Digital Architecture for Humanitarian Design in Post-Disaster Reconstruction

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Abstract

Digital tools and computational design processes are rapidly changing architecture. Nonetheless their applications in humanitarian design remain under researched. Generative algorithmic design is particularly useful in humanitarian design and post disaster reconstruction. Firstly, the extreme conditions in these contexts pose many constraints that can be parametricised and form the basis of a parametric design. Secondly, optimal use of scarce resources are enabled by integrating these interrelated performance requirements. Thirdly, a robust model definition afforded through parametric modelling enables a mass customised design to adjust for different site and user requirements, and most importantly it allows improvements in subsequent design based on community evaluation. As part of an ongoing research in fusing advanced computational techniques in humanitarian architecture, the post-tsunami rebuilding program of Emergency Architects Australia in the Solomon Islands is presented as a case study to identify successes, opportunities and limitations of a system of digital tools.
1. INTRODUCTION

Over the past decade computational architectural methods such as BIM (building information modelling), parametric modeling and GA (genetic algorithm) have been increasingly employed to generate design. Nonetheless their applications have not yet filtered through to applications in the field of humanitarian design.

This article describes the context and an proposal for applying architectural computing in humanitarian design in remote areas of developing countries that are the most technologically challenged.

It presents a case study of on-going disaster reconstruction in the Solomon Islands, which forms part of a research on the application of ‘high-tech’ technologies in humanitarian design in the ‘low-tech’ contexts. A system of digital tools, in particular parametric modelling and BIM, were devised to optimize the exemplar design for site and project specific needs, and reduce time and cost required in the overall design.

Starting from the premise that the constraint-bound context of humanitarian design particularly suit the rule-based nature of parametric systems, and that any level of automation to reduce time required for architects in the field would lead to optimal use of project funds, we devised and tested a system of digital tools based on 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 Design

Digital tools such as generative modelling are increasingly used in architectural design, but their major applications lie in a few high investments buildings or unbuilt proposals due to 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 ‘free-form’ 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. That is to retain the principles of achieving higher buildability from simplification, standardization, and modularisation, but moving from mass production to mass customization with the new digital tools available.

2.2. Humanitarian Design

The critique on the approach to social housing described above overlaps with some of the challenges and opportunities presented to humanitarian design – they are both limited by resources, and often are given a one-size-fit-all solution multiplied over a large area but insensitive to site or user...
specific requirements. Nonetheless the high number of units per prototype offers the economy of scale to develop a system that adapts for specificities unique to each unit.

Humanitarian design in a low-tech context involves many complex issues outside of typical construction. In the case of post-disaster emergency relief, speed and safety is the priority. This is where standardised, prefabricated solution is often seen as the most appropriate. However prefabrication also involves importing high-tech or expensive components that are foreign to developing countries. This conflicts with the other essential criteria for a successful design – one that local people can replicate and maintain with the technologies available to them. For example, Shigeru Ban’s Paper Tube Emergency Shelter for Rwandan refugees was found too expensive (Sinclair and Stohr 2006). Though justifiable for the case of immediate response to emergency relief, the potential of customization through parametric design has not been fully explored for transitional or permanent applications.

Currently the most successful model in post disaster reconstruction focuses on community involvement to achieve best value recovery outcomes (Lawther 2009). The underlying theorem is that the more the recovery relies upon local resource, the quicker the community will be able to move to self-sustainability, and thus from recovery to normalcy. Sullivan (2003) identifies the link between involvement of the community in post disaster recovery and mental recovery, noting that it ‘alters their status from passive pawns in the process, to once again active and contributing directors of their own destiny’. By extension, the success of a building design is impinged on parameters that encompass those psychological and social needs.

