Urban prototyping

Socializing the design to fabrication process

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Abstract. Within the context of burgeoning urban populations and the rolling back of state resources,there is growing interest in ways in which citizensmay participate in the creation of resilient and livable cities. This paper proposes the concept of ‘urban prototyping,’ and employs a designresearch methodology to develop and document thesocially-sponsored design and digital fabrication of an urban shelter.We explore how we might use networked design and fabrication technologies to leverage the social capital locked within non-professional communities so that our current cities might evolve into whatever our next cities need to be.

Keywords: participatory design,urban, prototyping,eco-digital fabrication,expertise, design futures, value frameworks.

1 Introduction

Both the urban environment and the design professions are experiencing change. Seventy-five percent of the global population is predicted to be urbanized by 2030 [1], yet most designers serve only a tiny percentage of that population.While design and construction are necessarily highly regulated, there is some urgency to make them more consumer-friendly and democratic[2]. The increasing accessibility of digital fabrication, desktop manufacturing tools and makerspaces offering open source and DIY tools and software, also causes us to question the protected position of the design and construction professions. How might the architect or designer operate in communities with increased access to networks of information, diverse expertise and new technologies?

In this paper we present a research project that investigates how, and to what extent, design and construction might be democratized[3].We document the design of a prototype 10m^2 shelter within a “software ecology”.We aim to enable the encoding of key aspects of a design as well asthe capability to pass other design and creative freedoms (that are traditionally the preserve of the design and construction professions) onto the citizen. We employ the notion of ‘urban prototyping’ to unpack the discourse around how we might cede certain responsibilities to communities

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without abandoning the professional obligations to quality, health and safely. Finally we discuss how the unit was appropriated when complete and note some of the unexpected consequences of devolving aspects of the design and construction to a community.

2 An Urban Prototype

In this section we document an urban intervention aimed at exploring potential design futures. EDFAB (eco-digital fabrication) is a research project funded by the University of Auckland and its Thematic Research Initiative ‘Transforming Cities’. Its aim is primarily to deepen our understanding of how changing technology alters skills, knowledge, practices and processes within the building sector as well as explore how social capital can be utilized within a modern urban context.

Previous work has explored how emerging digital technology has changed supply driven markets into more democratic demand driven ones [4], here we extend this discourse to investigate how design and construction can be more consumer-friendly.

Flat pack furniture already offers a potential methodology, where the design has been carefully considered for ease of assembly. Another is makerspaces or hackerspaces, the phenomenon of multi-use spaces that bring togethera varietyof design and manufacturing technologies and encourage the formation of public and/or non-professional communities of practice. Tools such as computer numerical controlled (CNC) routers and laser-cutters, which were until recently rare and expensive, are now relatively easy to access in many cities. This dramatic increase in digital technologies and servicesalso creates new possibilitiesfor developing alternative pathways from design to production. Typically, these rely more on the modeling and transfer of digitized 3D information models and less on abstracted 2D drawings. In the following section we prototype a possible “design to production” future through the design and construction of a small $10m^2$ unit. We develop a construction methodology, design and prototype the software infrastructure around it as well as use existing manufacturing tools in its fabrication and construction.

2.1 Context

If some of the key anthologies on digital fabrication[5], [6] and its stakeholders are examined[7], [8] a preoccupation with form becomes apparent. This is perhaps because digital fabrication most obviously lends itself to the efficient production of otherwise prohibitively complex forms. However, as both professionals and students become more familiar with, and desensitized to, the novelty of digital fabrication, a new criticality is emerging, questioning the values and benefits of emerging tools and techniques, such as linear kinematic robotics, nanotechnology and 3D printing.

Karl Marx[10] exhortation that the potential of automation is not about prosperity, but about the dangers of dehumanization. Although Marx was referring specifically to the workers who are replaced by technology, we might also apply this critique to the possible consequences ofdigital fabrication. Our recent history of prefabrication, when in its adolescence, createddehumanizing mass-produced housing. As a new wave of technology emerges, we have a responsibility to explore the potential not just for seductive form or efficient construction, but alsoto consider the lived experience of individuals and communities in their engagement with new technology.We seek to explore the deeper societal potential of technological changes, as well as the more immediate design and construction innovations.

