Fabricate it, paint it – and don't wait up

Separating fact from fiction with digitally sponsored fabrication

Abstract. This paper offers perspectives on emerging trends in digital fabrication. We explore effects on communication practices and investigate how the associated changing materiality of data is impacting collaboration and interoperability within design and making. Computer numerical controlled (CNC) routing and laser-cutting services are available in most major cities. Affordable 3D printer kits, CNC routers and DIY KUKA robot kits are available across the Internet. A considerable part of the attraction of these tools is the ability to fabricate physical goods without fabrication expertise. We look at this phenomenon more closely through making furniture with CNC techniques and the use of 3D printing for making robots as well as tangibles for a Microsoft Surface. In our examples it appears materiality remains an important factor throughout the design and making processes. We aim to unpick these examples to shed light on how these technologies actually impact design and making practices.

Keywords. Design, digital media, fabrication, 3D printing, CNC routing, materiality.

1 Introduction

Tony Stark: "Hey, I like it, fabricate it, paint it."
Jarvis: "Commencing automated assembly, estimated completion time 5 hours."
Tony Stark: "Don't wait up honey…"

The above quote is from the film Iron Man (2008) and perhaps serves as the example par excellence of aspirations surrounding digital fabrication; the materialization of designs without compromise from real world manufacturing limitations. We might argue that fact is not far from fiction, objects can be downloaded from Thingiverse.com and printed on Ultimaker or Makerbot 3D printer, which can be purchased for no more than a modest home theater system. So, to some extents, the reality of digital fabrication is delivering on our imagined aspirations.

However, computer scientist Paul Dourish claims materiality continues to have importance in our digital age [1]. He reflects on the historical shift from spoken to literate culture and the subsequent effects on knowledge practices. Breathtaking feats of memory and engaged storytelling receded as notions of correctness and accuracy came into relief. Dourish goes on to scrutinise the relational database from the same intellectual perspective and in a recent keynote at NordiCHI in 2012 he extended his critique to include cloud computing [2]. These examples are used by Dourish to reinforce the hypothesis that each innovation is changing the materiality of data and thus impacting surrounding knowledge practices.

Turning to research in the domain of technology within design and construction, there is a vast body of work, which continues to increase [3–6]. While this discourse is most often associated with material assembly, there is little reflection on the material representation these technologies privilege and the subsequent effects on surrounding knowledge practices. Current innovation seems to be emerging through parametric computer aided design (CAD) systems such as Rhino and Grasshopper, rather than traditional Cartesian CAD software. Are there consequences of working in the parametric rather than the Cartesian? It is relatively easy for a professional or amateur designer to engage a company offering 3D printing or CNC routing services. Does the inclusion of these tools help or hinder communication between people? What are the effects for inter-operability between software and systems within design and construction processes?

We will use selected examples to help illustrate this changing materiality and reflect on the consequences. The first selection comprises two pieces of furniture, designed and fabricated using CNC techniques. The second selection covers two projects that employ 3D printing, the design of a robot and the design of tangibles for a Microsoft Surface interface. We hypothesise transitioning to these tools, much like transitioning from a spoken to a literate culture, causes a material change in how goods are described. We ask how is this affecting the surrounding knowledge practices within design and construction?

2 What's in a drawing?

This section will scrutnise the tools of design, representation and manufacture through making pieces of furniture. Of interest here are the communication practices surrounding design and manufacture. It is perhaps useful at this point to distinguish between encoding of digital goods for the transfer of manufacturing knowledge and encoding goods for transfer to manufacturing tools.

