DIGITAL ARCHI FOR HUMANITARIAN DESIGN

A case study of applying digital technologies in post-disaster reconstruction

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Abstract. This paper describes the context and proposal for applying digital technology in humanitarian design for remote areas of developing countries that are the most technologically challenged. It presents a case study of on-going post-disaster reconstruction in the Solomon Islands. A system of digital tools, in particular parametric modelling, was devised to optimise the exemplar design for site and project specific needs, and reduce time and cost required in the overall design and construction process. Shelters developed under this system will start construction in 2010.

Keywords. Optimisation of design; parametric design; post-disaster; algorithmic modelling; developing countries.

1. Introduction

Digital technologies such as BIM (building information modelling), parametric modelling, CNC (computer numerically controlled) fabrication and GA (genetic algorithm) have been increasingly employed in the field of architecture. Nonetheless their applications are yet to be applied in the challenging field of humanitarian design.

This paper presents part of an ongoing research on the application of ‘high-tech’ digital technologies to humanitarian design in the ‘low-tech’ context of developing countries. It focuses on the use of parametric modelling, and its BIM capabilities when coupled with spreadsheets.

Starting from the premise that the constraint-bound context of humanitar-
ian design particularly suit the rule-based nature of parametric modelling, and that any level of automation to reduce time for expatriates’ tasks would assist in optimal use of project funds, we devised and tested a system of various digital tools through a real case study of post disaster development work in the Solomon Islands.

2. Theoretical issues of generative design and humanitarian design

2.1. PARAMETRIC / GENERATIVE DESIGN AND HUMANITARIAN DESIGN

Digital tools such as generative modelling are increasingly used in architectural design, but ironically their major applications lie in unbuilt proposals due to the cost-prohibitive nature of the complex geometric forms enabled by the software. Many question if such form-driven design process is ethical (Ostwald, 2009). Barrow and Kumar (2007) argued that obsession with ‘freeform’ generation has undermined the powerful function of advanced modelling to perfect performance and mass-customisation - these functions, rigorously exercised in industrial design, should be applied to housing design – retaining the principles of achieving higher buildability from simplification, standardisation, and modularisation, but moving from mass production to mass customisation with the new digital tools available. Hecker (2006) further illustrated this potential with CNC fabrication.

Likewise, humanitarian designs for developing countries and post-disaster areas overlook the potential benefits of these digital tools and suffer the same problems found in all mass-prefabricated, one-size-fits-all solutions. These often involve expensive foreign materials transported to site that are hard to replicate, such as Shigeru Ban’s Paper Tube Emergency Shelter for Rwandan refugees (Sinclair and Stohr, 2006). Though justifiable for the case of immediate response to emergency relief, the potential of customisation has not been fully explored for transitional or permanent applications.

2.2. CURRENT GAP IN RESEARCH

From our literature review, little research addressed the opportunities raised by digital technology in the valid application of humanitarian architecture – where the demand is the most pressing and the constraints most challenging. Out of the available research material, all are hypothetical proposals, and none addressed application for remote locations, nor for providing sustainable long-term solutions.

Sener and Torus (2009) proposed a parametric system to arrange shipping container shelters randomly within a site envelope for immediate post-disaster relief. However like most prefabricated solutions, it relies on adequate infra-
structure to deliver the containers, and would not be viable for developing countries or remote locations where logistics present a real issue.

Other research proposes using different digital tools such as generative algorithm (Wen and Chen, 2004) or interactive 3D virtual environment (Jinuntuya and Theppipit, 2007) for decision making support systems but not for producing architecture.

We aim to address the issues above and open up a field for further research. Through the case study presented below, we examined existing constraints, user requirements and a proven successful model of delivery. Opportunities for computer aids to improve various processes were identified, and a system of digital techniques devised for the next stage of construction. This is scheduled to begin in mid 2010, and any findings will be followed up to inform our ongoing research.

3. Case study: reconstruction in the Solomon Islands

3.1. CONSTRAINTS, USER REQUIREMENTS AND MODEL OF DELIVERY

The reconstruction from the 2007 tsunami and ongoing development work in the Solomon Islands are constrained in many ways. Human habitation is geographically spread out with minimal infrastructure, limiting choice of material and lengthening time for transportation. Material availability is sporadic and local builders use only very basic and inexpensive non-powered tools like handsaws and hammers.

Typically, assessment of site and needs, building design and supervision of construction are led by expatriates with a high cost base, until sufficient capacity can be built up locally. Any means to alleviate reliance on expatriate experts would allow funds to be spent more directly on construction and ensure programs continue after disengagement with international agencies. Engagement terms of field expatriates are often limited to a year. Moreover the pressing nature of field work inhibits proper documentation and transfer of the knowledge gained from field experience to local staff members and succeeding field workers.