The EDFAB project (Fig. 1) began by proposing to build and test a small timber based unit using some digital fabrication techniques that we had seen emerging in Europe and North America. The aim was initially to test the potential benefits of a ‘do-it-yourself’ (DIY) approach, and whethersuch a system could conform to New Zealand standards.

A ‘sleep-out,’ a freestanding additional room, is a traditional addition to the New Zealand suburban home. It is typical constructed in a ‘do-it-yourself’ fashion and although it benefits greatly the owners or occupiers, its ad-hoc construction causes problems. It can be damp, draughty, cold in winter and overheat in summer. The research takes its inspiration from other businesses such as furniture able to use digital fabrication to prepare some aspects of an object prior to shipping so that DIY assembly does not compromise the quality of the built object.

The project is located in Avondale,a neighborhood of the city of Auckland, New Zealand. Although Auckland is a relatively low-density city, recent population growth has exacerbated high land prices and a very aggressive housing market. Arguably, the city is becoming unaffordable for the average citizen. In Auckland it is possible to see how the existing neo-liberal design and construction procurement model could potentially fail to fulfill demand and the provision of healthy affordable homes..

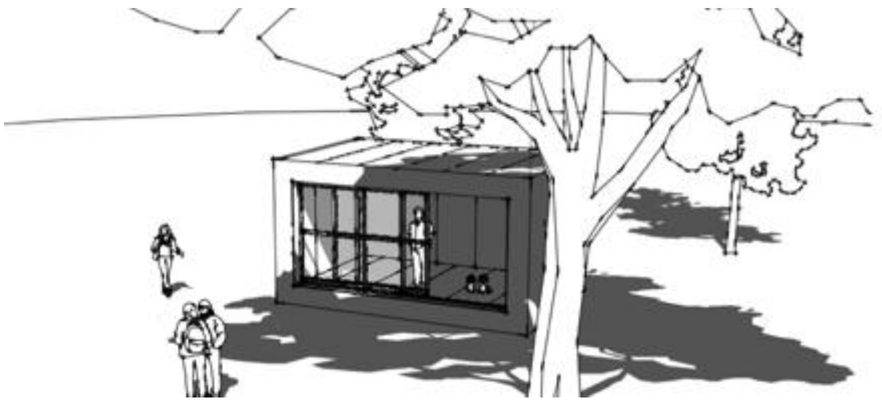

Fig. 1.The EDFAB construction system to build a ‘sleep-out,’ a common addition to NZ domestic space

Using Rhinoceros and Grasshopper 3D modeling software it was possible to create a parametric description of the 'sleep-out.' This software could automatically subdivide the unit into a number of rectangular box-like parts, then automatically compute the cutting templates that could be fed directly into a CNC router for fabrication (Fig. 2).

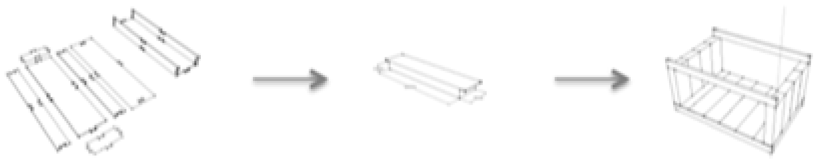

Fig. 2. Cutting templates, assembled into boxes, and boxes constructing a building

Through this process, constraints became opportunities. The depth of the unit was limited by the length of available plywood boards (2400mm) and the length was limited by the span possible using our chosen size of timber beam. By encoding constraints into the software, it was possible to avoid a user specifying dimensions that would result in parts that could not be fabricated out of standard plywood panels, or if fabricated, would potentially be structurally unsound. With these constraints encoded in expert software, it became obvious that we could create a very easy-to-use computationally light desktop application that would enable a user to manipulate and tailor a unit's size to their specifications (but within the encode constraints). When a particular size was agreed upon, the information could then be communicated to the expert software that would then undertake the computationally heavy generation of all the cutting component templates necessary. Making available a variety of customized solutions matching the pre-set constraints affords certain freedoms to the end user (a client or prospective owner); freedoms that typically have to be carefully managed as they can easily delay or complicate a careful programme of design and construction. Traditional skills such as structural and environmental design expertise remained critical, but they could be shifted from the late design phase to the initial one, i.e. during the development of our software and data interchange protocols. New skills were also required in the form of software developers, in particular ones that were attuned to design and construction. For this stage of the project, we were able to find them within the Department of Architecture, confirming what McMeel and Amor [4], [10] have discussed elsewhere, i.e. that the skillsets of emerging architects increasingly involves sophisticated computational abilities.

