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G-BIM framework: A feasibility study for the adoption of generative BIM workspace for conceptual design automation

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Abstract

The integration and automation of the whole design and implementation process has become a pivotal factor in Architecture, Engineering, and Construction (AEC) projects, especially regarding recent technological developments and emergent drivers in the field. Extant literature has highlighted a series of recurrent problems in process integration, especially at the conceptual design stage. This study presents the adoption of Generative Building Information Modelling (G-BIM) workspaces as an emerging technology. This has the potential to leverage conceptual design innovation in AEC projects. It builds upon the findings of an initial survey, and proffers a framework for using generative BIM workspaces at the conceptual design stage. This framework highlights the link and dependencies between generative/parametric tools and BIM applications to expedite information transition using generative tools primarily based on neutral BIM standards. Limitations of tools and approaches for providing accurate project information models are also captured in this framework. This paper demonstrates an overview of the G-BIM framework and the developed conceptual tool. Moreover, it reports on the challenges and opportunities associated with existing software applications. Findings reveal that the application of Generative Design (GD) can significantly enhance the design experience by assisting designers in the iterative generation of design alternatives and parameterisation processes. This framework purposefully integrates BIM with GD to enhance the design process at the conceptual design stage. This forms the rubrics for a working prototype which actively engages GD methods into a single dynamic BIM environment – the results of which will be presented in later works.

Keywords: AEC; automation; BIM; computational design; generative design; parametric design

1. Introduction

In AEC design practice, designers often put considerable [unnecessary] effort into design solution generation, often going through repetitious stages to seek viable solutions. Currently, designers usually take advantage of computational support such as Computer Aided Design (CAD) and BIM at later stages. However, during the early stages of the design process, decision making is a vital part of solution generation. The degree of automation through the design process is of great importance to the procurement of design alternatives. Cognisant of this, it is acknowledged that the use of generative systems as a design automation system at the early design stages could be very helpful for presenting viable [defendable] solutions quicker and more efficiently than conventional approaches. However, this should not obfuscate the need to satisfying the requirements of requirements capture, information modelling and data management; especially as projects are becoming increasingly more complex. Given this, multi-criteria design problems can be considered through the application of GD, the outcomes of which offer new innovative benefits to designers (and the design team).

Designers in current AEC projects, make use of advanced visualisation and modelling techniques at later stages, which result in almost losing the design knowledge of early conceptual phase, which is the origin of most of major decisions. Rahimian and Ibrahim (2011) linked this problem to the non-intuitive interface of the conventional Computer Aided Design (CAD) tools which make them not suitable for supporting the type of reasoning and cognition which appear during conceptual design phases. To tackle this problem, Lee *et al.* (2013) recommended the application of parametric design interfaces as a new pattern in CAD and BIM, as the mechanisms which are capable of producing design alternatives controlled by certain rules or limits, regardless of modelling and visualisation skills of designers. This approach proved beneficial for developing designers' creativity by equipping(providing) designers with synectics as an technique for forming idea (Blosiu, 1999) and supporting the design process through the unproblematic generation of design alternatives (Kim and Kang,

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2003) through altering various design parameters and observing (and reflecting on) the results in real-time (Goulding and Pour Rahimian 2012. To address this problem, the development of 'Generative BIM workspace' to provide design creativity, fluidity, and flexibility by the application of generative design approach was proposed by Abrishami *et al.* (2013). Using such an integrated platform (plan), this work considered the information relevant to the design requirements as the input to the system and the design algorithms as the design output. They also regarded this platform integration helpful for designers to solve complex multi-criteria design problems.

This work presents a G-BIM framework and conceptual tool, developed on a questionnaire survey conducted by Abrishami *et. al.*(2014). The survey aim was to explore different User Requirements Specifications (URSs) and various angles of integration of generative design algorithms to the existing BIM platforms, and to assist in identifying the conceptual framework's requirements for the G-BIM platform to maximise the efficiency of design teams and outline a new method for BIM applications to support throughout the design process; *i.e.* from very early conceptual design stages to final detailed design phases.

