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Parametric Modelling for Designing Offsite Construction

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Abstract

Increasing population and progressing economies around the world are generating huge demand for built assets. When this demand is dealt with conventional 'sticks-and-bricks' approach, it leads to usual delays, wastages, cost overruns, and quality issues, etc. Consequently, the traditional approach results in negative impacts on economic and social scenarios apart from being just unable to deliver required supply level of built assets. On the other hand, offsite construction techniques, when utilized appropriately, can significantly speed up the construction process and improve the quality of deliverables in addition to bringing in improved sustainability and better worker health and safety. But offsite practices are marred with a general perspective of its being cause of rigidity in the design processes and disproportional increment in coordination requirements. To address this perceived problem, the application of Building Information Modelling (BIM) has been conceptualized for the design of a prototype in this research. Simpler ways of modularization and effective optimization of design through parametric modelling has been developed. The methodology coming out of this design exercise, which is of reporting values of parametric variables real-time, is promising in the sense of ensuring the general and flexible usage of offsite practices. Further as experienced during the BIM modelling exercise for the prototype, the design iterations can be accomplished in a more informed manner and optimization run in an automated fashion by using the Application Programming Interface (API) of BIM authoring tool by taking advantage of already defined key parameters. This paper addresses these important issues at the conceptual level and determines a roadmap for further research.

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1. Introduction

Addressing huge demand for built structures due to increasing population and progressing economies is not a normal task and is certainly cannot be done with the conventional approach. For reduction of waste, assuring better or rather far better quality with may be even zero defect while constructing at a faster pace and yet reducing hazards to labourers and improved health and safety, it becomes vital to deploy methods of construction which can be performed in modern controlled facilities and with better predictability. This predictability and controlled work environment is possible only when the customized site conditions away from the actual site are provided to achieve the aforementioned objectives. The type and extent of this offsite construction may vary upon the need, design method employed, material selection, etc. In any case, the building elements responsible for forcing the process to be called as offsite, though to any extent, are manufactured in a factory setup and then transported to the location of their use.

Advantages of offsite construction are ascertained only in the scenario of its adequate accomplishment by having extensive pre-project planning and co-ordination among consultants and participants from various disciplines involved in the construction processes is needed. Therefore, it needs a robust platform having a model-based approach in which flow of information can take place smoothly without errors and confusions. If stated more clearly, this would involve the creation of a digital model (BIM model) which embeds massive amount of information to be shared among all the stakeholders of the construction process.

2. Levels of offsite

Three principles of standardization, prefabrication, and systems building are the roots strengthening the industrialization in construction. Building components standardization was a prerequisite for the production in factory conditions which goes together with dimensional coordination that permit the growth of systems building [1].

Offsite pre-assembly can be subdivided into following four levels [2]–[4] based on increasing amounts of pre-assembling process and standardization involved.

- Component manufacture & sub-assembly
- Non-volumetric pre-assembly
- Volumetric pre-assembly
- Whole buildings

3. Role of BIM in Offsite

BIM brings design and documentation to not just the third dimension but also connects the whole design and documentation process with time and cost as the fourth and fifth dimensions respectively. It, therefore, contains information far beyond just geometry in terms of parametric data that can be manipulated in various analyses, quantity take-offs, detailed documentations etc.[5]. It involves representing a design as combinations of 'objects' – vague and undefined, generic or product-specific, solid shapes or void-space oriented (like the shape of a room), that carry their geometry, relations and attributes. BIM software defines these objects parametrically, so that if a related object is amended, dependent ones will automatically also change.

The pace and quality of construction execution are improving with offsite construction and utilisation of BIM, based on the abovementioned features [6]. The ease of design, scheduling, information flow and visualization through BIM brings operational, strategic, operational advantages to offsite construction [1], [7]–[10]. Also, being a parametric platform, it provides flexibility towards changes while having the ability of resolving issues before actual construction through clash detection, simulation and better visualization. These result in reduction in rework, modification during construction phase and actual execution time [5], [11]–[13]. The ease and flexibility in BIM along with huge information embedded helps in multiple design iterations and gives the designer tools to assess the options for aesthetical and performance related requirements.