Communication is critical during design and construction. Paper drawings are a long established means of transferring information between the multitude of professions and trades necessary to deliver a finished building. Drawings have evolved into a very effective tool to communicate, coordinate and help disparate stakeholders converge on a common understanding. DWG (the proprietary file format of AutoCAD) and DXF (Drawing eXchange Format) are the digital equivalent and have been used successfully since the 1980s for exchanging geometry in the form of drawings and models. We are, however, in the Information Age where CAD (computer aided design) has given way to BIM (building information modeling). Geometric models have given way to information models and exchange formats such as DXF and DWG have given way to IFC (Industry Foundation Classes) and CoBIE (Construction Operations Building Information Exchange). These digital standards and conventions seem in keeping with their paper predecessor, but there is a stark difference. Whereas drawings are a means to mediate the different languages, grammars and ontologies that make up the building process, these emerging standards are languages of themselves and, although they are descriptively adequate to communicate between virtual stakeholders, they are neither particularly efficient nor particularly optimal for communication between any roles or disciplines.

McMeel and Lee [11] have scrutinized construction ontologically and theorized an emerging pre-ontology, which provides a framework to conceptualize these communication conventions. However, they remain highly problematic in so far as the notion of a pre-ontology, be it in the form of IFC or CoBIE, does not seem to have a natural resonance with industry stakeholders. The industry's resistance to the uptake of these communication conventions is well documented. Design and construction is—like nature—a competitive ecosystem where the fittest and leanest survive. There is no room for inefficient communication, no matter how comprehensive it is.

Let us turn for a moment to the natural world's complex ecologies and communication systems. Where one insect uses color to fend off a predator, another uses scent to attract a mate; each affords specific and clear channels of communication. In *Life Itself*, theoretical biologistRobert Rosen[12] has conceptualized this in terms of 'dictionaries.' Each channel of communication has two dictionaries associated with it, one at each side of the communication channel, for encoding and interpreting the signal. Rosen makes it clear these dictionaries are not necessarily the same, but they are highly efficient. As anecology grows, so do the number of dictionaries, but importantly they are quite simple. It is the aggregation of these channels that makes for a complex ecology. This is in stark contrast to communication within the AEC (Architecture, Engineering and Construction) industries, where best practice is often to implement a complex interoperability protocol, which is highly technical and somewhat overwhelming. It is perhaps then natural that they are resisted.

In EDFAB we took a fresh look at communication and used Rosen's concepts of natural communication to inform our strategy. In the following sections, wedetail the three parts of the project, the construction method, expert user interface (xUI) and the end user interface (eUI). We will discuss the parts of the EDFAB ecology and how the efficiency of the communication protocol was addressed.

2.2 Construction

Exhaustive surveys of the impact of technologyon human interactions in office environments have been carried out by Robert Kling[14, 15, 16], an expert on the study of social informatics. One of Kling's key findings, which we might take for granted today, is that where technology is introduced unexpected things happen.

Often this is as a consequence of technologies' effect on human interaction. Technology alters the ease or difficulty with which we communicate, skill sets need to change and roles become redefined. He also recognized that technology is sometimes implemented for political reasons. In such cases, Kling found there is often little evidence that politically-motivated change actually delivers overall improvements. Turning to construction, we have lessons that can be learned; firstly to exploit digital fabrication technology change is necessary and secondly these changes will likely have consequences well beyond the places they are implemented.

In the last ten years a method of construction has been emerging and documented[3] that capitalizes on digital fabrication. This method has been used successfully by Facit Homes, a bespoke house design and manufacturing company in the UK. The system breaks a design down into building blocks; one might draw the analogy of a LEGO system for grownups. Each block is then broken down further into flat pieces that can all be cut out of standard sheets of plywood by a CNC router and easily assembled. The blocks are easily carried by two people and built up on site.

