these normative interpretations have led to a variety of conceptions and intentions of use.

As a normative approach to problem solving, 'Design Thinking' has three distinct features. The first is its focus on abductive problem situations. Secondly, the methods and processes prescribed in Design Thinking toolboxes incorporate different ways of reasoning but focus on skills development in abductive reasoning. Thirdly, Design Thinking uses an interdisciplinary approach, incorporating diversity and leveraging different paradigms and tool sets from professions so as to analyse, synthesise, and generate insights and new ideas. The interdisciplinary nature of Design Thinking is therefore aimed at ensuring innovations are balanced between technical, business, and human dimensions.

The Design Thinking approach is most often applied as a sequential process model that describes a series of methods, which are applied to help students apply design thinking principles to project exercises. Perhaps the most well known model, shown in Figure 1, was formalised by the Hasso Plattner Institute of Design at Stanford, and is used as a didactic process model for Design Thinking education (Plattner *et al.,* 2009). The model distinguishes six phases: 'understand', 'observe', 'point of view', 'ideate', 'prototype', and 'test'. As Figure 1 shows, the phases are in a sequential order, and linearity is avoided through iterative links.

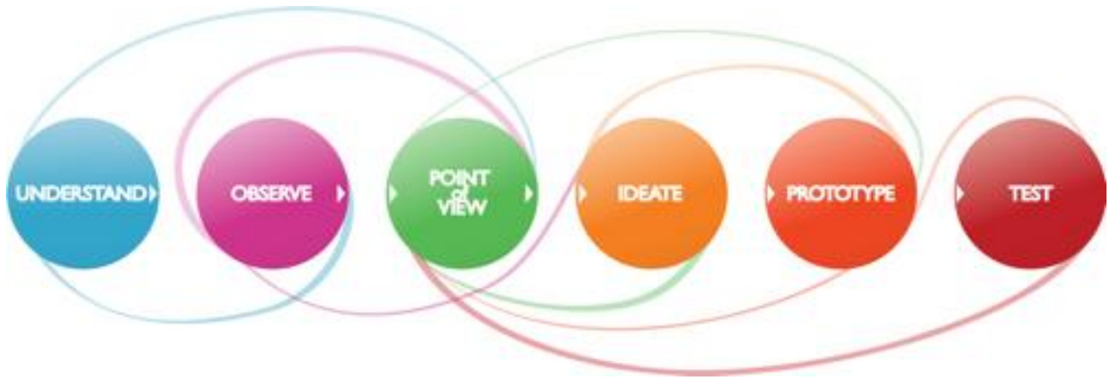

Figure 1. Didactic Design Thinking Process Model (Plattner *et al.,* 2009)

Design Thinking process models have a prescriptive and concrete character, providing instructions for practical use. Consequently they have been criticised for imbalances between their flexibility and sequentiality (Lindberg *et al.,* 2010). However, despite various criticisms of normative and didactic approaches, a number of 'non-design' schools now include course offerings in or based on design thinking principles. Such approaches have become common for courses focusing on practices for creative innovation and organisational (re)design. Such initiatives can be seen in educational institutions such as Stanford University's d.school (see d.school.stanford.edu), K-12 education (see K12.com), and the University of Technology, Sydney's u.lab (see u.lab.org.au).

With this understanding, the remainder of the paper explores the role of design thinking in construction management education as a way of addressing the problem solving skills and knowledge requirements underpinning the new digital literacies of BIM supported teaching and learning.

4. Developing Digital Construction Literacy Led by Design Thinking

Alongside the digital innovations in AEC practice, are calls for a new type of digital literacy, including a new information-based literacy informed by critical analysis and the theoretical and practical knowledge of the construction profession. Construction management students therefore require a new form of digital literacy. However the literacies surrounding the BIM methodology constitute a set of abilities and skills where aural, visual and digital competencies overlap with creative problem solving abilities. They include the ability to read, manipulate and transform the parameters and properties of 3D, 4D and 5D models and exploit the innovative potential of process simulation, analysis and animation. It requires the ability to innovate traditional approaches to construction management by creating and exploring virtual prototypes, to distribute building information pervasively, and to easily adapt this information into new forms. In many ways, the new digital literacy surrounding the BIM methodology in construction sounds very much like designing.

