IS CONVENTIONAL KNOWLEDGE ENOUGH?

Playing the devil’s advocate in the adoption of digital fabrication technology

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Abstract. Building on the research on the industrial potential of digital fabrication technologies commenced by the late University of Melbourne academic, Professor Bharat Dave, this paper explores actual patterns of technological adoption within communities of practice bound together in a few selected projects. Its main aim is three-fold: 1) highlight the distribution of knowledge required for the actual take-up of digital technologies; 2) look for the presence of possible gaps in such work landscapes; and 3) discuss the transformations that may occur in practice as a result of the conflation of innovative technologies and established professional cultures. The research being reported in this paper examines the socio-technical environment of the projects selected and the challenges intrinsic to the introduction of innovative digital technologies. Its findings suggest that the inherent complexity of building production needs to be considered in a far more nuanced and substantive manner than generally assumed by mainstream technological positivism.

Keywords. Innovation; digital technologies; digital fabrication.

1. Introduction

This paper relates to research exploring patterns of adoption of innovative digital fabrication technologies by Australian architecture practices. Specifically, the research aimed to develop better understanding of (1) emerging opportunities for design and construction of non-serial architecture using digital fabrication technologies, (2) possible gaps in work landscapes and (3) cascading transformations in established norms of design practice that follow adoption of such fabrication technologies.
The gradual shift to production of built environment using fabrication technologies extends earlier passages from craft-based, manual processes to mechanised and standardised industrial techniques. The increasing informatisation of design and construction processes is accompanied by opportunities and costs. Whereas most published literature offers descriptive accounts of designs as constructed, a few detailed studies describe procedural trade-offs and transformations that professional practices undergo once they embrace innovative digital technologies (Schodek, 2005; Pfammatter, 2008). This research provides an understanding about the transformations that occur when innovative technologies and established professional cultures come together, investigating the interaction between communities of practice. It relates to the idea that what is still developing is not only how one designs buildings, but also how one manufactures and constructs them (Callicott, 2000; Kolarevic, 2003; Schodek, 2005). Therefore, digital technology (adequacy of software, translation of information, material fabrication, etc.) and project sociology (patterns of communication) need to be investigated together.

2. Background

The use of digital fabrication technologies in architecture is most visible in the works of Frank Gehry, whose practice has experimented with and skillfully integrated use of digital technologies for representation, fabrication and assembly. (Shelden, 2006; Boland, 2007).

With the subsequent development of computer graphics and computer-aided design systems beginning in the 60’s, Computer Numerical Control (CNC) systems were developed to aid efficient production of machine parts directly from digital data in the automotive and aeronautical industries (Callicott, 2000). These developments are currently embraced in the architecture and construction community in the form of digitally fabricated design projects (Kolarevic, 2003; 2015). From integrated digital tools to design through fabrication and assembly, a different paradigm of file-to-factory informatisation has emerged which allows a shift of emphasis from design projects comprising repetitive, mass produced elements and which feature low complexity to one of mass customisation or buildings comprising non-repetitive elements often featuring high complexity (Kieran, 2004). This transformation to non-serial architecture hinges upon use of integrated design, fabrication and construction processes underpinned by digital tools and technologies (Schodek, 2005). A robust theoretical account of innovations in design practices is offered by Boland (2007). Based on the multi-project and multi-year study of the firm of Gehry, the notion of “wakes of innovation” is intro-
duced that propagate among heterogeneous communities of practice but deviate from established norms, occurring at different rates and times in different professions, and diffuse through at the permeable zones between communities of practice bound together in a project.

The focus of this research is just on these lines of demarcation: how and in what ways digital fabrication technologies are adopted and how they reconstitute knowledge boundaries in contemporary design practices. For their very own nature, these questions cannot be addressed adequately by studying technology alone or patterns of communication among or organisational structures of project teams in isolation, but need to be investigated together.

3. Methodology

A case study approach has been adopted with material presented in this paper arising from open-ended interviews undertaken with key members of project delivery teams. The research agenda is organised around three Australian design projects, each representing a distinct scale, function and character and each illustrating the use of a distinct palette of materials, fabrication technologies and project organisational structures: Webb Bridge, Burst House and Southern Cross Station.

Webb Bridge (2002) grew out of a winning competition project by a collaborative team of DCM Architects and mixed media artist, Robert Owen, in Melbourne. The bridge is a serpentine construction consisting of steel hoops that vary in width and height. Each hoop is an ellipse of a different size, centred differently across the span of the bridge. The steel straps that span between hoops also vary in width and height of the coil to accommodate the levels of the bridge. The design evolved from the artist sketches and physical models into a parametric 3D digital model.