This system was modified to accommodate the plywood availability and building standards in New Zealand. A 1:1 scale prototype of one section of the sleep-out was built (Fig. 3) to test the system, detailing and tolerances. This information will be built into the digital models and software interfaces to ensure some similitude between the digital model and the final real building. The system uses a 'butterfly' plug that is hammered into place between each block; this interlocks the blocks and creates a robust structure. In Europe the current best practice is to tape the joints in lieu of wrapping the structure in a vapor barrier membrane.

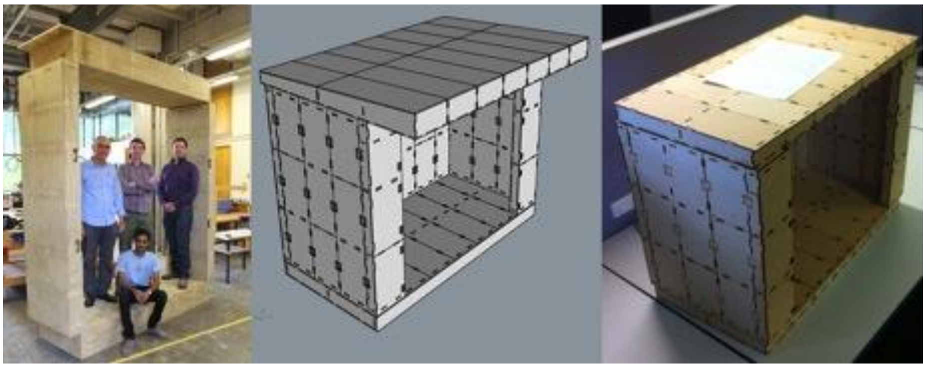

Fig. 3. 1:1 prototype, digital model and 1:6 scaled model of the sleep-out

During this process a number of factors emerged. Locally-available New Zealand plywood for general building construction is not as dimensionally stable as its European counterpart. Latvian Birch appears to be the plywood of choice for this method of fabrication and construction. Imported Chilean plywood was also used and also found to have deviations that cause problems for digital fabrication. Even with these stability issues it was possible to construct the 1:1 section. Having completed the section of the 1:1 model and modified some details, a 1:6 scaled model (Fig. 3) was construed to assess the new details, the overall construction concept and also to check for ‘creep’, i.e. the phenomenon where small deviations in the physical construction are aggregated over the length of the building causing the combined components to be of a different length than intended.

2.3 Software

The expert user interface software is closely linked to the construction technique, as much of what was learned through the building the prototype and model was necessary, as aspects of it would be encoded into the software interface. The interface is built using Rhinoceros (http://www.rhino3d.com/), a popular 3D modelling software, in combination with Grasshopper (http://www.grasshopper3d.com/), a parametric plugin that provides a ‘procedural’ interface for Rhino.

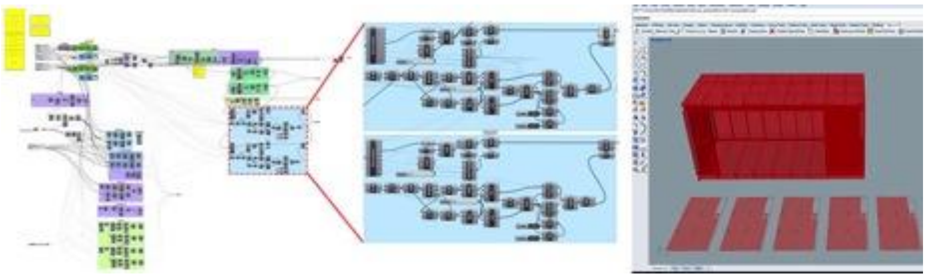

Fig. 4. On Left the xUI Grasshopper description; Centre a detail of its complexity; on right a screenshot of the xUI building the model and its components

A sense of the complexity of this process can be gleaned from Fig. 4. At the extreme left we have an illustration of the software, the center diagram is a detail of its complexity - each box represents a calculation or decision. For example, one of these boxes contains a detail drawing of our butterfly joint. If we decided to change the joint we could change the detail once and have it changed throughout the project automatically. The illustration on the left of Figure 4 represents only fifty percent of the software, which executed choices and decision based on what we have learned from building the prototype section and the 1:6 model. It is interesting to look at an image of what is essentially a digital encoding of the design decisions necessary to create the construction components from a 3D model. Itgives us pause for thought about the complexity of a typical design and construction process, where here there are literally hundreds of interconnected decision and choices necessary to deliver a relatively small and regular shaped building.

