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Virtual Generative BIM Workspace for Maximising AEC Conceptual Design Innovation: A Paradigm of Future Opportunities

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Abstract

Purpose – Problems relating ostensibly to failures in computational support for the conceptual design stage are well-documented in extant literature. These failures are multifarious and significant, with several deficiencies being acknowledged in the Architecture, Engineering, and Construction (AEC) industry. Whilst acknowledging this, extant literature has highlighted the importance of computational design in the AEC industry; and failures in this area include the need to strengthen the congruent links and support mechanisms in order to exploit the opportunities presented by new computational design methods. Given this, it is postulated that the application of generative design could enhance the design experience by assisting designers with the iterative generation of alternatives and parameterisation (change management) processes. Moreover, as Building Information Modelling (BIM) applications are increasingly providing comprehensive support for modelling and management, then additional synergies could be examined for further exploitation.

Design/methodology/approach – This paper focuses on the potential for developing an interactive BIM environment that purposefully adopts generative design as a method of computational design for the early design stages. This research facilitates the automation of the conceptual architectural design process, using BIM as the central conduit for enhancing the integration of the whole building design process (including design interfaces). This approach is designed to improve designers' cognition and collaboration during the conceptual architectural design process.

Findings – This paper evaluates the existing methods and decision support mechanisms, and introduces the potential of combining different concepts into a single environment (generative design/BIM).

Originality/value – This research is novel, since it critically appraises virtual generative workspaces using BIM as the central conduit. The outcome and intervention of this research forms a theoretical basis for the development of a '*proof of concept*' prototype, which actively engages generative design into a single dynamic BIM environment to support the early conceptual design process.

***Keywords*:** Generative Design, Parametric Design, Evolutionary design, BIM, Conceptual design, Computer-based environment.

Introduction

The Architecture, Engineering, and Construction (AEC) sector is one of the largest industrial employers, representing 9.8% of a countries' Gross Domestic Product, and employing over 7.1% of the workforce (Business Watch, 2005). However, the fragmentation of the AEC industry is well recognised - the consequences of which have led to well-documented problems relating ostensibly to failures in communication and information processing (Egan, 1998; Latham, 1994). These failures have contributed to the proliferation of adversarial nature of the different parties involved in a project (Forcade *et al*., 2007), which has also affected the veracity of design information (Cera *et al*., 2002; Fruchter, 1998) within the project lifecycle. In essence, the nature and complexity of communication within AEC projects has changed significantly over the last ten years, especially with advances in technology, and the increased prevalence, of web-based project collaboration technologies and project extranets. Within the AEC sector, Information and Communication Technology has revolutionised production and design (Cera *et al*., 2002), which has led to dramatic changes in terms of labour and skills (Fruchter, 1998). However, it is also important to acknowledge that the capabilities of such applications (and implementation thereof) in predicting the cost and performance of optimal design proposals (Petric *et al*., 2002) should enable design engineers to compare the quality of any one tentative solution against the quality of previous solutions. This was reinforced by Goulding and Rahimian (2012), regarding the ability to experiment and experience decisions in a '*cyber-safe'* environment, in order to mitigate or reduce risks prior to construction. Consequently, the success of AEC projects is highly dependent upon the '*type*', '*level*' and '*quality*' of the innovative communication exchange of various disciplines involved in the design and implementation phases.

One of the key debates with respect to advanced technology adoption to the AEC industry is the level of automation throughout the project lifecycle (Frohm *et al*., 2008; Skibniewski, 1992). This includes offsite manufactured construction with a high product variety and significant variations in demand (Veenstra *et al*., 2006; Wikberg *et al*., 2010) which entails flexible and reconfigurable manufacturing systems (Colombo and Harrison, 2008), effective/cohesive supply chains (Arif *et al*., 2005), and integrated and automatic modelling, simulation and decision support systems (Fruchter, 1998). Gu and London (2010) asserted that this is unlikely to happen unless construction information is represented and managed throughout all stages of the project lifecycle, including early conceptual design and planning processes. Previous efforts with respect to BIM adoption have not really covered the operation of such systems during the early stages of design and planning. Rahimian *et al.* (2011) related this gap to the fact that conceptual design automation systems are still in their infancy. This causes problems with respect to data interoperability (Santos, 2009) especially, between various teams of designers with software and platform incompatibilities (Fruchter, 1998).

