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ARTICULATED TIMBER GROUND, MAKING PAVILION AS PEDAGOGY

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Abstract. Designing and making a pavilion within a studio setting has been undertaken by various educators and researchers as a valuable pedagogy in the past 10 years. It aims to construct a collaborative environment that allows students to develop an integrated approach to learning; through association, teamwork and creative collaboration. Usually the tacit knowledge applied and acquired through making, and the knowledge of design strategy and analysis are separated in the way they are taught; it is often difficult to integrate these within the same coursework which often leads to students using digital software and fabrication tools as problem solving devices. This paper looks at an integrated approach to learning computational design and digital fabrication through the making of a pavilion by a Master level design studio. The paper discusses the pedagogy of making through creative collaboration and integrated workflow. It focuses on the use of digital and physical prototypes as devices to stimulate an oscillating dialogue between problem solving and puzzle making; a counterpoint for students to develop and search for new knowledge in order to create personalised learning experience. The paper concludes with an examination on the limits of digital prototype when interfaced with physical environment.

Keywords. Digital Fabrication; Collaborative Design; Design Workflow; Pedagogy, File to Production

1. Introduction: Making pavilion as pedagogy

Designing and making a pavilion within a studio setting has been undertaken by various educators and researchers as a valuable application of pedagogy in the last decade (Walker and Self 2011). It aims to construct a collaborative environment that allows students to develop an integrated approach to learning; through association, teamwork and creative collaboration (Kalay and Jeong 2003). Usually the tacit knowledge applied and acquired through making, and the knowledge of design strategy and analysis are separated in the way they are taught (McCullough 1998, Salama 2008). It is often difficult to integrate these within the same coursework due to time constraints, which leads to students using digital software and fabrication tools as problem solving devices.

This paper looks at an integrated approach to learning computational design and digital fabrication through the making of a pavilion by a Master level design studio. It discusses the pedagogy of making with focus on the use of digital and physical prototypes as devices to stimulate oscillating dialogue between problem solving and puzzle making in digital design and fabrication. Kalay (2004) suggested that design processes necessitate the need to move between the two above mentioned paradigms in order to achieve a balance between the goals and the solutions. In this paper, the author suggests that this dialogue provides a counterpoint for students to develop and search for new knowledge in order to create personalised learning experiences.

2. Background

2.1 BRIEF

The studio set out to design and fabricate a pavilion in 12 weeks, with a constraint of 25 sheets of 18mm plywood supplied by our sponsor, OH&S requirements and a site boundary of 4 x 4 x 3 metres high located within the University grounds. The brief called for a pavilion that examined the relationship between ground and envelope while engaging with the context of the campus. The objective was to generate a workflow that is manageable and yet complex enough to stimulate an intense office environment for the students. Formally, the project was developed from ruled surface geometry.

The vertical studio had 14 participating students and two studio leaders. The design of the pavilion was selected through a two phase competition structure; refer to section 3.0

2.2 FILE TO PRODUCTION WORKFLOW

The scale of the pavilion allowed students to be immersed in and experience first-hand file-to-production workflow. There are two principal workflow procedures that are explored in this project. Firstly, the continuous feedback loops between digital design information and physical prototyping (Knapp et al 2014). This took place from the early design stage and continued through to the final prototype stage. Secondly, the process of refining the digital information, free of representational annotation, allowed the students to interrogate modelling information for fabrication sequence and assembly (Garber and Jabi 2006). This included preparing files for production and checking procedures. Both of these workflows are widely documented but rarely taught in design studio concurrently.

Figure 1. Articulated Timber Ground pavilion within the University ground.

2.3 DIGITAL FABRICATION AS WICKED PROBLEM

While a typical design studio concludes at the representation of design proposals, even among digitally focused studios, this studio challenged students to take the design one step further to construction. It forced the students to examine the constructability of their design in greater detail and remove their perception of digital fabrication as model making techniques only. By integrating buildability issues with the computational workflows demands a continuous feedback loop between digital analysis and prototyping with 1:1 physical testing and making. Students are confronted with the wicked problem of design (Kalay 2004).