The only input the expert system needs is three Cartesian coordinates that represent the length, width and height of the sleep out. With the deepened understanding of the system we could impose limits on these dimension to ensure constructability and structural stability. With this in mind we commissioned a standalone easy to use application that could be downloaded by an end user to tailor their design requirements. Concurrently we were devising a communication protocol to exchange information between the end user interface (eUI) and the expert user interface (xUI).

The eUI: end user interface (Fig. 5) was written in C++, which was chosen because it can be compiled to run on almost any computing device, such as Windows PC, Mac OSX or handheld devices running the iOS operating system from Apple. None of the sophisticated construction information is replicated here. This is a simple application that gives the end user the visual appearance of the sleep out construction, and offers the ability to easily change some of the dimensions within the limits we have specified. A silhouette gives a sense of scale and there is an approximate floor area provided – a value that is useful to a potential end user. In essence, having worked through a processes to capitalize on digital fabrication and build software that enable us to leverage the benefits, we have been able to pass certain freedom, in this case design freedoms, onto the end user. These design freedoms are not afforded under traditional design and build processes as they have the potential to compromise the construction programme.

Fig. 5. EFFAB end user interface software

When the need for information exchange arises within a traditional design and build programme, a geometric model interchange standard is used. Most of the standards for digital information exchange in the AEC industries are for communicating geometry (OBJ, DXF, DWG, 3DS). Within our ecosystem we have no need for communicating geometry. Instead, we need to send some coordinate information and the xUI will build the geometric model according to its needs, initially we explored IFC and CoBIE, which have been mentioned earlier in this paper. Both are very comprehensive but IFCs have a very complex syntax associated with them and CoBIE seems to privilege a spreadsheet layout, which is not optimal for application data interchange. We instead adopted a CSV (comma separated variable) file syntax, which has a very simple structure (Fig. 6). This file type is quitecommon for transferring information to and from databases and subsequently is suited to both data exchange and to efficient digital communication.

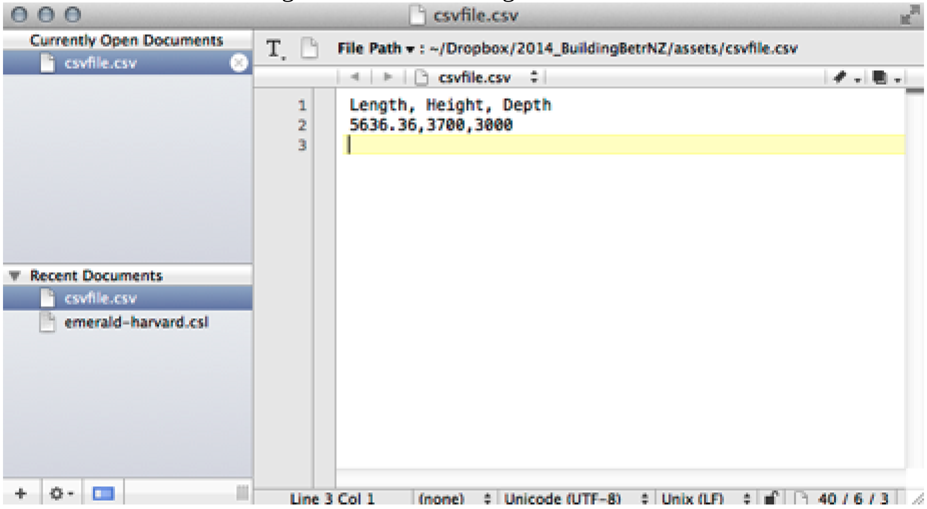

Fig. 6. The CSV file for exchanging information between the eUI and xUI

This was the simple ecosystem we developed to leverage the possibilities of digital fabrication. It is still a work-in-progress and at the time of writing we are exploring the possibilities of further structural encoding as well as utilizing JSON (JavaScript Object Notation), a file type that is very popular for data exchange, particular in the burgeoning area of GIS (geographical information systems) and geospatial data, when vast quantities of data need to be transferred quickly and reliably.