This paper explores methods in which BIM is employed; not as a representational tool for visualisation *per se*, but as a comprehensive support tool for the entire design process. Given these challenges, the specific research focus is to improve the conceptual design process by developing a framework that enhances designer's abilities to procure evolving novel and challenging solutions to assist the designer throughout the process (change management, modification of the model etc.). Whilst the methods introduced are in abstract form, they explore many potential directions of computational design. Currently, designers usually adopt computational support (CAD, BIM, etc.) at a much later stage in the design process; however, vital decisions have already been made throughout the earlier phases (Paulson, 1976). As a solution, the application of generative design within existing tools could assist the designer to solve complex multi-criteria design problems. The research suggests building a genotype of the design within a BIM application at the early design stage, so that the designer can generate new design alternatives by varying the pre-defined parameters based on the design constraints and associated requirements. The generated alternative population could then be amended and improved using BIM parametric features by the design team. This method would allow users to exploit BIM capabilities, especially collaboration, parametric change management, simulation and analysis throughout the early design phases.

The suggested conceptual "*Generative BIM"* (*G-BIM*) framework presented in this paper adopts the same approach used in the conventional/existing design process. Even though it enables design creativity, fluidity, and flexibility by the adoption of generative design, it makes minimal changes to the common design process. Therefore, relevant information to the design requirements forms the tool *input*, and the proposed system generates the design output within the BIM context. The proposed system provides design solutions based on input data such as: site data, constraints, and requirements; likewise, during the conventional design process, the same data is considered by the designer. The application of BIM in architecture and construction can fully embrace new methods such as generative design. Whilst existing generative design tools provide good support for early design stages, they have yet to be fully exploited.

The first part of this paper introduces the basics of conceptual design, followed by a critical review of design thinking within the design process. It then provides a roadmap for conceptual design and computational support – the primary focus of which is on the early conceptual design stage. Existing tools and decision support mechanisms are investigated as part of this process. Two investigation steps (studying the design process individually, and tools that support early design stages) were envisaged to help realise the potential for an interactive BIM environment to support the conceptual design process.

Research Methodological Approach

This paper was framed using a literature review to identify: current challenges; competing technologies; design challenges; new opportunities. This helped define and refine the knowledge gap, leading to development of a conceptual framework. The research methodological approach was purposefully aligned to tease out both the philosophical underpinnings of the design theory continuum, matched against the practical constructs of research practice (including the technology and tools used to deliver this). The research core-drivers were identified through the literature review analysis, the outcome of which was employed during the forming the conceptual framework phase.

Literature Review Design

The first part of this paper included a literature review using the top ten journals associated with design, as well as various conference proceedings and core research databases in design and automation. The study used NVivo software for analysing the content of the selected publications by refereeing to NVivo's "*Word Frequency Query*". The minimum length for words in the frequency analysis was set to five, and the similarity scale was set to four out of five in order to increase focus and veracity. Table 1 provides the word frequency calculation by NVivo.

Table 1: Word Frequency Analysis

Word	**Length**	**Count**	**Weighted Percentage (%)**
construction	12	181772	0.43
design	6	142779	0.35
artefact	8	117323	0.32
architecture	12	109693	0.31
thinking	8	106158	0.25
CAD tools	5-13	104665	0.25
method	6	101403	0.24
BIM	5-11	101033	0.22
generative	10	100921	0.22
parametric	10	71977	0.20
create	6	65308	0.19
collaboration	13	63723	0.19
attributes	10	61388	0.17
system	6	57514	0.17
development	11	45604	0.16
environment	11	39701	0.15
figure	6	38654	0.14
building	8	36716	0.14
object	6	10586	0.13

During the development of the theoretical foundations of this study, content analysis as a qualitative approach (Creswell, 2002) was adopted in order to uncover a deep understanding of the current state of computational support during the conceptual architectural design phase. The main issues focused on identifying the theoretical framework (for adopting generative design) as a method of automation for conceptual design. The identified core drivers and corresponding seminal authors are presented in Table 2 and the following sub-sections.