In the context of learning digital design and fabrication, the wicked problem starts when digital data interfaces with the reality of construction, budget and material constraints. Here, students had a preconception that the precision in digital fabrication and workflow naturally leads to a zero tolerance construction process. The reality is a messy business of learning to balance design integrity with constructability, budget, manoeuvring through university OH&S requirements, variable site conditions, just to name a few. The above pedagogy shifts the output of the design studio from the hypothetical to the real; what Salama (2008) called the systematic pedagogy (as opposed to the mechanistic pedagogy) where students grapple with the different aspects of the bodies of knowledge and restructure them to formulate new knowledge and personalized learning experience.

3. Approaches to learning

A common tendency among students which the author observed from both undergraduate and graduate teaching of digital design and fabrication is that students generally have an understanding of the impact of digital fabrication in contemporary practice through various reading. However, understanding of the practical workflow itself is limited; this may be due to the fact that knowledge gained is built on a foundation of limited duration (Boza 2006). From this context, the studio focuses on the following aspect of learning:

- Collaborative design methodology. This is explored through a two phase competition at the start of the studio. Four design teams are formed through self-selection. By Week 3, two proposals are shortlisted; the eliminated teams joined the shortlisted teams to continue to their bid for the project. By Week 6, a jury panel selects one winning scheme to be constructed by the entire studio. After Week 6, the entire studio operates as a single office; refer to Figure 2. The author role changes from tutor to consultants/client representative.
- Constructing a project specific design to fabrication workflow. This is explored during the two competition phases where each team formulates their design based on the concept of ground and envelope learning through precedent study. Each team grapples with their own design workflow with an emphasis on developing both digital and physical prototypes. This is the students' first attempt at constructing a feedback loop between design and fabrication.
- Develop tacit knowledge of tooling and its relationship to the design process. During the competition phases, all the design teams are introduced to a flatbed 3-axis CNC router; from tooling to toolpathing. This expands the fabrication repertoire of the students and forces them to make a leap from model making to large scale prototyping. During this period, individual students build up specialist knowledge of the machining process. This proves to be exceptionally useful during construction phase.
- Examine the haptic relationship between fabrication, material, tooling and the overall design process; the messy business of making. Here, students are challenged to take on a variety of roles; as project coordinator, team leader, quantity surveyor, designer and maker. The feedback loop between digital and physical prototypes becomes multi-layered compounded by environmental and structural digital analysis as well as information gathered from physi-

cal prototypes; buildability, construction sequence, fixing types and load testing results of 1:1 prototypes at the Engineering department; refer to Figure 3.

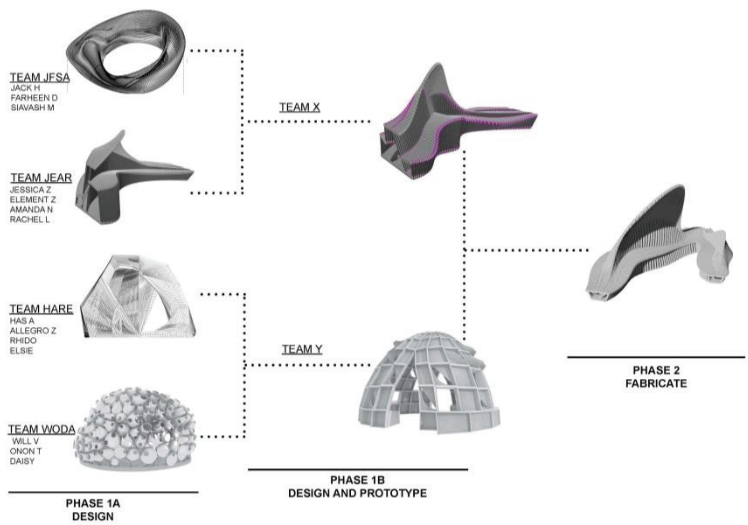

Figure 2. Competition structure showing design selection

3.1 LEARNING WORKFLOW

Like similar digital fabrication research in recent years, this project utilised McNeel Rhinoceros, with Grasshopper v0.9.0076. Structural analysis is carried out using Karamba, a plug-in for Grasshopper. Solar analysis is undertaken using Geko, a plug-in for Grasshopper. This suite of software has become a standard tool kit for the design studio. By keeping within the same modelling software, it facilitates a coherent collaboration (William et al 2014) where feedback loops between design and analysis are direct. In contrast, Autodesk Vasari is used for wind analysis. It remains 'external' to the Rhino modelling environments where feedback into the design are primary based on judgement through iterative analysis instead of direct response to geometric changes.