From this perspective, BIM-supported education provides an opportunity for digital construction-based literacies and design thinking to coalesce. The capabilities of BIM and the virtual products and processes that can be modelled and simulated provide opportunities for construction management students to engage in abductive problem situations in a digital PBL setting. Through the use of virtual prototypes, abductive problem situations can be presented to students and the Design Thinking processes that incorporate 'understanding', 'observation', developing a 'point of view', 'ideation', 'prototyping', and 'testing' can be utilised. This recognises that by immersing construction students in BIM technologies, core design thinking principles can be embraced — principles based on discovery, creativity, critical thinking, collaboration, and innovation.

From modelling, simulating and analysing construction products and processes, new forms of thinking and making in construction education can be realised. To achieve this and enable deeper reflection from the iterative development of digital solution prototypes, a process or workflow is required that guides students in the methods of design thinking-led problem solving. Through process simulation, the creative and intuitive aspects of construction practices can be revealed and transformed into analytic components in a process of design thinking. Consequently, for students the design thinking approach can provide a way of learning and knowing that is a fundamental shift in the way they are able to engage in construction management problems and practices.

The objective of BIM-supported construction management education must therefore be based on allowing students to engage more deeply in problem situations, develop content expertise, and cultivate project skills in interdisciplinary collaboration, systems thinking, and being able to plan, search for, and explore – that is to *design* – new solutions for construction management. The role of design thinking is highlighted in the situated and contingent nature of construction management problems and how BIM is able to better support process analysis and decision making. In acknowledging these characteristics, opportunities for the meaningfully integration of BIM and design thinking in teaching and learning appear, namely opportunities surrounding: (1) deployment of abductive and analytical reasoning in complex construction management problem solving, (2) communication of complex and rich building information, and (3) exploration of the interface between construction management methods, digital technologies and design.

5. Connecting Digital Construction Literacy and Design Thinking

In the development of a programme that supports a design thinking led approach to new digital construction literacies, new ways of thinking and making that expand the notion of BIM-supported construction management education are required. As a result of reviewing precedents of BIM-supported teaching and learning (see e.g., Wilkins & Barret, 2000; Horne, 2007; Silva, 2007; Taylor *et al.,* 2008; Sacks & Barak, 2010, Peterson *et al.,* 2011; Forsythe *et al.,* 2013) and examples of design thinking in education (see e.g., Brown, 2008; Drews 2009; Dunne and Martin 2006; Martin 2009; Plattner *et al.,* 2009), a three-part framework was developed (see Figure 2). The framework is aimed at establishing a PBL experience that enables students to explore and innovate key digital construction practices via the process and methods of design thinking.

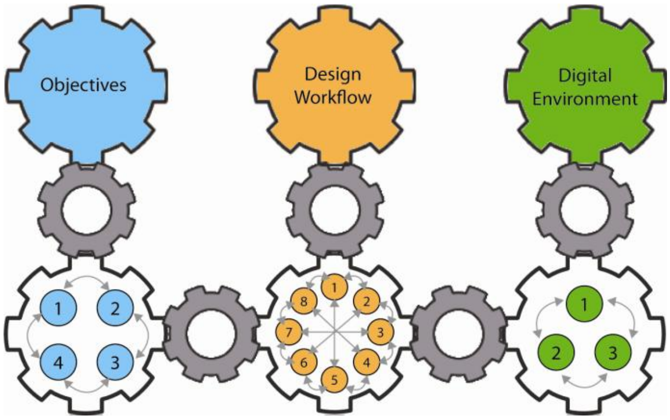

Figure 2. Three-part framework for implementing a design thinking led approach to the development of digital construction literacies

The framework consists of the definition of: (1) programme-level objectives, (2) a structured workflow based on design thinking principles, and (3) the integration of design and construction in collaborative digital environments. These three constructs are seen as necessary in defining how construction management students should engage with the problem situation, subject content, and other students during teamwork.

Part 1: Identification of Programme-level Objectives

The programme-level objectives of a design thinking approach to developing digital construction management literacies for BIM-supported teaching and learning are based on four concepts derived from the work of Burdick & Willis (2010) who identify similar points of connection between design thinking and digital learning objectives. The focus here includes how the programme, teachers and students approach: 1) Problem solving – as situated, networked and contingent; 2) Interaction – based on a human- and user-centred approach; 3) Communication and representation – as conceptual and solution oriented; and 4) Multidisciplinary collaboration – with an attention to the interpretive and performative aspects of digital ways of working, thinking and knowing.