4. Parametric Virtual Prototyping

The idea of design coordination with Design for Manufacture (DFM) and Design for Logistics (DFL), the idea of virtual model is also added to enhance prefabrication design, production, transportation and installation. Virtual Prototyping (VP) technology is adopted to provide a collaborative platform for all participants and interest groups, including architects, structural engineers, BS engineers, owners and contractors. All these participants are able to use VP technology to conduct and update the design in real time in a virtual 3D main model (termed here a digital mock-up). This digital mock-up is a parameterized 3D model which consists of not only the geometries of all parts of a building but their formulated dimensions [14].

DFL is also conducted at the design coordination stage to reduce transportation problems. Prefabricated components can be put into vehicles and can also be transported to the construction site in a virtual environment to check the feasibility of the dimensions and shapes of the components for transportation. All parties can identify transportation problems and solve them as soon as possible by using the virtual platform ahead of the real construction process to ensure efficient construction progress [14].

5. Case study

This study has been done in a case study manner for which Plant Station Buildings (PSBs) of a prominent public sector company of India were selected for redesigning and prototyping. The whole exercise aimed at following issues of those PSBs:

- Remote locations of sites
- Fragmented design and execution process
- No consideration of climatic conditions
- Cast-in-situ methods
- Poor resource usage and site management

6. Methodology and concept of design

The methodology to make the traditional design to be fit for offsite consist of following parts:

- *Preparation of as-built model:* The conventional design is converted in to a 3D model with several information embedded into it for making the model ready for further manipulations.
- *Segregation of disciplines:* The as-built model is then segregated into all the disciplines: architectural, structural and MEP (not in this case). This way the segregated model can be used by consultants from different disciplines to work efficiently on their own part.
- *Modularization of design:* After all the disciplines are properly segregated, offsite experts from each discipline can work further on the model related to their field for defining modules depending upon the level of offsite to be achieved (see Figure 1 and Figure 2).
- *Optimization:* This process of design is not proper if it is one way and while modularizing it and refining it one should keep analyzing its performance in all the aspects. So, it is a back and forth process to make the design fit for offsite as well as to impart more qualities into it.
- *Offsite manufacturing:* When everything gets finalized, final construction modelling is done and shop drawing is made, which can then directly be transferred to offsite factories where the CNC machines would shape the material based on the drawings fed into them. And then, depending upon the application of offsite, they are assembled to modules or packed individually, loaded into loaders and then transported to site.

- *On-site assembly and erection:* At last the transported building units, modules and/or elements are placed on the site based on the design details and erection takes place.

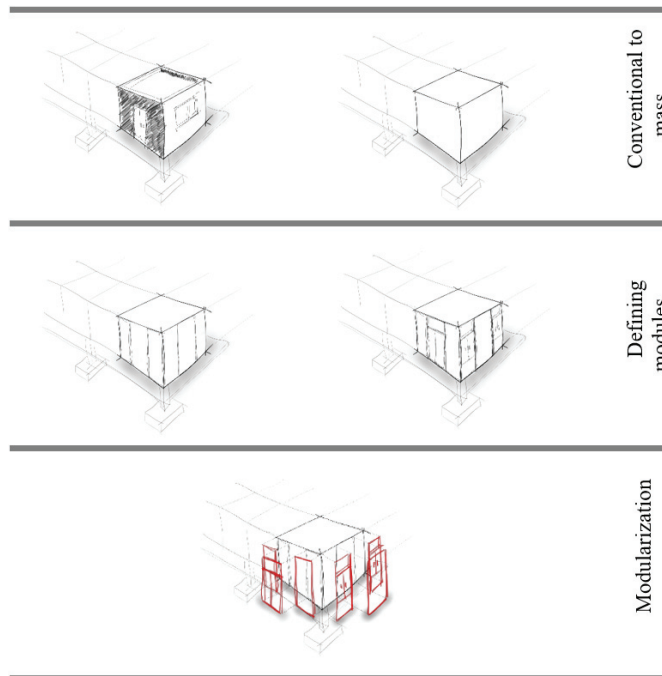


Fig. 1. Concept of modularization.

7. Prototype Development

Based on the drawings and physical inspection of one of the facilities, the process of making the as-built model with the BIM platform was started with the intension of comparing it with the final design prototype surfacing after the conclusion of the whole study. After completing the as-built model and its segregation, an exercise of finding out and defining modules from the as-built model was started. Once the modules were finalized, these modules were then modelled in BIM modelling software with the relevant parameters.