The studio recognised that it was not possible for students to learn and be involved in every facet of the project. Students were encouraged to specialise towards the construction phase of the studio, developing a particular skill set learnt during the Phase 1 competition stage. They were categorised into the following team of expertise;

1) The scripting team was responsible for the Grasshopper definition of the global form and the fabrication script - the digital prototype.

2) The prototyping team was responsible for the development of physical prototypes; joints systems as well as learning the operation of the CNC machinery and generation of toolpath cut file.
3) The analysis team's task was to bridge between the digital and the physical prototypes; providing feedback, constraints and opportunities to the design team.

The three teams operated concurrently; refer to Figure 3. In order to manage the design workflow, tutorial sessions became team meetings chaired by the studio leaders; problems were aired, discussed and worked through while new issues, analysis and problems were flagged, similar to a coordination meeting in any building project. The meeting concluded with the cost review and programme to ensure the project hit the required milestones. An action list was issued so students felt accountable for their own work. There became a sense of ownership over the project as opposed to authorship. The organization was by no means perfect but nevertheless it showed cross over and sharing of skillsets, resources and knowledge; what Kalay (2003) called creative collaboration.

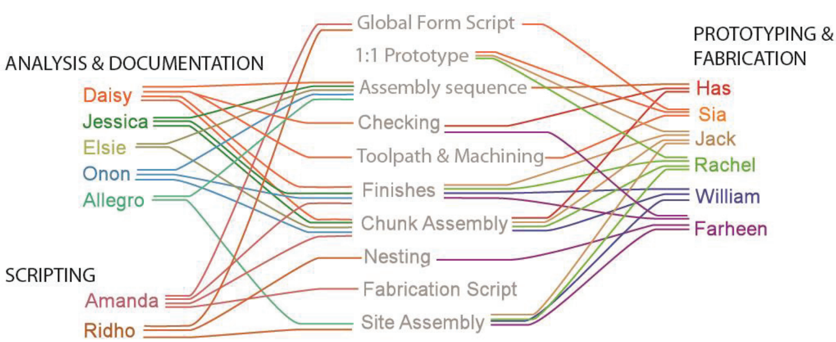

Figure 3. Diagram illustrates the crossover of roles between teams during Phase 2

4. Limits of prototypes

As Neil Denari (2012) explained, the digital workflow is not without its limitation; the precision of the computational process engenders a myth or faith in a perfect error free realization. He compares building workflow with those of product design; where precision is achieved through serial iteration, building on the other hand has other factors such as tolerance, human error and unpredictability in material to complicate the process. This means that the accuracy in building the physical object is a matter of degree of closeness to digital prototype quite unlike product design. Contemporary digital fabrication workflow is akin to product design in the sense that building, as Denari (2012) pointed out, exists as a digital prototype where the 'build-up of data prior to construction represents a kind of laboratory version of the building itself'.

4.1 OPEN VS LINEAR SYSTEMS

In this project, students were faced with the discrepancy between their digital and physical prototypes. The scripting team treated the digital information akin to product design, inputting design data and designing its layers of algorithmic structure to a near complete set of information. Up until the stage of the final check of the digital model, the model consisted of the cutting profiles and drill holes positions only. As the exact joint type varied throughout the system, it was not assigned until the final stage of the 'baked' process. Here, the digital prototype remained an open system where data could continue to be altered until the last minute. However, despite openness of the system, it became obvious that once all the parameters were identified and fixed, the digital prototypes risked becoming a problem-solving tool, which required another set of dialogues to make it responsive again.

In contrast, the physical prototype team evolved the joints system as a trial and error procedure. The aims of the physical prototypes were:

- To develop a rubber joint that allowed the seat of the structure to move locally to absorb ergonomic movement when one sits on the structure; the rubber insert bounces the joint back to its original location like a cushion.
- To develop a so called washer joint that dissipated the ergonomic movement across the chain link surface; without this, the surface would remain static.
- To test the construction sequence. The structure was designed to be assembled on site in chunks. The design team articulates the rhythm of the structure so the ruled surfaces could have a varying level of porosity. This reduced the amount of material required.