Burst House 003 (2005), located in a mid-north coastal NSW town, is an experimental prototype of a laser-cut plywood house designed by SYSTEmarchitects to serve as a “weekender” for its owners. Working from New York, the firm utilised software that took as a starting point space requirements, site and climatic data, from which were generated spatial configurations. The project, evolved into a second iteration via the participation by the architects in the 2008 MoMA exhibition Home Delivery: Fabricating the Modern Dwelling.

Southern Cross Station (2006) is a major infrastructure project being the refurbishment and extension to an existing public transportation hub in Melbourne. The project was delivered as a Public-Private Partnership, with Leighton Contractors engaged to deliver the works, with architects Grimshaw in collaboration with local practice Jackson Architecture. Its iconic
wave-form roof of naturally ventilating “moguls”, together with skewed geometry of the tracks from the street edge, results in steel members and components that look alike but are in fact unique in terms of their geometry and dimensions.

4. Scale, context and challenges

The three case studies demonstrate that the uptake of digital design technologies are not necessarily contingent on the specific project or its scale or context, yet project specific challenges remain influential to its implementation.

The concept of Burst House 2005 evolved out of a digital technology determinism geared towards the possibility to provide an alternative to mass-produced housing, seeking parametric conditioning accounting for site, context and environmental responsiveness. Utilising Maya software to generate a 3D model, a large number of design iterations could be generated quickly, which could evaluate environmental performance and prefabrication production methods, which could be optimised through nested software to limit wastage in its plywood structure (Architect: 2015 personal communication).

The idea of optimisation of prefabricated ribs – which ideally lowers project costs, as well as wastage on the building site – reflects how new digital processes may enable considerations of resource minimisation embedded into design conception and construction.

Despite these aspirations, the project had to proceed under a self-build construction procurement regime due to difficulties in obtaining a head contractor within budget. The formal complexity of the building system placed time and labour demands in positioning and assembly of the numerous frame components. This necessitated the engagement of a site architect to operate as a mediator between the digital information and site personnel assembling the building componentry. Significant on-site adjustment led to cost implications that eroded the objective of cost-effective, ease and speed of construction. Factoring for the inherent difficulties encountered, the 2005 Burst House in many ways represents a precursor of a new way to interpret the customisation of prefabricated building systems, as demonstrated by later examples, such as Alastair Parvin’s 2011 Wikihouse.

The Southern Cross Station demonstrates that project specific challenges may support an interest in digital design uptake, in this case, by facilitating rapid design optioning, modelling and testing for the roof system in dealing with the discharge of diesel fumes via natural ventilation systems. It is the capacity of the digital domain in its application to the supply chain where the close integration between architecture, structural engineering, shop-drawing
production, and fabrication came to the fore in meeting site, program and cost constraints. This resonance of Charles Eastman’s (1975) postulation of the potential of computer-based building representation, its parametric design opportunities and linkage to production suggests that the Southern Cross project cannot be considered innovative in engaging with a Building Information Modelling (BIM) process, but in its manipulation of the process in meeting project specific requirements and revealing how digital technologies can be conditioned by the supply chain context in proceeding through different disciplinary territories of architecture, engineering, fabrication and construction. The roof structure comprises of approximately 8,000 tubular steel members with 3,500 connection nodes. The tube lengths vary in size due to the variability of the roof geometry. The decision to engage only one steel shop drawer, responsible for the whole project, and introducing this entity upstream into the project process allowed for the generation of one 3D digital model. (Project Manager: 2012 personal communication). From this the quality, accuracy, form of information output and its dispersion, despite the fragmentation of production across different suppliers could be controlled to ensure the exact coincidence of information and program scheduling.

5. The uptake of digital technology is not exclusively a technical decision

Initial uptake of digital technology may not derive from technical capacity building, BIM leverage or supply chain production management. In all three cases these followed cultural inclinations motivated by formal decisions independent from production. The Webb Bridge project arose from funding sources related to urban art patronage and developed via the interaction between artist and architect. The scheme was viewed as a development from previous urban design project interests and practical compliance issues related to pedestrian gradient considerations. The realisation of the difficulty in the refinement of the formal aspects of the design using traditional representational systems led to the adoption of 3D digital modelling techniques. The further development of this model for fabrication occurred via the engagement of the same shop drawing production agency that would be utilised for Southern Cross Station.