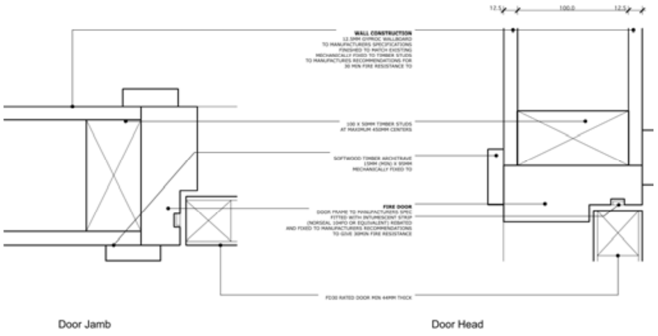

Fig. 1. Detail of a typical construction drawing

The authors positions on the complexities of communication in design and construction have been documented elsewhere; including investigations into technologies such as phones and augmented reality [7–9]. Yet in light of the burgeoning field of technology in design and construction drawings still remain the primary means of communication. The traditional construction drawing illustrated in **Fig. 1** is an example of what we call *encoding digital goods for the transfer of knowledge for manufacture*. This drawing was abstracted from a highly detailed and accurate 3D digital building information model (BIM). While this model was continually updated and contained detailed materials, specification and furniture information, drawings like that in **Fig. 1** are the primary means of transferring knowledge to other groups of people for manufacturing and construction.

Fig. 2. The soft table digital file and finished product

By contrast the 3D table model in **Fig. 2** is an example of *encoding digital goods for transfer to manufacturing tools*, sometimes referred to as direct digital manufacturing (DDM). This model was initially printed to scale on a 3D printer and eventually subdivided for direct manufacture with a computer numerical controlled (CNC) router; which we are going to discuss in some detail in the following section. In both instances of encoding for manufacturing, people are involved. The knowledge practices that surround the encoded drawing in **Fig. 1** involves people interpreting of the encoded goods. The people involved at the manufacturing end of the table illustrated in **Fig. 2** do not need to interpret the goods. Throughout the course of this paper we will reveal the consequences of this important difference.

2.1 Digitally encoding a 'soft' table

The soft table design is heavily influenced by the work of artist Salvador Dalí; the table is intended to give the impression it has melted at one side (**Fig. 2**). The table was sketched manually over a period of days; the specific geometry was eventually resolved using the Rhino modeling software. Renderings like the one illustrated in **Fig. 2** were brought to the traditional woodworking shop and the digital fabrication workshop within the School of Architecture and Planning at the University of Auckland. These were initially used to prompt discussions with the different traditional and digital workshop fabrication specialists, regarding how the piece could conceivably be manufactured. Eventually it was agreed to manufacture the soft leg and tabletop separately by CNC routing, and then assemble the two parts with manual techniques.

There were a number of manufacturing challenges with the leg that led us to mill a prototype out of polystyrene. This revealed two problems, firstly where the leg joined the table, its geometry tapered exponentially to zero. This caused the material to break erratically at that edge. Secondly the steep sides to the lower part of the leg resulted in the collet (or chuck) that holds the router cutting bit to occasionally collide with the leg while cutting, causing inaccuracies in the geometry. The first problem was resolved by changing where the tabletop and leg were separated; the second problem was solved by imperceptibly altering the geometry of the leg. The amended digital files were the only documents passed to the digital fabrication specialist for manufacturing. The plywood was prepared in the traditional workshop before being transferred to the digital fabrication workshop for routing, the pieces were then returned to the traditional workshop for careful assembly, sanding and finishing; a detailed video of the process can be found at https://vimeo.com/35361578.

Both the tabletop and the leg required routing treatment on opposite sides. After the initial routing both pieces were turned upside down and further routing cuts were executed on their underside. What followed was a moment of crisis, when the digital fabrication specialist, having just turned the tabletop over, noticed the initial routing cuts were actually off center and not aligned to the center of the table. She had assumed the leg was centered on the table and was only now realizing this was not the case; she did not *know* the correct position of the table leg. However, that did not matter as the position of the table leg was encoded correctly in the digital representation, and the digital fabrication specialist applied the correct CNC processes for milling. Thus when the router was started it moved quickly to the correct offset position and began cutting. It is perhaps also worth explaining the disparity between the length of the table in the rendering and the final product. On a hand drawing of the blocks of wood to be prepared for routing a ‘1’ was mistaken for a ‘7,’ it was assumed then that the dimension as written was 750.0mm and not 1500mm.