Currently the most successful delivery model involves international aid agencies designing and building exemplar prototypes as a way of transferring knowledge to communities. Funding and drawings are supplied to communities for the next build. However the prototype often requires further modifications to suit site and project specific requirements. The field architects and engineers must then manually repeat the calculations and documentation, lengthening the process.

In summary, a successful design would require economical use of simple
locally obtained material that can be built easily and quickly with the most basic tools and skills, and allow participation by everyone in the community. The system should be designed to adapt various site and user requirements, and to absorb unforeseeable circumstances such as shortages in certain materials. To ensure long-term viability of the projects, designs should also be easily replicated by communities with minimal external assistance.

3.2. PARAMETRIC OPPORTUNITIES IN HUMANITARIAN DESIGN

The constraints and user requirements discussed above often call for innovative solutions that have not been tested. However the repetitive nature of the work from one prototype raises opportunities to evaluate the design and construction process and incorporate users’ feedback to improve subsequent sets of designs.

Similarly, application of digital technologies such as parametric modelling lacks built examples. The few built works tend to be expensive one-offs and require a long time to design and construct, limiting application of lessons learnt to new projects. In contrast, development work from one prototype has the potential to allow these technologies to be tested and refined on comparable basis over time.

3.3. VIP LATRINES IN RANONGGA AND GUADALCANAL

In addressing the above, we selected the Sanitation and Wash Project in Guadalcanal for the Ministry of Education and Human Resources Development and World Vision for this research. An exemplar VIP (ventilated improved pit) latrine had been designed by EAA (Emergency Architects Australia) and built (figure 1); with many more still to be erected within a short time. So, timely evaluation data can be gathered to inform sequential design on a consistent and comparable basis for advance modelling.
The project requires assessing schools and improving water and sanitation within a strict budget. EAA had completed the site and requirement assessment and the BOQ (bill of quantities) for four schools in Guadalcanal, to which the output from our system was compared. We focused on two school sites requiring VIP latrines and modified the existing exemplar design to suit.

4. The system, design and design parameters

From the built VIP latrine project in Ranongga, we identified areas where digital technology can significantly benefit the overall process. The urgency of aid works prompts us to approach the problem by introducing a number of small packages of digital tools, with the intention of improving and adding more varied tools over time, analogous to inserting acupuncture needles at various points throughout the design and construction process as shown in figure 2.

4.1. ASSESSMENT OF REQUIREMENTS INTO PARAMETRIC MODELLING: DESIGN DEVELOPMENT THROUGH ITERATIVE STUDIES

The data gathered from site assessment was fed into a spreadsheet which calculates the additional water and sanitation requirements for the schools.

The values from the requirement calculation spreadsheet are fed into the design parameter spreadsheet which stores all the parametric values for the digital model. This spreadsheet is bi-directionally linked with Grasshopper - allowing the model to be updated by values in the spreadsheet or directly con-
trolled with sliders in Grasshopper. The link enables instant updating of the quantity and cost of material and fuel, and estimates of how many deliveries are required to transport all the material, as shown in the BOQ.

Study of the model and adjustment to the parameters gives the user the ability to attain a final desired outcome through informed decisions. Various options can be captured for rapid prototyping, allowing further study and comparison in reality. The model and the BOQ also inform the user of potential areas for cost savings, as well as opportunities for increasing amenity with a very slight increase in cost, as seen in figure 3.

4.2 DESIGN AND DESIGN PARAMETERS

There are many parameters and constraints in the Grasshopper script. The major inputs are the number of female/male students and staff (to generate the capacity required), the size of the modules, availability or selection of material, and slope of the roof and inclined wall.

All parameters are interrelated to various degrees, but can be classified into five categories:

1. Required capacity: number of toilets and water storage required.
2. Overall geometry / aesthetics: to determine the form of the building.
3. Material availability or selection: the supply of material.
4. Funding and procurement: time and budgetary constraints.
5. Constraints, tolerance, miscellaneous.

Figure 3. Flowchart summarising the parametric description of the system. Top row from left to right: (a) requirement assessment; (b) parametric values in Excel spreadsheet; (c) BOQ generated by the parametric model. Bottom row from left to right: (d) slider for selected parametric values in grasshopper; (e) grasshopper script; (f) parametric model interface
4.3. OUTPUT: DOCUMENTS FOR PROCUREMENT AND CONSTRUCTION

Once a desired final design is achieved, the data from the model generates the following documents for procurement and construction:

- **Final bill of quantity** based on major elements in their nominal dimensions.
- **Graphical schedule of timber members** – with dimensions, quantity and description of all the timber members required for milling and cutting in the bush and on site.
- **Graphical step-by-step instructions** for the construction process – show how the building is built in 3D, similar to an ‘Ikea’ instruction.
- **Conventional construction documentation** cut from the 3D model for skilled carpenters, and for community members wishing to learn how to understand conventional construction drawings
- **1:1 paper / plastic templates** for building elements where they need notching or trimming in specific ways
- **File for laser cutting** of all major elements for a 1:10 model. The model will aid understanding of how to assemble the building.