In this paper a new method for BIM applications is introduced, which supports conceptual design by incorporating GD into the BIM applications. A genotype of the design within a BIM application is proposed to allow the designer to give rise to new design alternatives by changing the pre-defined parameters with respect to the design constraints and requirements. Then the design team amend and improve the population of generated designs by the application of BIM capabilities. This method enables users to make use of BIM capabilities (such as collaboration, simulation, parametric features, etc.) through design. An overview of the framework and the conceptual developed tool is represented in this paper. It initially describes the integration using the framework, and then each element of the suggested framework is presented in Section 4. The conceptual tool development process is also discussed. G-BIM adopts the same approach as conventional and existing design process. Although the adoption of G-BIM develops design creativity, fluidity, and flexibility; it brings about minimal changes to the common design process. Therefore, relevant information to the design requirements forms the system input, and relatively the design algorithm generates the design output. The suggested system offers a design solution based on the input data (site data, constraints, and requirements); and during the conventional design process the same data is taken into consideration by the designer. G-BIM is fully making use of the potential of two existing individual generative systems; employ parametric change management of BIM applications and changes dynamically according to the generative mechanism attached the generated model(s).

2. Background study

The focus of contemporary AEC design projects is increasingly moving from an architecture with aesthetical emphasis towards performance (structure, environment, construction, socioeconomically and cultural, etc.) based architecture (Roudavski 2009). This shift in design attitude is inviting architecture to adopt new technologies that can support this transition. The AEC designers started adopting technology from industrial design, mechanical engineering and product developments, where performance tends to play a crucial role, as well as adopting new computational design methods such as generative and parametric approach, isomorphic surfaces, kinematics and dynamics, topological space are also being engaged. Given these changes and new inertia, this research study explores the potential of a BIM design environment integrated with new computational design methods in order to maximise their opportunities. G-BIM exploits generative design for creation of alternatives at early design stages, and existing parametric algorithm in BIM tools for modification of the chosen alternative(s) and change management during the late design stages up to the construction level.

3. Methodology

In this research, during the development of the theoretical foundations of the study, the employed qualitative approach provides a broad and deep understanding of the current state of computational support during the conceptual architectural design phase. In addition, the new empirical assessment techniques which are utilised in this study led to the possibility of investigating design protocols in a quantitatively manner (measures of diversity, time-related events and derived design processes) besides the using standard statistics possibilities when dealing with design protocol data. Therefore relying on both theories, the research seeks for clues of design support tools' quality by investigating design protocols and artefacts. Figure 2 presents an outline of the research design methodology. The research uses process modelling concepts to develop multi-disciplinary computational framework containing three main levels; process metal-level, process model, and development. This paper presents the process model stage of the project and highlights the potentials of the developed framework at the process meta-level phase.

The conceptual framework was developed using a process-centred environment for describing and evaluating evolving software process (Finkelsteiin, 1994). This development process consists of three levels: meta-process modelling, process model, and development iteration. During the meta-level, required information and key concepts are gained and classified; which will provide guidance for the development process (Rolland, 1998). Thereafter, the framework will be analysed and compiled through interviews and observations from experts in BIM and GD. The research aim will be achieved by developing a new design methodology based on Schön's (1983) "reflective practitioner" theory, Fitts' (1964) "motor learning" theory, and then verifying its effectiveness with empirical data. The research adopts 'sequential mixed method research' approach which starts with qualitative approach and continues with quantitative approach (or vice versa). Hence, the study follows Creswell's (2002) guidelines in designing the sequential mixed method research by pursuing a single research aim. This paper presents the meta-level of the project and highlights the potentials of the proposed framework. This paper is purposefully aligned to tease out both the philosophical underpinnings of design theory continuum per se, matched against the practical constructs of research practice (including the technology and tools used to deliver this).

This paper builds on the work of Abrishami *et. al.*, 2014, which conducted a detailed study using qualitative approach to adopt process modelling to develop a conceptual framework for Generative BIM Workspace. This paper presents part of an ongoing research study investigating the automation of conceptual design by integrating of GD and BIM as the central conduit; particularly by comprising both design method and computational architecture. This is expected to improve BIM's performance during conceptual architectural design process. The research aim is to examine the feasibility and applicability of the integration of GD and BIM. The main focus of this paper is on the formulation, implementation, and presentation of G-BIM which supports conceptual design automation through a generative process. First part of the paper explains the construct of the research study, including the detailed framework, potential, and barriers. The second part of the paper reports the tool interface and development, reaffirming how the framework/tool can overcome these problems.

4. G-BIM Framework

Integration of generative tools with information modelling combined with advanced 3D knowledge-rich systems is creating new potential for designing and coordinating amongst various stakeholders in AEC (Kocaturk and Medjdoub 2011). The use of GD can be defined as exploitation of parameters created at the early design stages. Since the generated solutions to the design problem (population of design alternatives) are the results of an algorithm (consisting design constraints, routines, and data files) by changing the inputs of the algorithm, the final design would be altered accordingly, like creating a basic model based on '***Routines***', and generating different design alternatives by adjusting very basic design parameters.