1. Problem Solving as situated, networked, contingent: The aim is to develop students' hands-on experience with the instrumentality, systemic 'embeddedness', contextual specificity, and the social operations that surround the BIM methodology. This objective provides a useful frame of reference in the syllabus and forms the foundation for reconsidering a generic notion of digital construction literacy as simply acquiring a set of skills. Instead it casts digital ways of working as situated, networked and contingent, and as such, something continually negotiated. The premise of the didactic design thinking process model utilised in the course (see Part 2) is therefore aimed at supporting this continual emergence and negotiation.

2. Interaction as human and user centred: A design perspective of BIM-supported construction education provides a shift from a technical tool-based orientation (that may be predicated on the knowledge-base and constraints of digital technologies) to a human-centred and user-oriented approach that takes into account not only how a software application is used but also the kinds of stakeholder positions and project perspectives it affords. This user-orientation in higher-education is closely aligned with learner-centred educational theories (Armstrong, 2012).

3. Communication and representation as conceptual and solution oriented: The conceptual, solution-oriented yet propositional (or speculative) aspect of thinking through making can inform new solutions to construction management problems – for example via the simulation and analysis of different construction schedule options, building information can be visualised, communicated and represented in a variety of formats – providing the capacity to re-represent discipline specific design information as well as construction management concepts. This approach is generally acknowledged by advocates of BIM-supported education as being significant in syllabus development, but is rarely considered as a key outcome of learning.

4. Collaboration as interpretive and performative: Understood broadly, design has its foundations in visual representation and semiotics, which are essential when interpreting symbolic dimensions. Interpretive and performative activities map directly to the development of digital literacy and fluency – especially those surrounding 4D and 5D modelling, whereby students must develop an understanding that critical interpretation of digital construction prototypes is as significant as traditional time management practices.

Attention to an understanding of these objectives is foundational to syllabus development so as to attune the digital literacy requirements surrounding the BIM methodology to the principles of design thinking. Upon establishing these objectives, a process model must be adopted so as to guide students through a design thinking-led problem solving process.

Part 2: Incorporation of a Design Thinking Workflow

In any design thinking-led problem solving process, there are certain sets of activities that recur. The working modes and rules (Tables 1 and 2) developed by Lindberg *et al.* (2010b) attempt to avoid the danger of falling back upon typical sequential process models of design thinking.

Lindberg *et al.* (2010b) suggest avoiding the traditional process terminology consisting of phases, sequences and feedback loops, and consider that design thinking workflows are 'shaped by underlying principles giving rise to processes without prescribing them'. Their approach models those principles on a *concrete* level by distinguishing between 'working modes' and 'working rules'. Working modes are recurring steps of the problem solving process, and working rules are heuristics that help to decide how to link the modes to a helpful process (Lindberg *et al.,* 2010b). The more advanced a designer is, the less normative should those rules be regarded.

Research has shown that the physical environment can positively impact on innovation processes and fuel creativity (McCoy & Evans, 2002). Space is therefore integral to the design thinking process and how it can become a tool. In the PBL setting, the teaching and learning space should therefore play a central role in driving a culture of innovation and supporting creativity. Five ingredients were identified as significant.

1. Flexible and dynamic – a space that is adaptable, and can be shaped to suit a variety of activities.
2. Technology-enabled, but not technology-dominated. Including digital workstations, equipped with laptop ports, BIM and other auxiliary software, large interactive displays, interactive whiteboards, WiFi, video projectors and screens, and the freedom to use tablets and smartphones. However the space should not be only about the technology, it's about people and ideas.
3. Facilitate the generation of ideas – a space that includes whiteboards and walls to write and stick things on.
4. Support prototyping – including a variety of prototyping methods and materials.
5. Provide an area for relaxation – when communicating ideas students need to feel relaxed to express ideas and to gather round for team presentations and pitches.

The collaborative digital environment should therefore enable students to engage in rapid iterative development cycles, where teams can build rough, ''throw-away'' virtual prototypes of the process (or physical prototypes of alternative construction techniques) for validation with other project stakeholders and the client.

Thus the three-part framework anticipates that students will have the opportunity to not only develop digitally based project management competencies but also understand how innovation occurs using the BIM methodology. Together the subject values, design thinking workflow, and digital environment provide support for a variety of decision-making activities in a PBL setting.

6. Conclusion

This paper explores the role that design thinking can play in the digital learning environments of construction management, which are rapidly evolving as a result of the growing interest in the BIM methodology by AEC industry practitioners. In order to realise the full benefits of BIM-supported construction management education and move beyond the teaching of software, the philosophy of design thinking should be embedded in the design and implementation of digital subject areas of construction.