Southern Cross Station presents a digital uptake profile similar to Webb Bridge, in the early realisation that arose from working through various digital representational tools in dealing with the configurations of design elements. The continued development of digital technology for use along the supply chain, then responded to conditions specific to those actors within the context of the overall project, such as engineering constraints or fabrication,
supply and assembly efficiencies. Although sophisticated digital modelling was undertaken, the initial uptake did not arise from purely technical considerations in digital adoption.

The Burst project arose as a prototype for an interest in demonstrating what fabricated housing can achieve by mining the possibilities of the computer. This approach accords with notions of “critical design” speculation as articulated by such proponents as Dunne (2013). The use of heuristic algorithms, responding to environmental and space planning inputs whilst accounting for its structural use of plywood components as a flat pack assembly system was presented as a prescient response to a more general condition of residential construction design and production innovation. Here the challenges are largely cultural, and the Burst project demonstrates that these cultural challenges exist beyond just customer or client support but also within industrial context and communities of practice.

6. Communities of practice, construction procurement, industrial capacity in adopting digital technologies

The adoption of digital technologies relies on the actors of the community of practice, in their capacity to drive, enable, follow or hinder an innovative process, having coincidence of means, motives and opportunities. It demands the adoption of integrated information and therefore a deep collaborative design strategy which may determine the success or the failure of the process, as much as in the role of drivers, enablers, user, and reactionaries. In the Burst House the architects, the only driver along the supply chain, assumed responsibility to facilitate the fabrication and assembly process, having the view that the risk involved arising from the complexity of the project could not be contained well enough to convince contractors that risk was limited. (Architect: 2015 personal communication). The owner/builder construction procurement approach for this bespoke residential house facilitated an experimental process of digital design speculation, underpinned by the argument that the digital design method and the mode of fabrication production afforded ease and speed of construction, within budgetary limits. Despite these intentions the project was plagued with budget and time over run. The second iteration of the Burst project at the MoMA, used different materials and fabrication processes, a different contracting regime and less budgetary conditions. The building process took 10 weeks, 4 off-site and 6 on-site, demonstrating the iterative nature affiliated with prototyping new technologies and systems.

In Southern Cross Station, resistance to digital uptake and BIM innovation lay with a fabrication industry embedded to tooling and production
methods which reflected prior modes of operational practice. The response was to identify specialists with the capacity to provide the services to push the adoption of innovation along the supply chain. The ability to innovate in the construction industry is limited by its fragmented structure as a project based industry with a low volume output characterized by ever different products, assembly plants, and strategic coalitions. The procurement system and scale of the station and in part the bridge provided the framework for push-pull dynamics of innovation to be implemented. Critical path items could be modelled and reviewed, such as, various iterations of 3D steel component profiles accounting for requirements such as minimum head clearances and high-tide water levels. Developed as a Public-Private Partnership model, the Southern Cross Station mandated cooperation between the actors: architects, consultants, contractor and sub-contractors. The central shop drawing coordination agent was identified as being a key player, who picked up the fabrication component of digital design production. This coordinating agent evolved as a central driver for digital uptake taking a determining role by assuming responsibility for the digital information and the coordination of the other actors involved. The involvement of the shop drawer from an early stage can be considered an endemic consequence of this kind of procurement, but the introduction of a 3D model, entirely managed by a single coordinator, was considered to be one of the meaningful reasons of the success of this project. Given that the same fabrication information agent had worked on the earlier Webb Bridge the flow on of expertise developed in the complex geometry of the steel framed bridge is noteworthy in the role these types of projects play in knowledge transfer and as innovation incubators.

A defining condition that individual actors have as their starting position is often set within the framework of the industrial capacity and the operative characteristics in which they must engage. While every building imbues decisions affecting its various aspects, every building also implies a different combination of those decisions, produced on the basis of established priorities and existing operative conditioning. The Burst House concept seeks to apply a new ideal of mass customisation to the residential construction sector arising from an attempt to reconcile singularity with customisation whilst negating a corresponding increase in costs. But this project, with its bespoke nature, in attempting to pull the industrial status quo forward, in demonstrating pathways for digital supply chain networks and connectivity, faced an industry that had not reached maturity in its adoption of digital technologies both in its social context and market setting. Webb Bridge and Southern Cross Station operate within different frameworks having a different order of complexity in terms of the number of components and number of parties in-
Involving the whole processes. The use of parametric modelling for generating and fabricating variations within a geometric schema, in the bridge represents how constraints of fabrication and assembly become integral to design development from the earliest stages of design.

