No Place for Drones

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Building design is a process often divorced from considerations about construction. Digital design methods are increasingly challenging the historic relationship between architecture and its means of production, but this extended reach is not necessarily accompanied by extended understanding or leverage of the production process. We present an urban sculptural project, The Travellers, in which digital techniques resolved critical issues of design, documentation and fabrication, but more importantly facilitated highly beneficial processes of negotiation. We suggest that this case based research has implications for future interactions between designers, makers and managers, shedding additional light onto issues of negotiation, responsibility, risk and trust that are often critical to the pragmatic undertaking of making.

Keywords: Design integration; digital design; fabrication; negotiation

Introduction

“The freer people are when they’re thinking about a building, the more important it is to button down into how it’s going to be made. Therefore we'll have to be working more and more closely with the people who are making it.”

Mike Cook

Complex geometries, limited budgets and short time scales place particular pressures on the design process, and successful outcomes are increasingly dependant on the capacity of the project team to synthesize, at an early stage, issues which occur across domains at different levels of precision. In examining the benefits that the computer brings to enabling design and its communication, we can ask to what extent the digital realm can support the confidence and buy-in necessary for working together more closely? In this paper we suggest that the development and implementation of strategies for co-rationalisation whereby processes of design can intersect with processes of making, is a point at which the computer can discernibly aid in managing the more elusive issues of responsibility, risk and collaboration.

Project description

The Travellers are a series of 10 stainless steel sculptural figures designed by Nadim Karam and Atelier Hapsitus, constructed in 2006 on Sandridge Bridge, Melbourne. Each ‘traveller’ is a free standing stainless steel frame figure 7.5 m tall and between 5-10 m wide comprising of hundreds of connecting stainless steel RHS pieces, formed from “families” of members that
make up two similar planar surfaces connected by a series of diagonal curves. Each planar member and its identical “twin” in the parallel plane (they average 750mm apart), are joined together by a diagonal member whose curvature in turn is defined by the two co planar members. The process of designing and constructing the Travellers was characterized by complex geometry, a limited budget and a project timescale of 9 months between conceptual sketch and being completed on site.

The project artist, Nadim Karam, was located in Beirut and the rest of the project team in Melbourne. This team included the Melbourne City Council as project architect and project manager, Arup structural and mechanical engineers and fabricator Silverstone Engineering.

In his recent review of the piece ‘Something Rich and Strange’, Ronald Jones discusses this divide between design and production, warning that “the disjunction between conception and execution means artists miss vital iterative relationships between idea, medium and technique”. While traditional notions of authorship fixate on conception and relegate production to “the labour of drones”, in this case the collaboration between drones is credited with the successful translation from concept to a well built “pearl” (Jones, 2006). The following account explores the issues involved and describes the collaboration that evolved during the project, revealing the process to be no place for drones.

**Conceptual framework**

Working collaboratively demands that “almost invariably we are working with others whose skills we lack or have only to a limited degree” (Thornton 2007, p. 102) however this relationship is limited by the fact that, with few exceptions, designers and makers tend to optimise within their own domains (CRC CI, 2002) and operate virtually discrete processes when designing the same building (Howrie 1995, p. 8). As Charles Eastman has noted, “the easy, close-working relationship between designers and builders has largely disappeared” (2004, p. 20), to be replaced by concerns over liability, responsibility and risk management.

It has been argued that the current design-bid-build method of contracting promotes litigation and restricts innovation (Eastman 2004, p. 21), and that the inadequacy of traditional drawing techniques has exacerbated the gap between “design and producing that opened up when designers began making drawings” (Mitchell and McCullough 1995). Kolarevic has added the view that “as digital data is increasingly passed directly from an architect to a fabricator, so will the building design and construction process become more efficient” (2001, p. 274) however simply substituting 3D models for drawings does not automatically guarantee a coherence of information, as Maher and Burry (2006, p. 202) have noted. Most of the cost and technical knowledge for the manufactured portion of buildings does not reside with designers but rather with specialty trade contractors and manufacturers.

The generation of trust, or buy in, by all parties is critically important to the success of any project, yet the amount of discussion concerning how this might be generated and supported lags far behind the default discussion of any BIM conference: how risk and liability might be covered (in the design world, claims to authorship generally do not correspond to acceptance of responsibility). Dennis Shelden (2002, p. 25), in discussing some of the reasons why Gehry Partners has pursued non-conventional methods to document and communicate design, explicitly addresses some of the barriers to buy-in:
While fabricators could build the shapes, the process of bidding and coordinating the projects presented difficulty to construction managers. Accuracy of quantity takeoffs could not be guaranteed using conventional methods of measuring off the plans. Shop drawings – necessary for describing the detailed fabrication geometry – were difficult to render into orthogonal views... The limitations of understanding the project geometry through the lens of two dimensional views exacerbated perceptions of project complexity.