Table 2: Research Focus: Analysis of Core Drivers

Subject	**Description**	**Seminal Authors**
Design research: Conceptual design and design thinking	The process in which designers collaboratively author an assembly design	(Cross, 2007)
Modern Design Opportunities	Computational support for design	(Narahara, 2007; Do & Gross, 2009; Johnson *et al.*, 2009)
Generative design	Using a set of rules or an algorithm in order to generate designs (architectural forms)	(Cera *et al.*, 2002; Narahara, 2007; Leach, 2009; Roudavski, 2009)
Parametric Design	Use of parameters to define a form and relations	(Fischer *et al.*, 2005; Butz *et al.*, 2005)
BIM	Intelligent model-based process	(Ibrahim 2004)
CAD tools	Computer aided design tools	(Whyte *et al.*, 2000; Cheon *et al.*, 2012)
Knowledge sharing: collaboration	Collaborative design	(Cross & Clayburn, 1995; Cera *et al.*, 2002)

Tool development	(Johnson *et al.*, 2006; Narahara, 2007)

Framework Development

In accordance to the two main constructs of the study (i.e. information modelling and form generation), the main focus of the framework was on the integration of BIM and generative design for automation at the conceptual design stage and to exploit generative design. The framework was developed based on the results of a substantial literature review and a detailed qualitative study by Abrishami *et al.* (2013). This research employed process modelling concepts to develop a multi-disciplinary computational support framework. The framework was developed with a view to make the results usable for development of a working prototype based on a process-centred environment (Finkelsteiin, 1994) in order to describe and evaluate evolving software process. The framework development process in this study consisted of three different levels: meta-process modelling, process model, and development iteration. Throughout the meta-level, required information and key concepts were classified to provide guidance for the development process (see Rolland, 1998). The framework section presents the meta-level of the project, which highlights the potential of this proposed framework.

Modern Design Opportunities

The focus of contemporary AEC design projects is increasingly moving from 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. These computational design tools include CATIA, Inventor, Digital Project, SolidWorks, Pro Engineer, etc. Moreover, new enhanced computational design methods based on existing methods and concepts such as genetic algorithms, parametric design, isomorphic surfaces, kinematics and dynamics, topological space are also being engaged.

Acknowledging the development and evolution of the industry, the success of AEC projects is still highly dependent on the decisions made during early conceptual design and planning processes, where 70-80 per cent of the production overheads are usually determined (Paulson, 1976). This position has still not really changed. For example, tools for supporting advanced design planning, data-rich models (e.g. Building Information Modelling) are now drawing design teams' attention (initiated by Eastman, 1999; Fischer, 2000) to coordinate the fabrication of different building components. From a definition perspective, Isikdag and Underwood (2010) defined BIM as the information management process throughout the lifecycle of a building which focuses on collaborative use of semantically rich 3D information models. It is also acknowledged that other definitions also exist. Notwithstanding this, BIM models contain rich geometric and semantic information about the building and depending on the business need, different views/sub-models (e.g. Design, HVAC, FM) can be derived from them. The use of building information models in the design of buildings are also revolutionising the whole AEC industry, most notably by: enhancing team collaboration (Gu and London, 2010), improving project integration (Woo *et al*., 2004), leveraging better construction information flow (Ibrahim *et al*., 2004), helping documentation flow (Popov *et al*., 2006), and providing construction simulation for teamwork planning, clash prevention and coordination interface (Fischer and Kunz, 2004). In line with these expectations, the UK Government announced the "*Government Construction Strategy*" which included a mandate for the implementation of BIM Level 2 on all public projects by 2016 (BIM Task Group, 2013). BIM Level 2 requires digital building models to be shared/exchanged between parties in the design/construction process for 2D/3D spatial coordination based on BS1192:2007.