3 Analysis

The implications of this research for design and construction will be discussedthrough three themes, they are:*expertise*, *design futures* and *value frameworks*. While this work in progress was not without challenges that prohibit a prescription for success, we can draw from it a number of lessons.

3.1 Expertise

What is perhaps most apparent from the design and building process outlined in section 2 is the extensive, specialist and cross-disciplinary knowledge required in its realization. The unit is in no way exempt from building regulation and still has to comply with the plethora of codes and guidelines. Rather than becoming redundant this knowledge continues to be important.So although we were able to encode aspects of the building code, it was still necessary, in the first instance, to draw on experts with this knowledge. In fact,if we look at design and construction in general there are an increasing number of specializations, in resilience and environmental efficiency, for example, which continues to support the argument that knowledge and expertise is key in the design process.Although this is not without economic impact; increasing specializations increases the size of the design team and ultimately the budget. In light of WikiHouse founder Alistair Parvin's claim that the architecture profession only reaches one percent of the global population [2] there would seem to be an urgent need to make good design more, not less, accessible and economically viable.

Although the research project documented here was modest in scale it offers a more consumer-friendly design and construction methodology, which is both more accessible and economically viable. It is similar to many popular consumer-friendly furniture concepts where the complexity is engineered into the parts, leaving assembly much simpler.

3.2 Design futures

The research raises the two-part question 'to what extent can a design to fabrication process be encoded, and made easier to use by non-experts?' Although our encoding was limited to structural guidelines, it may be possible to encode important design principles. Using geo-location to encode wall construction for thermal performance or encoding window and door size and orientation to capitalize on natural heating and cooling principles seems a logical step.

The development of the software ecosystem created the possibility of more personalization by an end user. Initial experiments with prefabrication in the 1950's resulted in a high degree of standardization in housing, which because synonymous with social deprivation. While recent off-site manufacturing trends have brought some choice back into the prefab market, Toyota homes are perhaps the most extreme example [17]. While prefabrication continues to improve the provision of choice, the utilization of the parametric architecture in our system offers the possibility of extreme personalization within a fixed prefabricated system.

3.3 New value frameworks

The construction system was intended to be accessible and during the building process we had participation by members of the public, including children(Fig. 7). An unexpected side effect of the construction system was the extent to which the process was highly social. We attribute this to the considerably reduced risk that the digital fabrication process afforded construction. Also the highly technical aspects, such as structural engineering had already been designed into the system, leaving the construction process more akin to building 'Lego.' It was relatively safe and a very tidy construction process. Upon completion, while the rest of the site was slowly reclaimed with graffiti and vandalism,our prototype unit was not (Fig. 8). A local gang initially claimed it as a base by hanging their 'official' colors on it and moved furniture in, before eventually a local homeless person appropriated it for sleeping.

Fig. 7. Children joining in the construction process

Fig. 8. Finish unit as site beings to exhibit signs of vandalism

4 Summary

This prototype was constructed in the suburb of Avondale in the city of Auckland, a community that has recently been made responsible for a number of initiatives by the local council. Including a survey to gather data on where residents would like change, festival organization and art brokerage. As this trend is set to continue the research has investigated a possible future where some of the aspects of architecture have been cede by the design and construction professions.Perhaps most interesting however, was the sense of community-ownership that developed around the build and persisted as resisted vandalism and was appropriated by a gang and the homeless.

The design methodology, construction system and software ecology that grew around it point to alternative models of design, procurement and building. The intention was to investigate how, to what extent, control of design and construction can be ceded to citizens. As individuals and groups often have valuable knowledge about the community and what is and is not required.

This research extends the discourse beyond the provision of installations for temporary activation and explores the concept of 'urban prototyping' as a means of advancing the discourse on how future cities will be designed, procured, constructed and regulated, and presents a possible design future that is more economic, egalitarian and sustainable.

Further research will examine potential changes to public infrastructures, investment and organizational systems that will be required in order to demonstrate scalability of the participatory pilot project explored here.

Acknowledgements

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