Peter Rice has described addressing similar issues at Arup in the 70’s – “it is part of our procedure, in designing unusual buildings, to explain precisely what it is we’re doing... so that [all parties] understand that they aren’t taking exceptional risks” (1991, p. 104). These views suggest that at least part of the current concern about who holds responsibility for the accuracy of information is misplaced, and that instead one of the most immediate problems lies in developing ways to mitigate risk through increasing understanding. Processes and representational techniques that make it easier to understand and utilise design information are certainly central to addressing this problem. A second and rather obvious problem lies in generating accurate information in the first place.

Rationalisation, understood as the resolution of rules of constructability into project geometry (Shelden 2002, p. 78) comes in three forms (Fischer p. 13). Pre rationalisation defines the construction system before the design, whereas in a post rationalised approach the construction system is imposed after design has been finalised. Co-rationalisation sits between these two strategies, and occurs when the construction system is defined “alongside and to some extent through the process of defining a form” (Loukissas 2003, p. 32). Examples include the work of Gaudi (Burry 2003), Gehry Partners (Shelden 2002) and the Shoal Fly By project (Maher, Woods and Burry 2003). Co rationalisation requires that the designer and the fabricator work closely together during the design phase, with the result that making, and knowledge about making, informs both the design process and the generation and communication of design information. Such an approach has significant demands and impacts on the way we collaborate, some of which were encountered on the Travellers project.

Project process / design

To successfully respond to the issues of geometric complexity, budget and timescale previously described, the Travellers project required a design and procurement process that is unusual in an era of design-bid-build and competitive tendering. A key decision was made to include a specialist stainless steel fabricator as part of the project team from the beginning, so that practical fabrication advice was put into the process from the outset. This section examines how the impact of working ‘more closely with the makers’ affected the project, and describes the digital means by which this interaction was supported and its benefits incorporated into the design and documentation process.

Early costing and material purchase

The Travellers are made from stainless steel RHS, which is imported into Australia with a lead time of 12 or more weeks. This represented a third of the total project time, and it was quickly realised that it would be necessary to pre-purchase the steel before the design, analysis and fabrication processes had been finalised. Initial spline based 3D Rhino™ models had been supplied by the artist, which immediately provided rough schedules and costing information based on member lengths. After this information was extracted from the rhino models, the project manager (MCC) pre-purchased the stainless steel required to fabricate the sculptures - a quantity that was equal to all the stainless steel available in Australia at that time. As well as taking advantage of favourable pricing conditions, this removed a number of variables from the subsequent tender process: precise material lists (of which there was now a guaranteed supply) were supplied as part of the tender documents.
Full scale prototyping
The process of developing a modelling and representation strategy that best fit fabrication and analytical requirements also commenced at the project outset. Scaled wax rapid prototypes and 1:1 steel prototypes were generated from the 3D models to explore different connection options, which were discussed by the artist, architect, engineer and fabricator. The prototyping process gave all parties the ability to understand the requirements of the fabrication process and the geometric constraints that needed to be taken into account, and to deal with fine detail at a time when design had only just begun. As well as resolving issues about preferred connections and finishes, the prototyping process was instrumental in identifying where conflicts occurred between analytical and fabrication requirements, and in identifying strategies that minimised welding.

The largest and most complex sculpture was developed further than the others and provided the basis for a full scale prototype. At an early stage, it became obvious that it would not be possible to fabricate all the sculptures in the given time without additional geometric rationalisation of the radii used in the curving of the sections, particularly the larger 80X80 perimeter sections. This knowledge, as well as that gained about other geometric, representational and fabrication requirements, informed the design process for the other figures.

Geometric rationalisation
The artist’s Rhino models used spline geometry which needed to be approximated with a standard series of arcs and straights for fabrication. Early prototyping had revealed that an additional level of geometric rationalisation was required. This second level of rationalisation was incorporated into the first, which had been coded as an automated process within Rhino™. The rationalisation process, scripted within the software, found the inflexion points along each spline, split the spline at these points and then matched each fragment with the closest arc from a standard series, the second level of rationalisation. Arches are separated by a straight line tangential to each – by inserting this minimum length line each member could be rolled as a continuous piece, greatly minimising time spent welding and polishing in the shop.

A second script generated each diagonal member. Geometrically, each sculpture is defined by two planes and a series of diagonal members that move between them, and these diagonal members can be generated directly from the corresponding members on the top and bottom planes. Automating the rationalisation process greatly decreased the time needed to model each sculpture, and resulted in a standardised set of parts that significantly reduced the time required for fabrication. Additionally, the process ensures accuracy and nodal connectivity between members, streamlining the analysis process.

Structural analysis
Because of the pre-purchase of steel, structural analysis for 9 of the 10 sculptures was performed after the stainless steel sections had already been acquired. 316 L stainless steel RHS was chosen as the primary material, and a sufficient degree of triangulation was incorporated at the nodes of steel member to member connections to enable for a relatively efficient structural system to be developed. Full strength butt welding at joints provide rigidity at all joints and also contributed significantly to the stiffness of the system.