Despite these developments, there is some consternation and global reluctance amongst certain designers for implementing technology-driven solutions. For example, some studies identified that this gap was due to the '*weakness'* of the current Computer Aided Design (CAD) tools to support the intuitive design process that architects preferred in the early stage of the design lifecycle (Bilda and Demirkan, 2003). This is a concern, since during the design stages of an Integrated Building System (IBS) project; architects often handle numerous repetitive building components with almost similar embedded information during the modelling of prefabricated building projects. In these types of exemplars, there is a need to embed full-scale advanced manufacturing and rapid delivery of industrialised projects, (e.g. Design for Manufacturing and Assembly) to support the Multi-Dimensional data-rich modelling process.

Given these changes and new inertia, the research exploits the potential of a BIM design environment integrated with new computational design methods in order to maximise their opportunities. For example, the proposed framework exploits genetic algorithm to generate different alternatives, and throughout the modification of the chosen alternative(s) the tool uses parametric algorithm for change management during the late design stages through to construction (Abrishami *et al*. 2013). The following sections describe these features in more details, the narrative of which identifies the different concepts and methods adopted by the proposed framework.

Virtual Reality Applications

Early studies using virtual reality (VR) in the AEC industry tended to mainly use this as an advanced visualisation (representational) medium. However, from around 1990 VR has become widely used, as it now provides an intuitive medium for designing 3D models which can be spontaneously manipulated and collaboratively used in order to reveal the various phases of the building construction (Whyte *et al.*, 2000). VR is also now used as a mainstream design application to provide joint visualisation for improving the construction process (Bouchlaghem *et al*., 2005). However, the expectations of VR have changed again during the last decade in particular. For example, Sampaio *et al.* (2010), noted that it is increasingly important to incorporate VR 3D visualisation and decision support systems to perform real-time interactive visual exploration tasks. This thinking supports the position that a collaborative virtual environment can be considered a 3D immersive space in which 3D models are linked to databases which hold (inherit) characteristics. This premise has also been presented in construction planning and management – especially linking 3D models to time parameters (Fischer and Kunz, 2004) to design 4D models which are controlled through an interactive and multi-access database. Acknowledging this, 4D VR models are now being used to improve many aspects and phases of construction projects by providing better communication among partners (Leinonen *et al.*, 2003), enhancing design creativity (Rahimian *et al.*, 2011), improving coordination (Khanzade *et al.*, 2007), improving construction processes (Fischer, 2000), and integrating with BIM to further enhance data integration (Xie *et al.*, 2011).

Building Information Modelling

As construction projects increase in complexity, alternative modern methods of construction and design have been seen to have increased in popularity (Cooke and Williams, 2009). For example, Suermann (2009) asserted that BIM used by designers, construction managers and contractors now have the ability to accomplish tasks more efficiently than ever before - paving the way for future construction professionals. Furthermore, clients increasingly require BIM services from the designers and contractors. In the UK for example, the government (the largest procurement client of building and infrastructural development) has mandated BIM conformance levels, requiring fully collaborative BIM Level 2 compliance by 2016 (Cabinet Office, 2011).

There are several definitions of BIM. The two most common definitions are as follows: in the UK, the Construction Project Information Committee (CPIC) defined BIM as: "*...digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its lifecycle, from earliest conception to demolition*" RIBA (2012). In the USA, the National BIM Standard (2007) defined BIM as "*a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward*" (NBIMS-US, 2007).

Notwithstanding these definitions, a BIM model is primarily a 3D digital representation of a facility along with its core characteristics. It consists of intelligent structural components which include data attributes and parametric rules for each object. For instance, a window will be comprised of certain materials, shape and dimensions, along with its parametric link (e.g. a wall), and other attributes (e.g. time etc). The details supported are usually proportionate to that particular object (classification). Thus, BIM can provide a constant and coordinated view (and representation) of the digital model. It is therefore increasingly becoming a standard through which established communication and collaboration protocols are being operationalised.