Using this approach, the design character to be generated can be defined by the design team in order to reach an appropriate level of variability. When G-BIM is used, a large number of design alternatives (solutions) can be studied by the design team through the generation of the initial information mapped by the design team along with G-BIM's generative mechanisms. All the modifications take place in the central BIM software using the advanced BIM modelling features. The following section demonstrates how the G-BIM framework is used to develop the preliminary conceptual tool.

5. Demonstration

The research adopts Janssen's (2006) evolutionary design approach, comprising design method and software system. As it is shown in G-BIM framework (**Hiba! A hivatkozási forrás nem található.**), the proposed method is described in three phases; coding, generation, and modification. Coding phase is formed by routines and data-files. At the routine coding stage a generative process is defined with the capability of metamorphosing a genotype into a phenotype (like generating a 3D model of a design). At the data-file coding stage design context and constraints are specified. The generation system uses the Industry Foundation Classes (IFC) for representation of the generated designs. Using IFC model, make the representation of the information-data associated with the model available for using in advance analysis and simulation features of BIM application. Using the G-BIM, an existing BIM application (Autodesk Revit) is used at the modification phase. As the generation system is integrated with Revit, designer(s) can make use of its advanced modelling and analysis features. The generative evolutionary design assists designers through the early design stages, while the BIM parametric capabilities provide a direct relation to physical production process (construction). The presented example illustrates how G-BIM supports and enhances conceptual design through a flexible exploration of design solutions using a fully automated BIM system. The generated models interact with the BIM parameters and information data.

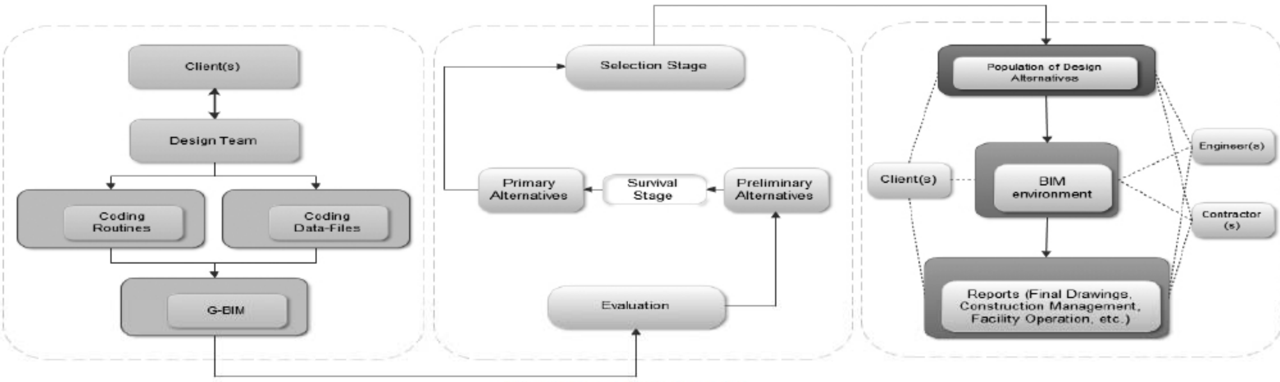

Figure 1. G-BIM framework

The system will be developed using a programming language embedded in Revit, allowing the generative process to make direct use of Revit modelling functions. Moreover, the Revit will also be used for visualisation, with all feedback from the evolutionary process being displayed in the system interface. There are evolutionary systems developed (Frazer & Connor 1999) using AutoCAD and Sun's systems (Sun 2007) integrated with MicroStation. G-BIM captures the information associated to the users' way of designing as well as design requirements, and simplifies the process of mapping this information by using Visual Dataflow Modelling (VDM). Moreover, it supports designers' interactions throughout the different design phases. Also there has been several attempts to make a link between generative and parametric tools and BIM tools like Geometry Gym, to enable exchange of generative tool models primarily using neutral BIM standards like SDNF, CIS/2, and IFC2x3 (Mirtschin 2011); but due to limitations of generative tools in providing accurate information models, these solutions often fail to provide an overall enhanced solution (to some extent); whereas, it is intended that the proposed system will enhance BIM applications for both generating and visualising forms. Thus, the evolutionary system will be developed and fully integrated in the BIM environment.