What is of interest within the context of this discussion—and we will scrutnise in the following section—is how the nuanced offset of the leg was carried through to the finished product without actually being known by any of the manufacturing stakeholders in either the traditional or digital workshops and yet the length of the table was lost-in-translation.

2.2 Reflections on direct digital manufacture

Design descriptions are traditionally in the form of plans, sections and elevations; Cartesian geometry used to record information for transfer between people. Although there are notable exceptions in contemporary design and construction [3–5], this is generally still the case. Even where sophisticated building information models (BIMs) are employed, they are eventually abstracted to a drawn schematic for manufacturing and construction purposes. Yet in our example it was the manual drawing that was misunderstood, the digital encoding of the table and practices that surround it reliably carried the design's nuances through to manufacture. If we are finding better ways to translate goods between design and manufacturing, why does the drawing remain so pervasive?

It is easy to overlook how harsh the construction environment is and how robust and resilient traditional drawings and communication processes are to operate successfully within that environment. However, let us not underestimate the privileged position drawing holds within design and construction. On the education of the architect, Vitruvius, in the first chapter of book one of *The Ten Books on Architecture* states "let him be educated, skillful with the pencil, instructed in geometry" [10]. Establishing the importance of drawings and Cartesian geometry. There is also the story of the Italian painter and architect Giotto who displayed his skills to Pope Boniface the Eighth by drawing a perfect circle [11]. Suggesting drawing ability as a surrogate metric for measuring skill or craftsmanship. In our soft table example drawings were not used for the transfer of information for manufacturing, they were used extensively during discussions in the early stages. These observations support the hypothesis drawings are loosing value as a mean to transfer knowledge through Cartesian geometry. Although it also reveals they continue to have value for helping different stakeholders converge on mutual understanding. A subject Michael Reddy has explored in some detail through the *Toolmakers Paradigm* [12].

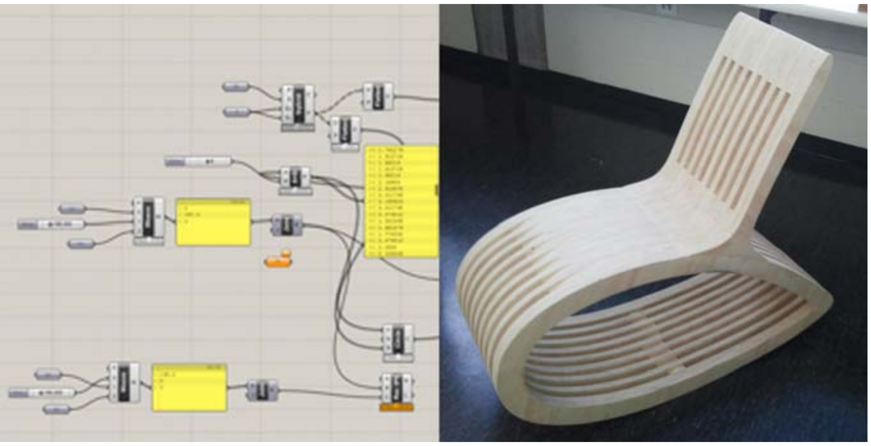

Fig. 3. Parametric description and manufactured rocking chair by Lynda Ea

A follow up design studio in the School of Architecture and Planning introduced parametric tools into this digitally sponsored fabrication process to explore further aspects of digital materiality. Observational evidence from the studio, perhaps best reflected in the *rocking revival* project (**Fig. 3**), also supports the thesis that drawings are being challenged as the primary means of transferring knowledge for manufacturing. The parametric description of the chair let the designer alter the height and width of the seat. The parametric description was automatically slicing the chair into the required sections, which could be passed straight to the CNC router as simple vector files. When the designer changed the chair parameters, the parametric description changes relational parts to the appropriate size. As this is then passed to the CNC router with minimal human intervention, knowing the specific dimensions and geometry of the individual parts is now redundant. The etymological origins of this practice are perhaps telling, para - 'contrary to' and metric – 'that means by which anything is measured.' Which places the parametric ideologically in opposition to the dogma of Cartesian measurement that underpins design and making practices. Which may have it merits, as a deeper reading of Vitruvius reveals his rules are flawed, particular where geometry and measurement are called for. McEwen draws our attention to the use of *tempering*—meaning to soften or mitigate—by Vitruvius in reference to rules of symmetry [13]. The point Vitruvius makes is the appearance of symmetry is more desirable than geometric symmetry. Here, one of the first authoritative design and construction manuals recognizes measurement as suboptimal for encoding design intent.