Generative Evolutionary Design

Generative design refers to any design practice where the designer uses a system, such as a computer programme, which is set into motion with some degree of anatomy contributing to or resulting in a completed work of art (Janssen *et al.*, 2006). The application of evolutionary algorithm is recommended for the generation of design alternatives in the BIM environment. It is advocated that this approach could enhance the system's capabilities by allowing the generation of complex forms with various details and layouts that would not be possible without using such a system. Several researchers have highlighted the benefits of using evolutionary design (Frazer, 2002; von Buelow, 2007; Janssen, 2006; Narahara *et al.*, 2006). In addition, architectural design has benefited from the application of generative algorithm by adopting five different techniques: genetic algorithm, cellular automata, L-systems, swarm intelligence and shape grammars (Janssen, 2006). Indicative examples are presented in Table 3.

Table 3: Developed Tools

	Specifications	**Tools**
Non-commercial tools		
Constraint-based representation	The tool maintains the constraints and the integrity of the design	SketchPad (Sutherland, 1963); The Sketcher (Medjdoub, 1999); CoDraw (Gross, 1992); BRIAR (Gleicher *et al.*, 1991);
Associative representations	Design relations constitute dependencies that are defined by the structure of the underlying model	ReDraw (Kolarevic, 1993)
Design grammar representations	Designs are represented by means of a vocabulary of shapes, (defined by lines and labels) and a set of production rules; design relations as well as design transformations are encapsulated in those rules.	Discoverform (Carlson and Woodbury, 1990)
Hybrid representations	Combination of different representational models	SEED-Layout (Flemming & Chien, 1995); Floor Layout and Massing Study Programs (Harada, 1998); Performance Simulation Interface (Suter, 2000)
Commercial tools	Industry-standard CAD tools	Revit (AutoDesk); GenerativeComponents (Bentley tools)

Given the importance and potential of generative design, the emphasis of this research is not to epitomise existing systems and approaches (*vis-à-vis* improvement *per se*), rather, to endeavour to optimise the design process by integrating an approach such as generative design. The evolutionary design method uses evolutionary software systems (genetic algorithm) in order to enhance designers' ability during the design process. Evolutionary design is broadly recognised by the parametric evolutionary design and generative evolutionary design (Janssen, 2006).

Parametric evolutionary design

This approach is taken in late design stages in order to find the best solution to the design problem amongst different design alternatives. A basic design concept is established in advance. Thereafter, components are parameterised by the designer for further improvement. The system evolves these parameters at the last stage into generative alternative design solutions (Janssen 2006). Application of parametric design has been successfully adopted in a number of BIM applications as a change management engine. Although parametric systems have evolved into effective drawing tools, but still they are not considered as comprehensive AEC design applications (Rasheed *et al.*, 2005). An example of parametric restriction and change management within a system is the distance of a door from the wall or riser of the stairs to ensure furnishing clearance.

Innovative Opportunities

There are evolutionary systems developed by Frazer (2002) using AutoCAD and Sun's systems integrated with Micro Station. By integrating the evolutionary system with and advanced BIM modelling applications, the generative process can make use of complex geometric functions on the BIM application in the developmental step. In order to explore the potential for one possible future direction of computational design strategy, general aspects of what our contemporary practice of architecture is facing is discussed. The following is some opportunities raised from the literature:

- Collaboration in design: new technologies and systems such as computer networking, video and computation integration etc. have made new and more advanced opportunities for synchronous and asynchronous collaborative design (SCD and ASCD);
- Sketch-pad systems: computational support for sketching;
- Integrating computational sketching systems into Augmented Reality architectural form: combining sketch-pad tools with real time three-dimensional environmental information on the site would help the designers to have a better understanding of how their designs would be in real site, from the early design stages. This could be extended, so the design support environment elaborates more detailed information such as temperature, brightness, humidity, wind direction and sound from early design stages;

- Digital mock-ups (3D Sketching): Three-dimensional sculpture like interface as a replacement for early design mock-ups;
- Given the challenges identified, it is advocated that tools that proactively support and underpin the intrinsic skills needed for effective early design are evaluated through 'objective' measures in order to provide further insight.