The nascent research surrounding BIM-supported teaching and learning in construction management requires new modes of understanding that must be developed, practiced, and theorised. It is imperative that the construction management education community be involved in the development of the emerging teaching practices that will shape the contours not only of new models of teaching and learning for construction management education, but of research in this area. The time for academics and practitioners to engage in the development of digital construction management education is now, while the field is relatively unformed. This is a pivotal moment for the new digital paradigm in built environment practices.

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Table 1. Summary of Working Modes, see Lindberg *et al.* (2010a)

Working Mode	Goal	Means
1. (Re) Framing the Design Problem	To frame and reframe the scope of the problem space and thus the question to ask for further learning.	How to frame: e.g., Fractionation (e.g., de Bono 1970). How to reframe: e.g., Synectics (Gordon 1961)
2. Grasping External Knowledge	To collect problem-related knowledge not already part of the team's expertise. Studying who stakeholders are and how they think and act.	Communicating, observing, recording, and empathizing, supported by interviews, survey questionnaires, focus groups, cultural probes etc. (e.g., Laurel 2003; Visocky O'Grady 2006).
3. Knowledge Pooling (Presupposes teamwork)	To combine the versatile amount of knowledge so as to create a mutual knowledge base among all team members.	Inform team members about insights from user research and share empathic knowledge collected. A common method is Storytelling (e.g., Quesenberry & Brooks 2010).
4. Synthesizing	To synthesize information by grouping, structuring or condensing them to a (preliminary) conclusion as basis for further work.	1. Creating abstract frameworks, e.g., 'Concept Mapping' (e.g., Kolko 2010). 2. Converging into concrete representations, e.g., 'Point of View' or 'Persona' (fictional character profile) (e.g., Long 2009; Laurel 2003).
5. Path Selecting	To decide what questions will guide further exploration of the problem space and or ideas will be worked out to solution concepts.	Group discussions, 'Elevator Pitches' (e.g., Pincus 2007), voting techniques e.g., 'Dot Sticking' (e.g., Baxter 1995; Tague 2005).
6. Ideating	To create manifold ideas on possible solution paths without judging or criticizing (wild or seemingly strange ideas are welcome) in order to achieve a large quantity of ideas.	'Brainstorming' (e.g., Brandes *et al.* 2009), 'Brainwriting' (aka Method 635) (e.g., Baxter 1995), Mind Mapping (Buzan & Buzan 1996) and 'Synectics' (Gordon 1961; Jones 1992).
7. Concept Specifying	To bring certain ideas on a more detailed level. Asks to think with scrupulousness about an idea and to concentrate on facets that should be incorporated in next prototype.	Different means to support concept generation (Pugh 1990), e.g., 'Concept Mapping', 'Frameworks' or 'Process Diagrams'
8. Making it tangible	To visualize and objectify ideas and concepts to enable feedback from potential users and stakeholders.	In early stages, typical means are simple visualizations e.g., sketches (e.g., Visocky O'Grady 2006). Later all prototyping methods: e.g., low- and high-fidelity prototyping, mock-ups or wireframes (e.g., Warfel 2009).

Table 2. Summary of Working Rules, see Lindberg *et al.* (2010b)

Rule	Description
1. *Every Mode Is Important:*	All modes should be incorporated in a design thinking workflow
2. *Initial Problem Space Exploration*	At the beginning, the problem space has to be extensively understood before one can pass over to the solution space. The team iteratively executes the problem space modes.
3. *Finding a Viable Scope Before Entering the Solution Space*	Two criteria help to answer the question when to enter solution space for the first time: a) there should be a certain scope of the problem to which the gathered knowledge has been converged and that does not alternate substantially with further iterations; b) the team should regard this scope as a viable background for ideating and concept development.
4. *Problem Space Exploration as Combination of Unfolding, Selecting and Re-Representing Solution Paths*:	Solution Space exploration relies on three aspects: a) finding manifold potential solution paths via ideation techniques, b) learning how to select a group of solutions to put more attention on, and c) learning about their facets by means of diverse representation techniques (e.g., concept drafts, sketches, prototypes).
5. *Balancing Solution Paths with Problem Space when Tangible Representations are Available*:	The problem space should be re-entered when a tangible object is on hand that allows collecting feedback from stakeholders with the purpose of supporting revising, refining or rejecting a certain concept.
6. *Ending the Workflow when a Concept is Saturated:*	The design workflow should ideally come to an end when balancing problem and solution does not suggest significant modifications of the design concept. Then the concept is saturated.

Part 3: Collaborative Digital Environment