Central to the structural design development process was the management of a single electronic file for each figure. This file was circulated in turn to the client, architect, and Arup designers, to be worked on/developed at each interface. Arup firstly rationalized the proposed geometry, and then analysed and checked these models for structural adequacy. Changes were proposed as necessary to ensure the sculptures were both buildable and structurally adequate, and these would be fed back to the client and ultimately the artist for their consideration. Convergence to a solution typically required two or three iterations to this process, and the City of
Melbourne played an important role as reviewer and in facilitating the speedy flow of information to and from the artist.

The Arup in house structural software GSA™ was used during the analysis, with input directly from Rhino™. The 3D model was prepared prior to importation into GSA™ so that all arcs were pre-faceted to control their approximation and to ensure that the geometric file was as “ready for analysis” as possible. This was important to model the geometry accurately and better estimate the structural performance of each traveller. The models were exported as DXF files; later design iterations and refinement generally involved tweaking, deleting, and inserting individual members, and not re-exporting the entire model.

**Building without drawing**
A series of protocols were developed to coordinate the modelling process between the various parties, which codified the ‘rules of engagement’. These included a specified information flow and required that information passing between the parties would be 3D models in specific formats. The digital models contained only centreline geometry and numeric annotations and, along with a series of spreadsheets, were the only documentation produced.

Documentation for each sculpture consisted of a 3D centreline model and an 8 page spreadsheet, one page per section type. A visual basic routine run from Excel™ extracted length and radius information from each member to the spreadsheet, and tagged each member and element numerically within the 3D model. The time taken to extract the spreadsheets was less than half an hour per sculpture, and the information they contained was fed directly into the bending machinery. The 3D model was used by the fabricators to check the numeric spreadsheet information on the shop floor. To aid the process of moving from spreadsheet to model, a scripted routine was written to select and zoom to any given member within the 3D model from the spreadsheet, as it was found that it was easier to locate members from the spreadsheet than to search for them within the 3D model.

**Manufacturing process**
While digital technologies were used extensively in getting 4455 stainless steel pieces onto the shop floor, the figures needed to be assembled, welded and polished by hand. While future projects seem certain to make use of emerging RFID tagging technology to help automate parts of this process, in this case a hybrid strategy of digital data and templating was employed. The digital extraction process numbered each piece, and this mechanism, in conjunction with plotting a full scale centreline template for each figure, assisted the fabricators to locate the members in each sculpture.

Close and early involvement from the fabricator, and the production of a full scale prototype, had a significant impact on the manufacturing process. The manufacturer of the prototype effectively ran workshops for the other three fabricators involved, going through the process and lessons learnt with each as the prototype was being built. This gave all fabricators, as well as the extended design team, confidence that the project could be systematically approached despite its apparent complexity, and again represents the highly unusual level of cooperation and information sharing achieved in this project.

**Conclusions and implications for the future**
Implicit and significant to this process was the level of engagement by the fabricator early in the piece, and the spirit of cooperation displayed by all disciplines to working towards favourable outcomes for the client and ultimately for all involved. A comparison with the traditional delivery process of jobs within the building industry reveals the following:
- Very few RFI’s were generated during the fabrication process, as design and buildability issues were generally resolved during the design process with the contribution of the fabricator. Significantly more information was available at the tender stage than is usual, reducing the perception of complexity and associated costs.
As information describing the full set out of each Traveller was passed on to the fabricator in an electronic format, shop drawings were not required at all. This significantly streamlined the fabrication process, as there was no requirement for the information to be interpreted, "handled" and checked a second time prior to enabling for fabrication. The absence of shop drawings meant that real savings were made in time, money and resources - while an estimated $20-30K was saved in fees for the production, review and finalisation of shop drawings, the real savings occurred in the avoidance of delay and the associated risk of liquidated damages.

The culture of cooperation consequently allowed for the efficient production and supply of information from the design team to the fabricators. This meant that the often confrontational and sometimes discordant nature of builder / fabricator / design team interplay observed on some building projects was nonexistent in the delivery of the Travellers project.

In addressing the benefit that digital tools brought to the process of realizing the Travellers, we can immediately move beyond the low hanging fruit of increased efficiency and the ‘file to factory’ communication of complex forms. Rather, the point is that the entire design and fabrication team were involved in processes of learning, and if the same project had moved through a traditional representation and procurement cycle then both that, and the collaboration engendered, would not have occurred. In recognising that a conventional approach to procurement means digital tools cannot be used to their full advantage by the design and construction team, we raise a significant question: if the tools are to be used to their full advantage, then does it demand a non traditional procurement process? In the opinion of the authors the answer is yes, because taking full advantage requires an education process involving the entire design and construction team which, in demanding increased involvement, transgresses many traditional boundaries. The observed benefits of collaboration make it difficult to return to the old ways.

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References

Loukissas, Y. Rulebuilding. Exploring Design Worlds through End User Programming. Master of Science