The Conceptual Framework for BIM Integrated Generative Tools

One of the main achievements in AEC design has been the introduction of CAD. These tools have been openly acknowledged as being able to enhance designers' capabilities – especially in drafting and modelling. Moreover, these tools made possible working with complex forms and complicated design tasks by assisting the designers with drawing and editing objects and properties, free-form curves and surfaces editing features, compound objects, lighting, material editing, and rendering capabilities. Through the next step forward, algorithmic codes and scripts was integrated with CAD tools in order to enhance the design process. Therefore, CAD commands evolved into codes which could be applied to a variety of tasks throughout the early design stages (generative design).

Having a single, flexible, and dynamic 3D environment which covers a wide range of architectural design requirements through the design process (early design to construction stage) is a vital necessity for designers. The generative evolutionary design assists the designer(s) through the early design stages, while the BIM parametric capabilities provide a direct relation to physical production process (construction). Not only the proposed system bridge the gap in existing BIM process, but also it targets flow of information in an era with complex projects and increasing quantity of information to be processed which is a key concern in today's AEC design. 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). This proposed framework presents a valuable set of rubrics in order to support the early design process, specially:

- Creation of models with relevant links to all required information and details for the development process;
- Creating a generative process capable of controlling the variability of design outcomes, and generation of designs with required level of complexity. Moreover, generate alternatives that differ significantly in terms of overall organisation and configuration;

- Creating an innovative collaborative environment which enables designers to communicate in an efficient way through conceptual design phases (enable both short-term asynchrony and long-term asynchrony);
- Creating a computational design environment that support sketches (either by scanning hand-made sketches or by drawing-on-tablet technology) in both 2D and 3D environment;
- Enable designers to edit, save, and improve sketches and designs in a communal environment, hence, all designers (from different geographical regions) can contribute towards the design process;
- Enable designers to take their sketches (2D and/or 3D) to the next levels in order to shape their thoughts and guide it to the final phases gradually.

Integration of generative tools with information modelling combined with advanced 3D knowledge-rich systems are creating new avenues for designing and coordinating various stakeholders in AEC (Kocaturk and Medjdoub, 2011). From a definition perspective the use of generative design can be defined as the exploitation of parameters created within the early design stages. Given this, the generated solutions to the design problem (population of design alternatives) are the results of an algorithm (consisting design constraints, routines, and data files), and by changing the inputs [of the algorithm], the final design can be altered accordingly - like creating a basic model based on '*Routines*', and generating different design alternatives by adjusting very basic design parameters (Figure 1). Moreover, materials, fabrication constraints, and assembly logics can also be parameterised in response to the environment.