5. Evaluation

5.1. DESIGN DEFINITION: ADAPTABILITY AND OPTIMISATION

The system enables a high level of automation throughout various stages of the project. Time spent performing tasks such as requirement calculations, BOQ and documentation are significantly reduced, and errors that could occur during the otherwise manual procedures are minimised.

The direct link between design parameters and cost allows instant and accurate cost implications to be analysed. Potential savings can be identified and a balance struck between such parameters as material quantities, structural analyses, transportation and desired amenities, without compromising the design and preventing over-provisioning of materials using volumetric calculations. Based on the digital model, our system found the timber requirement to be forty percent less than the initial assessment.

In the parametric definition created, many known and perceived constraints have been included to increase the flexibility and application of the system to a range of possible situations. This gives a designer control of the parameters, and allows quick iterative digital sketches to be developed based on permitted variables.

As a result of the visual variable control afforded through the Grasshopper interface, mixed with the information-rich input from a spreadsheet, the designer is able to quickly determine an optimum solution for a given scenario, work within the computed constraints and develop a sensitive design
solution. More factors can be considered in this way than if done without the aid of the developed digital tools.

Iterative studies of building proportions and formal relationships of the building elements, as shown in figure 4, produces a more refined architecture. This process would have been prohibitively time consuming if performed manually. Better visualisation tools and rapid prototyping also enable the designer to make more informed decisions for the final design.

![Figure 4](image1.png)

**Figure 4. Iterative studies for Rate Primary and Junior High School, Guadalcanal.**

### 5.2. INNOVATION IN CONSTRUCTION DOCUMENTATION

Parametric modelling facilitates innovation in construction documentation to better suit the scale of the building and the local context. The *graphical schedule of timber members* assists accurate procurement and expedites an often lengthy procedure. Timber members can be cut to the correct lengths at the mill allowing easier handling during transportation, minimizing off-cut waste and cutting by handsaw on site.

![Figure 5](image2.png)

**Figure 5. The ’construction documents’ for Rate Primary and Junior High School, Guadalcanal – graphical schedule of timber and 1:10 laser cut rapid prototype model.**

The *graphical 3D step-by-step instructions* is easily understandable, regardless of prior training or literacy level. The *laser cut model* further assists in visualising how individual elements are assembled. These visual aids assist in understanding and encourage community participation.

Ease of construction provided by the *one-to-one scale templates* for slabs
and junctions allow local carpenters and people from the community to construct a more complex building than was previously feasible.

5.3. RETENTION AND ACCUMULATION OF KNOWLEDGE

The spreadsheets outlining the rationale for establishing user requirements, parametric design variables, the BOQ, and any additional data such as post-occupational evaluations are all interlinked with the parametric model. This acts as one platform for the retention and accumulation of knowledge for even temporary field volunteers, and allows disparate disciplines such as structural engineering and sanitation to operate on the same model. Further, this coherent body of growing knowledge allows management staff from non-construction related background to make more informed decisions.

6. Future research

We tested the use of digital tools for a simple building type as a start, with the intention of implementing the system on other building types such as classrooms, school halls and dwellings, where the benefit of the system for more complex buildings might be expected to be greater. Effective means of further optimisation in areas such as material and structural stability, sunlight and ventilation, will be implemented.

For the ongoing water and sanitation projects, we will expand the model to allow an even higher level of automation in various processes. For example, site selection based on wind and terrain data supplied locally in addition to GIS information; more detailed assessment criteria; inclusion of other toilet types. Evaluation of the effectiveness of the system onsite will be carried out when construction starts in 2010.

7. Conclusion

We started with the aim to apply ‘high-tech’ digital technology to support humanitarian architecture in a ‘low-tech’ constraint-bound context for those most in need. In the course of bridging the gap in generative modelling and humanitarian design, we found ourselves in an emerging field of research, and perhaps addressed some of the criticisms raised on the current use of digital tools by opening up the field to work in more pragmatic but challenging contexts.

Our developed methodology emphasises the need to understand contextual constraints, user requirements, and learning from experience. Building upon existing best practice developed from fieldwork, a system of digital tools was introduced in various stages of the project where opportunities arose.
The system improved accuracy and shortened time required to perform quantitative tasks. The parametric definition allows application of the prototype to adapt to a range of possible scenarios. Iterative studies linked to cost analysis enabled optimisation of solutions otherwise not feasible within time constraints. Construction documentation tailored for local needs improved procurement processes and encouraged community participation. Further, the model allows a growing, coherent body of knowledge for permanent and temporary aid staff to ensure highly skilled outcomes.

Overall, the system contributes to allowing more funds to be spent directly to the project and ensuring the reconstruction programs continue beyond expatriate presence. Further refinement of the system and evaluation of its benefits, as well as its implementation with other typologies will be carried out during and after construction in 2010.

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References