2.3 A shifting foundation of knowledge practice

Parametric materiality and digitally sponsored fabrication processes are altering, in particular, perceptions of Cartesian measurement. Mark Burry et. al. have conducted analysis of parametric encoding in relation to understanding [5]. Their findings suggest parametric schema can be used to improve legibility. This is of particular interest to Burry within the context of working with highly complex parametric schema in a highly collaborative and specialised environment. Our observations point to parametric schema offering the ability to deeply encode the designer’s intent and potentially make important—albeit esoteric—aspects of design more legible. As we draw this section to a close we suggest research surrounding digital materiality cannot be confined to matters of representation. Our observations point to it having consequences for understanding and knowledge practices surrounding communication and documentation, which are foundational practices that are deeply embedded in how we know design and construction.

3 Directly manufacturing robots

We now turn our attention to a selection of projects employing 3D printing. We believe this technique also has implications beyond simple novelty of fabrication. Our observations have led us to revisit Leví-Strauss seminal text *The Savage Mind* [14], and reflect on the relationship between materiality and ways of thinking.

3.1 Fabricating robots

The following project was undertaken on the Masters programme at the School of Architecture and Planning within the University of Auckland; the aim was to develop a novel fabrication robot. Initially two DIY robot kits were appropriated from the Internet; a KUKA style automotive armature robot and a delta robot. Both kits came as a series of 2D vector files of parts that could be laser cut and assembled. Later, as the student's knowledge grew, he modified the kits and eventually began hacking them together. One aspect of the delta robot that is of particular interest in the context of this paper is the manufacture of ball-joints by 3D printing (**Fig. 4**).

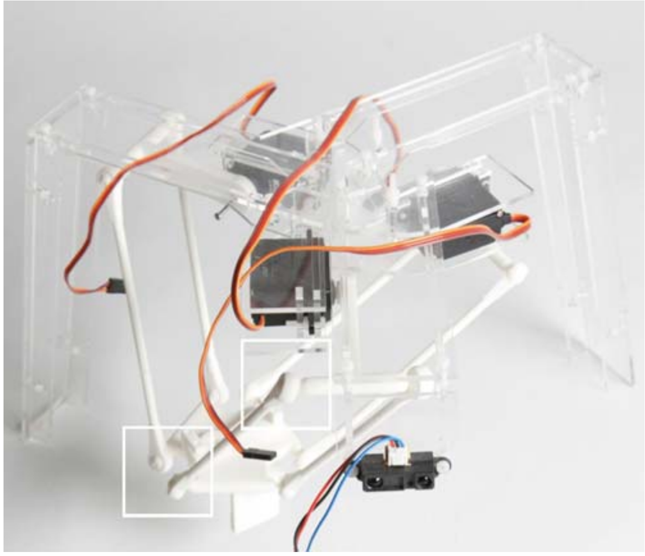

Fig. 4. Delta robot by Adrian Kumar with highlighted 3D printed ball-joints

The ball joints as highlighted in **Fig. 4** allow freedom of movement in all three axis (x,y,z) and are a key part of the design. A standard commercial brass joint cost approximately twenty New Zealand dollars. Although they are reliable the design required twelve, which was costly; also their combined weight might put the servomotors under stress and potentially adversely affect moment of the robot. The student suspected he could print them on a high quality nylon 3D printer; the resultant component highlighted in **Fig. 4** was strong enough to be fit for purpose, light and had a relatively low friction coefficient resulting in smooth movement. Eventually a large percentage of the delta robot armatures were being designed and printed because it was cost effective, the materiality was adequate to function structurally on a project of this scale, it made modifications quite easy as now all parts were under a state of contingency and could be changed if required.