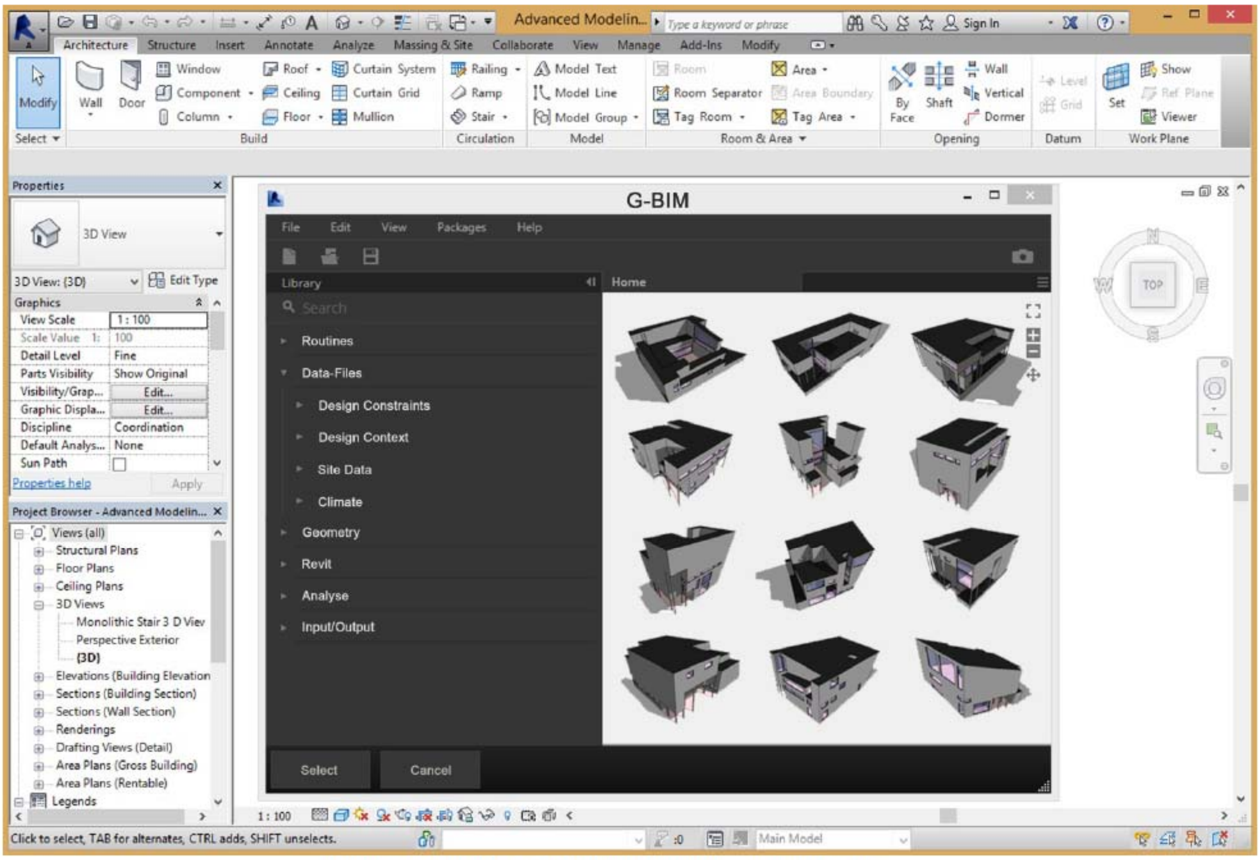

Figure 2. Conceptual Tool Interface: A set of generated designs

6. Conclusion

The paper presented a valuable set of rubrics for discussion in order to support automation in conceptual design stage. The paper presented a single, flexible, and dynamic 3D environment conceptual prototype which covers a wide range of architectural design requirements through the design process. G-BIM is developed based upon previous research, including Abrishami *et al.* (2013) conceptual framework, and Abrishami *et. al.*(2014) questionnaire by survey. G-BIM has the potential to enable automation at the conceptual design stage, by analysing a large number of possible design solutions. Moreover, G-BIM is capable of filling the gap in the current AEC projects, and meet the required automation level throughout the design and construction by its innovative integrated approach.

The developed framework and conceptual tool will be used to develop the final prototype. This will actively engage generative design methods into a single dynamic BIM environment. This study contributes to extant knowledge in this area by providing a 'stepping stone' for digital integration of all stages of an AEC project, especially concerning the implementation of BIM Level 3 (Cloud).

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