Component sourcing from state, national and international sources, require discussion to occur on the relative interfaces across boundaries. The diversity of components involved requires significant attention to interfaces between different geometries, materials and sequence in which they are assembled together. Specifically, it illustrates how careful attention to geometry and tolerances becomes a fundamental necessity not only during design and fabrication but also during intermediate and final construction stages in the project.

All three projects demonstrate that technological take-up is not contingent on developed knowledge or on existing industrial capacity. However, such innovations need to address both these conditions and are factors in the success of the outcomes of project realisation.

7. Discussion and conclusion

It can be argued that our understanding and exploration of digital technologies requires more than knowledge of the technology involved. It demands a deep awareness of its connection to existing practices of design, fabricating and building. The availability and adoption of integrated information processes acts not only as a change enabler but also as a change agent.

The implicit motivations behind this paper and, more in general, the funded research on which it is based, had to do with the validation (or, by extension, the dismissal) of a doubt about the determinants of technological adoption in the design and construction process, particularly when it came to digital fabrication techniques. Irrespective of the emphasis placed by IT pundits on the inevitable onslaught of numerically controlled machinery into building, should construction scholars let others worry about hardware, and rather concern themselves with the social software of the industry – its people, its work protocols, its established relationships, its culture? Are these the real determinants of – or barriers to – change, even in digital matters?

The socio-technical analysis of the three projects, succinctly described in the previous sections, seems to suggest that not only is there significant import to this proposition, but also that any agenda truly concerned with the introductory efficacy of digital techniques in building cannot afford to overlook some of the components that came out of the parallel examination of the procurement histories of the case studies undertaken: a small beach house, a bridge folly, and a train station. Firstly, the study of how each pro-
ject unfolded clarifies that the uptake of digital technology was never exclusively a technical decision. Although the introduction of digital fabrication methods differed depending on the scale of each project, the context of each project and the manufacturing challenges specific to each project, the decision to follow the path chosen against possible alternatives in each case seemed to be determined more by cultural inclinations (and, at least in one case, by ideological positions) than incontrovertible production advantages in terms of supply chain management. In many ways, the initial take-up was motivated by formal decisions in each of the projects analysed. Such decisions may not have made the procurement of the building “easier” (and therefore “economic” in every sense) but did indeed make the contribution of digital manufacturing processes vital to the viability of the ideas underlying the aesthetics of each building in practice. The “pull-in” from construction, in other words, could be considered necessary only post-facto – in terms of “bounded rationality”, that is – once other decisions, originally independent from production, were taken.

This finding introduces the critical role played by specific actors – literally, members in the community of practice of each project with the ability to act and to influence the behaviour of others or to follow directions that may not have been technologically driven or informed. Both adoption and application of digital manufacturing technologies, in other words, relied on the existence of driving champions and/or technical followers. Yet, caution should be exercised when placing excessive emphasis on individual actors’ drive. Although certainly critical to the eventual success of the enterprise, the study shows that the “existing” industrial capacity of the community of practice in which the project is embedded cannot be sufficiently highlighted. On the one hand, it is the level of related maturity of the industry involved in the project that enables both the adoption of particular techniques and the adaptation of existing work conventions to them. On the other hand, it is the morphology of building procurement – i.e., when and how, certain actors are expected/allowed to undertake certain tasks – that makes it possible for the community of practice to interact as necessary, either by following established procedures or by defying them. In the case studies examined, this second element produced some significant divergences, with the design and technology teams in the small beach house and bridge folly scattered across unconventional and informal landscapes of contributions, whereas work on the train station identified specialists with the capacity to provide the services needed in the position expected along the supply chain. This does not mean that technological take-up always took place under conditions of “developed knowledge” – in fact quite the contrary. In each one of the projects examined, uncertainty and specific inexperience were the markers of the
process. Thus, while actual knowledge gaps existed, these did not deter the decision to go ahead with the plan. Yet the fact that the three projects were eventually built (and received several accolades) should not underestimate the impact of “imperfect (technological) knowledge” on their design and construction performances. When looked at in detail, the physical results of the process undergone warn against the dangers of placing the digital manufacturing cart ahead of the industry’s ox, particularly when the pathway has not yet been cleared of longstanding hurdles. Even though each one of these projects may appear as a glistening example of digital manufacturing from a distance, it invariably owed its actual implementation to non-digital elements – either social or trade-based. By contrast, it is in their never-resolved (and opaque) problematic aspects that the study of technological innovation and its non-technological repercussions should dwell.

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