Post-disaster reconstruction and development work in the third world possesses some of the most extreme scenarios and challenging constraints. Firstly there is the limitation of resources in terms of funding, material, time, foreign expertise and accessibility of the sites. These interrelated constraints can be translated into the parameters for generative design to allow optimum use of those scarce resources. Further, a robust model definition afforded through parametric modelling enables a mass customised design to adjust for different site and user requirements, and allow a design that gives a greater sense of ownership to those recovering from trauma.

Secondly few organizations in development work have well-established protocols to revisit their works after completion to test if the design works according to intent. Even if post occupancy evaluation was carried out, this is often not translated into subsequent set of design due to the lack of an integrated platform to retain this knowledge or the tools to quickly regenerate new design in a feasible way.

Parametric systems offer a unique tool in support of communities and local people to manage these constraints. At present such constraints are usually managed by foreign aid workers at high cost. Although there is often a capacity building component in foreign aid assistance this usually becomes
a case of a local person with some technical expertise executing a limited array of tasks within the overall delivery. Parametric modeling could be employed at this stage to limit the costs. In consultation with communities, local technical participants, government and foreign aid workers could set up a parametric process that responds to this local consultation and provides an ongoing feedback loop. Local technical participants could then be tasked to work within this process and charged with varying various parameters within the model, thus giving greater local ownership over the process. An additional benefit would be the continued refinement of a process as opposed to a new process each time a project starts.

2.3. Current Gap in Research

Literature review shows that a limited amount of research addressed the opportunities raised by digital technologies 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 infrastructure 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 Jirayod 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. The objective is to optimize, customize, build, evaluate, improve and record. We propose to start with a small project and a targeted set of tools and expand on the complexity of the building and the array of tools over time.

Through the thorough field 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.

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 foreign experts with a high cost base, until sufficient capacity can be built up locally. Any means to alleviate reliance on foreign experts would allow funds to be spent more directly on construction and ensure programs continue after disengagement with international agencies. Engagement terms of field experts 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 post disaster reconstruction and development typically replicates hundreds of buildings from one prototype in many different sites over time - this raises opportunities to evaluate the design and construction process and incorporate users' feedback to improve subsequent sets of designs, not dissimilar to the rigour practiced in industrial design.

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. It would be much more meaningful, if research and development in architectural computing are geared towards real projects with real impact, than temporal installations and objects.
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 ventilated improved pit (VIP) latrine had been designed by Emergency Architects Australia (EAA) 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 modeling.

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 an Excel® 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 in Rhinoceros®. This spreadsheet is bi-directionally linked with Grasshopper® - allowing the model to be updated by values in the spreadsheet or directly controlled 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 give 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 of cost savings, as well as opportunities for increasing amenity with a very slight increase in cost, as seen in Figure 3.

Another important aspect is recording of the changes in scripted model and the iterative variations. The Grasshopper script is labeled with explanations on the rationale behind decisions made for the design model.
Changes to the parametric values resulting from post occupancy evaluation were also tagged on the script, to allow an integrated platform for knowledge retention.

4.2. Design and Design parameters

Based on the design and the post-occupancy evaluation gathered from the VIP latrines in Ranongga, areas for improvements and essential parameters for modeling were identified. For example, the availability of vent pipe diameters and the roof sheets thicknesses fluctuates, so the Grasshopper script was written to allow for those variables. When only the thinner roof sheets are available, the timber structure self-adjusts to allow for smaller spans. Another example is that the community members were overly enthused with digging the pit and the slab ended up being too small, so in the next revision of design we introduced reused perforated petrol drums found in abundance on the island for the soil to back fill against, and allowed greater tolerance between the drum rim and the slab edges. Figure 4 below illustrates some of these finer adjustments.
There are many parameters and constraints in the Grasshopper script. They are all interrelated to various degrees, but can be classified into five categories as shown in Table 1:

<table>
<thead>
<tr>
<th>Parameter group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Requirement assessment</td>
<td>Number of toilets and water storage required based on the number of female/male students and staff and the MEHRD water and sanitation guidelines. This determines the number of modules.</td>
</tr>
<tr>
<td>2. Overall geometry/aesthetics</td>
<td>To determine the form of the building. This includes the size of the modules, overall dimensions of the building, slope of the roof. As well as items such as the inclined wall, and smaller components such as size of slab hole and drum pit.</td>
</tr>
<tr>
<td>3. Material availability or selection</td>
<td>The supply of material. Many of these are also linked to site specifics, for example if the community has its own timber and mill, then the use of larger timber members would be selected. And in the case where the site relies on material transported by dugout canoes, the model would be constructed out of shorter smaller timber members.</td>
</tr>
<tr>
<td>4. Funding and procurement</td>
<td>Time and budgetary constraints</td>
</tr>
<tr>
<td>5. Constraints, tolerance, miscellaneous</td>
<td>There are provisions for higher tolerances for communities who have no prior knowledge to similar construction, whereas communities that have previous experience can fine-tune their skills to work on less tolerances.</td>
</tr>
</tbody>
</table>

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. DISCUSSION

5.1. The 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 the volumetric calculations prevents over-provisioning of material. 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 5, produces a more refined architecture. This process would have been prohibitively time consuming if performed manually, but crucial for a sense of unique ownership for the beneficiaries. Better visualisation tools and rapid prototyping also enable the designer to make more informed decisions for the final design.

▶ Figure 5: 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” (Figure 6) assists accurate procurement and expedites a particularly lengthy procedure in development work. 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.

The "graphical 3D step by step instructions" is easily understandable, regardless of prior training or literacy level. The laser cut model (Figure 6) 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. When the evaluation suggests a change to a parameter value, or a change to the script, it is labeled within the parametric script.

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. Preliminary feedback on the system from field workers indicates this feedback loop was valued the most highly, and should be further refined for the next stage of the research - as success does not result from the production of a predetermined product, but a system designed for refinement of appropriate outcomes.
6. CONCLUSION

Best practice humanitarian design differs fundamentally from the provision of design within the context of the developed world. Despite both require a high degree of professionalism however the focus should not be on a marketable product but on a process that empowers recipients, such as local communities, technical participants and local governance structures. Without local engagement and buy in into the development process, such programs are rarely able to build enough momentum to enact broad ranging improvements.

This article started with the aim of investigating how the application of 'high tech' digital technology could support such processes in the 'low tech' constraint-bound context of humanitarian architecture. 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 emphasizes address of 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 the time required to perform calculative tasks. The parametric definition allows application of the prototype to adapt a range of possible scenarios. Iterative studies linked to cost analysis enabled optimising solutions otherwise not feasible within time constraints. Construction documentation tailored for local needs improves the procurement process and will encourage community participation.

Further, the model allows a growing, coherent body of knowledge for permanent and temporary aid staff to ensure highly skilled outcomes.

Through the use of generative design, it is possible to build a system that facilitates the ongoing process with the main objective of empowering local people and responsive to evolving requirements. This is achieved by firstly recording the results of local consultation which then supports a feedback loop, and then entrusting the implementation of the monitored design at a local level. At anytime foreign expertise or external evaluation can be provided, however most importantly the system ensures that this input contributes as an evolution to the system. With lessons learnt and local requirements always addressed, the product becomes the embodiment of what local people require. And who could possibly understand their own development requirements better than those who strive to develop.

7. 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 would be expected to be greater. Effective means of further optimisation in areas such as material and structural stability sunlight and ventilation, will be implemented. More importantly, based on the preliminary comments from field experts, we will focus on how to better enhance the feedback loop in streamlining the evaluation assessments and the iteration of subsequent designs, and the recording of how the design evolves.

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 in the next step of this research.

Acknowledgements

The authors are grateful to David Kaunitz and Emergency Architects Australia for providing documents and valuable insights on the reconstruction work in the Solomon Islands. We would like to thank Prof. Marc Aurel Schnabel from the Chinese University of Hong Kong for guiding us with his expert knowledge from the beginning and supporting us throughout.

References


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