Keeping in view the non-availability of vast variety of useful materials fit for speedy construction, a few of the relevant material for the case taken in this study had been compared with conventional brick work based on various cost, functional and sustainability parameters. The comparison resulted in selection of RAPIDWALL (Glass Fiber Reinforced panels) as the most suitable material.

7.1. Modelling RAPIDWALL

RAPIDWALL was to be modelled in BIM for its use as the wall as well as roof system, both of which are system objects. Although, some modifications were possible, but the hollow cores shown in Figure 3(b) in the RAPIDWALL were impossible to model using the system objects approach. It also could not be made as a wall object, as wall object template does not exist among the predefined system templates. Also, making it as a generic model or as some other object would not have served the purpose for the reason it cannot host other usually able to be hosted objects like doors and windows. These objects like doors and windows can only be hosted on wall objects.

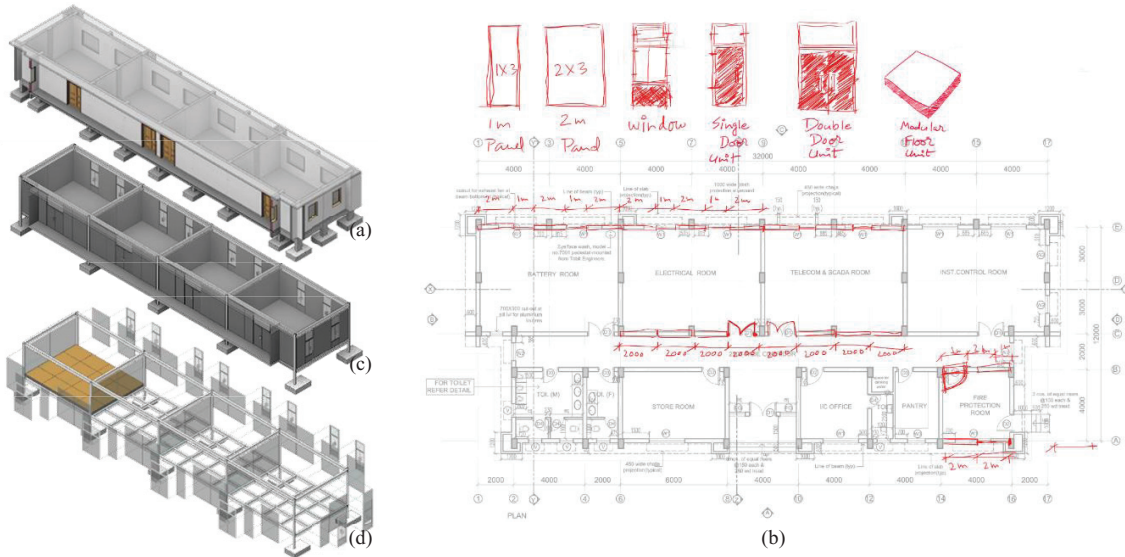


Fig. 3. (a) Part of the as-built model ready to be modularized; (b) Module identification; (c) Modular version of as-built model; (d) Demonstration of arrangements of modules in the modular version of as-built model.

Therefore, it was decided to proceed with making it as an in-place object instances. Here, the wall parameters and properties could be added and now it would be able to host doors and windows too. So, a parametric framework with the help of reference planes and dimensions having type as well as instance parameters was prepared in a generic