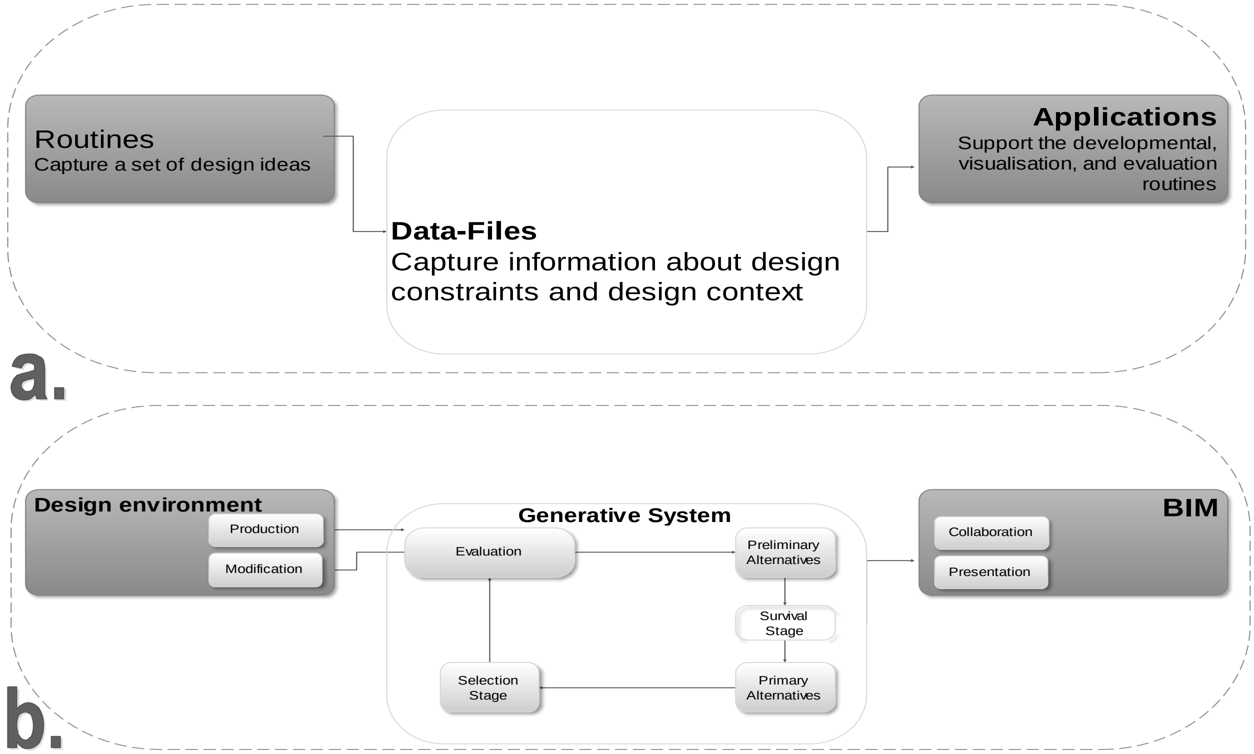

Figure 1: a. Framework Environment

b. Tool Schema

The generative process of designing is therefore capable of linking the geometric behaviour patterns and performance properties of the system. The design environment is constantly connected to the external environment; therefore, external behavioural tendencies alter the ontogenies through parameterisation (Hensel and Menges, 2008). Such an approach was used to shape, inform, and provide detailed granular data (to help identify the delimiters). The method described above was used to help shape the schema for the research model. Figure 2 presents an outline of the proposed Generative BIM Environment conceptual