Although empirical in nature, the physical prototyping process is less open and inherently linear as judgement and design decisions can only be made once the prototype is completed and tested at each stage. A number of reasons necessitate this linear procedure. Firstly, no computational software as yet available to the team can deal with structure and movement analysis on the localised level of the joint prototype. Secondly, the joint movement requires the ruled surface to act as a network. It was more immediate to construct 1:1 segments of the design to test the slight shift in movement; the movement was in the order of 15-50mm. Lastly, the rubber and latex used in the joint are non-standard and only through evolving the geometry through 1:1 testing could constraints be identified; the puzzle making paradigm. From observation, all the above issues concerned the resolution of the project where it is either too fine or too complex to reproduce in the digital prototype.

The discrepancy between the physical and digital prototype became obvious during the fabrication and installation process. Variations in material thickness, consistency of plywood, existing ground levels and human errors all contributed to the messy business of making.

4.2 CHECKING PROTOCOL

In this project, upfront investment in the Grasshopper definition as an open system allowed the design team to maximise their design period. There is a 1 week overlap between design and fabrication; that is to say the design continued to be adjusted while other parts of the structure were fabricated at the same time.

The concurrent workflow discussed in 3.1 enabled the above efficiency but meant a robust checking protocol was necessary. While normally checking protocols are on the validity of the data, because of the compressed time frame for this project, the team (with the assistance of the studio leaders) needed to undertake both design and information check simultaneously.

The aims of the checking protocol were:

- To identify geometric errors; both design and computational
- To check for completeness of information in fabrication cut files

It took 3 cycles of checks before the information was ready for fabrication. Each check was carried out manually through visual inspection of the digital prototype, layer by layer. To focus on one particular issue that arose during the design and fabrication process, namely the position of the drill holes relative to the cut edge. This example illustrates the feedback process between digital and physical prototypes and how the checking protocol allowed the students to learn from a systematic pedagogy (Salama 2008).

Our structural consultant had given the team a rule of thumb for the fixing position relative to the cut edge of each profile; typically 4 x diameter of the hole. This is to ensure there is sufficient material strength in the joint. When developed in the digital model, the radius of the input curve was too big for the stepping joint resulting in large segments where the fixing position is too close to the edge of the profile. The team compensated this through articulating the joint connection profile resulting in the bone-like structure which was subsequently load-tested at 1:1 scale. This still resulted with a small number of fixing positions shy of the parameter set by the engineer. These small numbers of joints were identified for the team to resolve. The team devised a simple and effective solution where the constraint diameter is extruded to highlight areas of error using Boolean logic as mean of visual inspection.

Figure 4. (Left) Joint design showing constrain diameter; (Middle) constrain diameter implemented over design, (Right) Boolean intersection to highlight area of error

The above example questions the type of errors in a digital workflow. Here, the word 'error' merely defines what is outside of a defined bandwidth of judgement or criteria. For example, errors in geometry for this project can only be judged as errors because they had not matched or satisfied the criteria of structural integrity or fabrication constraints based on tooling. From the above, it is useful to observe that errors in the digital prototype and physical prototypes are different in nature. In physical prototyping, the error is a question of tolerance; numeric accuracy of digital fabrication against physical variant in material thickness and ground condition. Here, tolerance is a range of data that can be resolved through anticipating the physical discrepancy.

In digital prototyping, scripting errors are typically either geometrically based, where a numeric discrepancy results in visually different geometry or is consequence of input errors. While most input data can be constrained within the digital prototype, it requires design judgement to question (and to qualify) the information and its output as either acceptable or as error. As this potential error is within the digital structure itself, it could only be identified through visual inspection of the digital prototype. To perform a digital check procedure would require the geometry to be completely associative. The authors' opinion is that this will only work in product design where serial testing and checks are embedded within the procedure. Returning to Denari's cautions earlier, it is neither sustainable nor practical for buildings to achieve a level of zero error.

5. Conclusion

This paper presented digital design and fabrication as a systematic pedagogy which, when operated concurrently and practiced in the form of making a full scale structure, sets up an environment for integrated learning and creative collaboration among students that is akin to the reality of an architecture practice. It fosters a personalised learning experience through structuring dialogue and feedback loops between problem solving and puzzle making as design paradigm. Prototypes, both digital and physical are devices that enable this dialogue. This paper highlights the messy nature of making; when digital information interfaces with the physical environment.

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