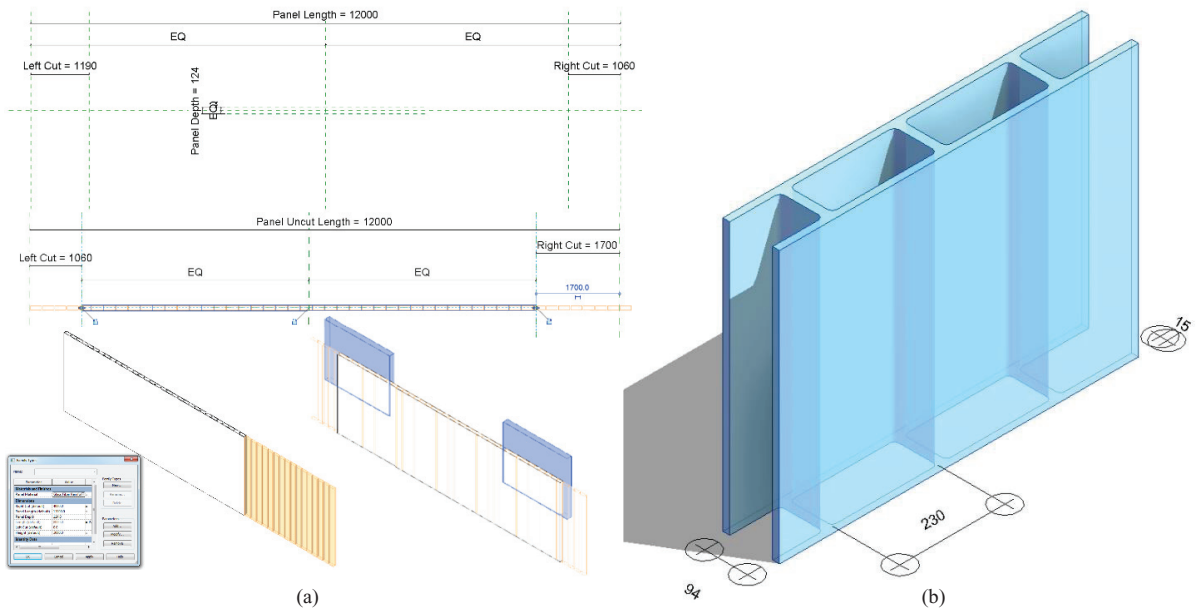


Fig. 2. (a) Successful nesting of generic solid panel object into the parametric framework already equipped with parametric voids as well as void-array modelled; (b) A small piece of RAPIDWALL with hollow cores inside it.

model template. The intention behind preparing the wall panel in the generic model template is to be able to nest it afterwards in the in-place element while still in editing mode.

Using this framework, for the modelling of 3D parts of this RAPIDWALL, placement of voids of the shape of hollow cores with the help of array tool and then the solid elements above it was tried. Although the geometry created was precise, but due to the crowding of elements it resulted in significantly degraded system performance and very low process speed.

For getting over this problem, the idea of nesting was considered. It was decided to make independent void-array (equal to the number of voids present in the actual full RAPIDWALL panel) aligned to the central reference plane