3.2 Bricolage or Engineering?

We couch our observations in terms of bricolage, which is one of two methodologies for problem solving established by Lévi-Strauss in his seminal text *The Savage Mind*. The other method—to engineer—is to design a unique solution to a specific problem. To engineer requires mastery of a specific domain and materials to conceive of and deploy tailored solutions to individual problems. Bricolage by contrast requires no such mastery; a bricoleur is in possession of a kit-of-parts, so to speak, appropriated from specific contexts. They have been appropriated for their propensity for reuse and recombination so the bricoleur might address problems. The difference is not in the complexity or sophistication of problem that the bricoleur or engineer can address, but rather in the methodology of problem solving. If we are to say the engineer designs their solution then the bricoleur divines his through bricolage, critique and iteration; finding the way to an acceptable solution.

The choice, by Leví-Strauss, to discuss his observations in terms of the engineer and the bricoleur, rather than engineering and bricolage, suggests they are mutually exclusive engrained cognitive processes. It suggests they are ways of thinking and not simply problem solving methods to be chosen as and when needed.

Yet, that is precisely what we observed, in the early stages of the project bricolage dominated; in the later stages of the build, particularly during decision making surrounding the ball-joints, we see engineering take center stage. The student with a deeper knowledge at this point and with access to a 3D printer begins to design bespoke components to address a specific problem and context. When questioned on the implications of having access to a 3D printer the student found it hard to elucidate his design process and the implication of the technology. It appeared his entire creative processes were put into a state of contingency, as the potential existed to redesign and print any components within the robot.

In a parallel project that took place within the Department of Computer Science using an Ultimaker 3D printer a group of students were creating *tangibles* small objects that could be place on a Microsoft Surface (Fig. 5). These objects could be individually recognized and used to interact with the Surface. Instinctively the students began creating their own 3D objects for printing, although it took a little time to grasp the materiality and digital requirements for building and saving digital objects for 3D printing. What is interesting is that both groups when provided access to 3D printing technology quickly moved to the creation of unique objects rather than downloading and printing set items from repositories such as Thingiverse.com.

Fig. 5. 3D printed tangibles for MS Surface, image by Keerthana Puppala

3.3 Scaffolding for problem solving

Rather than methods of problem solving being deeply engrained in cognitive process, our observations would perhaps point to it being informed through the tools we have at our disposal. Both projects displayed elements of bricolage, appropriating code and toolkits to assemble projects much faster than would be possible if they had to create everything from scratch. However when given access to 3D printing technology it was not used for bricolage, which would have been quite easy with large depositories of 3D objects available from Thingiverse (http://www.thingiverse.com/) and Google's 3D Warehouse (http://sketchup.google.com/3dwarehouse/). Within their respective creative processes we suggest the 3D printer did not promote this type of thinking, rather it seemed to promote the creation of bespoke and well-engineered solutions. We can couch these observations in terms of Andy Clark hypothesis on cognitive scaffolds, which argues our environment informs our though processes through situated cognition [15] and external scaffolding for the mind [16]. If we subscribe to this thesis, then DDM does not just provide novel methods for fabrication; it is creating new tools that support different ways of thinking.

4 Summary

We have briefly studied a selection of projects that we believe reveal important insights into the consequences of digital fabrication beyond novel material manufacture. While there is little originality in claims they change practices and processes, there is a suggestion here they exert influence on ways of thinking. There is a clear decline in the use of drawings as a means to contain and transfer Cartesian geometry, which is a foundational knowledge practice within design and construction. The drawing was by no means redundant in the processes we studied here, it helped to stimulate discourse and align understanding between different stakeholders. If the skills of drawing are in decline, then through our selection of projects that engaged in 3D printing we might be encouraged that it appeared—within the context of digital design and fabrication—to discourage appropriation and bricolage and instead encourage bespoke design and the engineering of unique solutions. There is more happening here than the often-cited Marxist position that technology deskills and does not favour the individual. Rather there appears the potential for this shifting materiality of our digital goods to positively impact ways of thinking within design and manufacture. Perhaps that much, the film Iron Man got right.

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