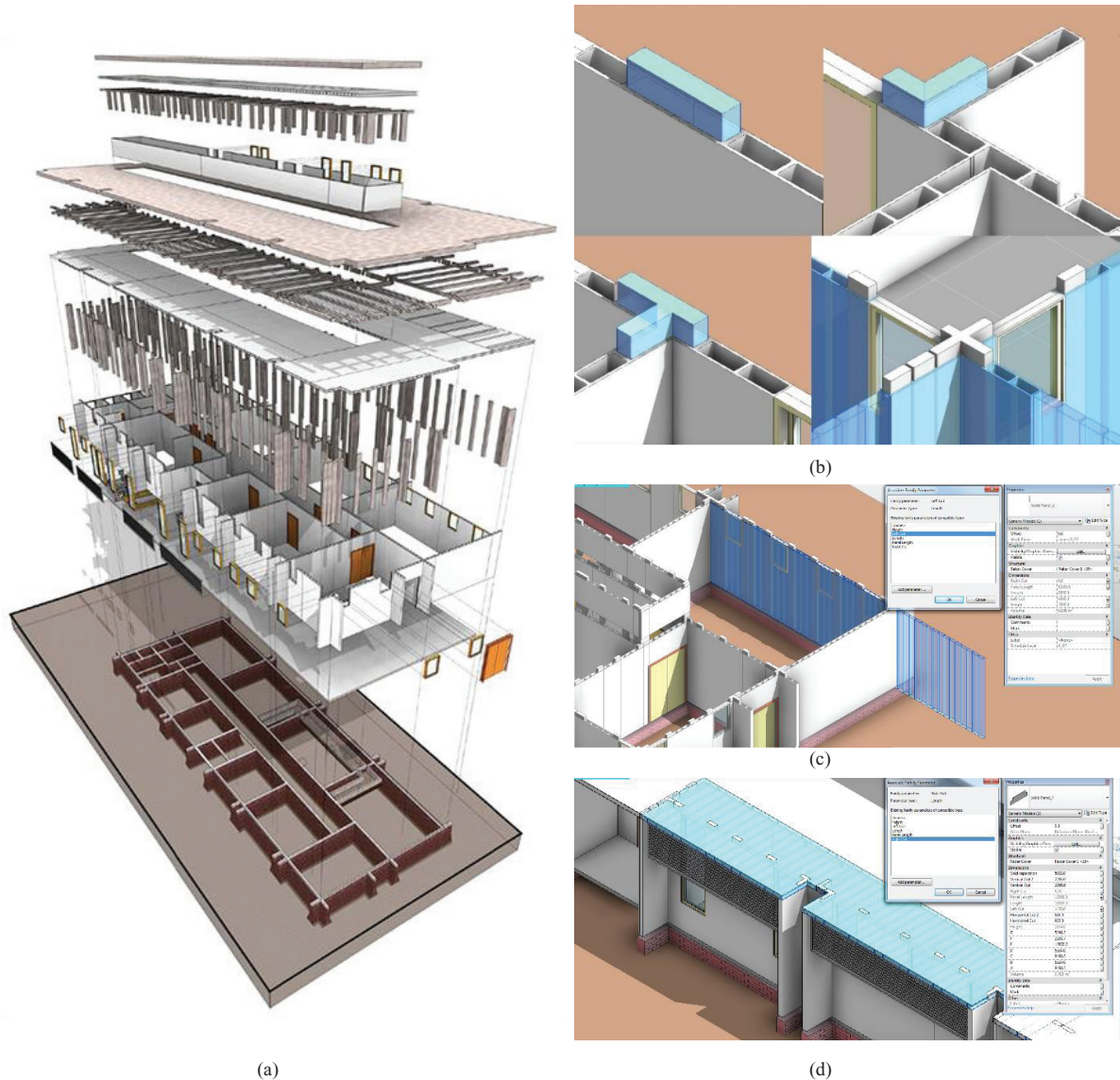


Fig. 4. (a) Exploded view of the final prototype; (b) Working with the digital RAPIDWALL in BIM environment; (c) Nesting of the Generic RAPIDWALL object into the in-place wall element and then associating the parameters; (d) Nesting of the Generic RAPIDWALL object into the in-place roof element and then associating the parameters;

with the parametric framework itself and then nesting the solid panel. The summary modelling sequence can be viewed in Figure 3(a).

And then, it was constrained to the ends of the reference planes defining the instance parameters, namely left cut and right cut provided to find out and scheduling the dimensions of the material being cut. These instance parameters can be directly fed into the CNC machines installed in the RAPIDWALL manufacturing plant to find out the desired panel length and height. Further, some more parametric voids with instance parameters and their perimeters constrained to strong reference planes were introduced in the generic object, so that shape handle could be formed making it customizable to the design needs.

As, the successful generic RAPIDWALL object had been created, it then was nested into the in-place elements for RAPIDWALL and rapid roof in their editing mode and then the parameters of the Generic object was associated with the parameters defined for those in-place elements as it has been shown in Figure 4(c) and Figure 4(d).

As depicted in Figure 3(a), the modelling of RAPIDWALL has been done with adding parameters 'Left Cut' and 'Right Cut' and 'Height' to define the dimensions of the panel in the CNC machine at the RAPIDWALL plant. The exercise included the provision of reporting of these cut parameters for overall optimization of material and operation. During prototype modelling it was kept in mind that minimum number of uncut panels should be manufactured and for this proper coordination among the sizes of all the panels has been insured.

The design has been carried out in accordance with GFRG/RAPIDWALL Building Structural Design Manual developed by IIT-Madras [15]. This manual clearly guides about joining methods of RAPIDWALL panels, inserting microbeams etc. which all have successfully been applied like a few digital illustrations shown in Figure 4(b). An exploded view of completed virtual prototype has been provided in Figure 4(a).

8. Conclusion

This comparison shows the superiority of RAPIDWALL on both accounts time and cost with savings of 74% and 7.30% respectively above the conventional design. It has been observed that the embodied energy been reduced by 26.23% and the carbon footprint has been reduced by 27%. Energy modelling of both the designs, the original one and the one with RAPIDWALL, in the energy modelling software tool eQUEST suggested a 10% saving of annual energy consumption.

The methodology, which resulted out of this research, is about real-time reporting of values related to parametric variables, which are decisive for final configuration of RAPIDWALL panels coming out of manufacturing unit to be directly transported and installed on site, and is promising in the sense of ensuring the general and flexible usage of offsite practices. Further as experienced during the BIM modelling exercise for the prototype, the design iterations can be accomplished in a more informed manner and optimization run in an automated fashion by using the Application Programming Interface (API) of BIM authoring tool by taking advantage of already defined key parameters.

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