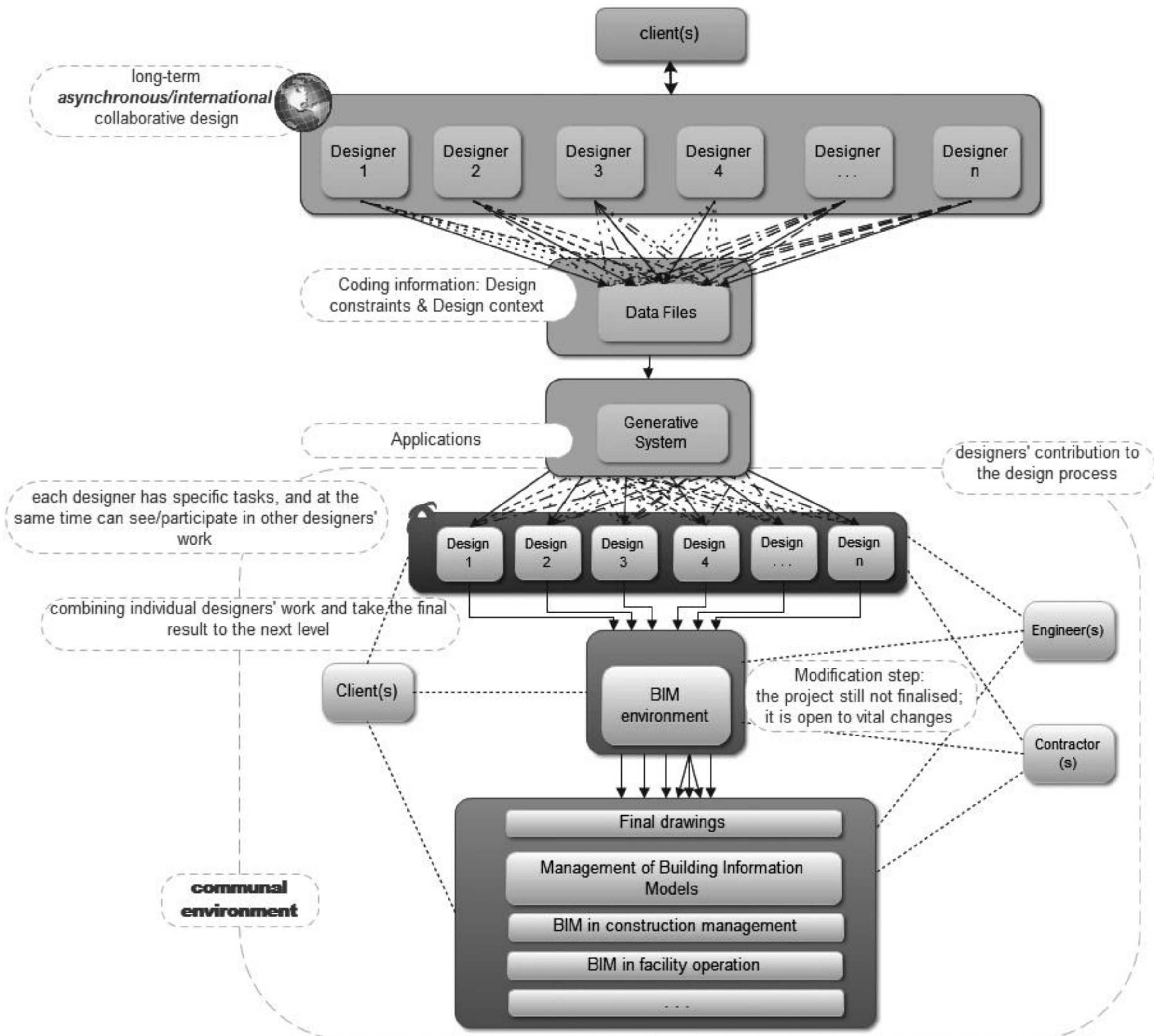

Figure 2: Conceptual Framework for Generative BIM Environment

framework.

From Figure 2, it can be seen that the rubrics support the processes of a synchronous collaborative design – from the coding engine, through to the BIM environment. This conceptual framework will be used to develop a working prototype. This prototype will be developed using a programming language embedded in Autodesk Revit. This approach will allow the generative process to make direct use of the Revit modelling functions, which will also be used for visualisation, (with all feedback from the evolutionary process being displayed in the Revit interface).

Technical implication for implementing Generative BIM workspace in the AEC industry

Existing evolutionary systems have ostensibly been formed based on source-code libraries or as programming toolkits. It is also widely acknowledged that heterogeneous parallel genetic algorithms are able to deal with a plethora of different operating systems (Alba *et al*, 2002). Given this, it is important to appreciate that the architecture and utilised methods for data creation and retrieval can have a direct impact on outcomes. Existing evolutionary tools are rarely implemented as ready-made menu-driven systems. The *G-BIM* prototype proposed in this paper helps to support the integration of evolutionary design. End users are not envisaged to be programmers, nor experts in genetic algorithms. Therefore, the proposed architecture uses an approach similar to current tools such as Grasshopper® (a graphical algorithm editor). This approach is suggested as recent developments in computational design have substantially changed the conventional design process (and by default, designers' way of working); such that, *"This new paradigm aims to locate architectural discourse within a more objective framework when the efficient use of resources supersedes the aesthetic indulgence of works"* (Leach, 2009).

Many available tools are capable of handling detailed design processes, however, none of these tools are fully capable of purposefully manipulating conceptual design data. In order to overcome this barrier, this research proposes a framework which exploits and combines new concepts into a single BIM environment. Using the *G-BIM*, routines are encoded and developed during the design brief (preparation stage), which forms the genotype for the generation step - this initially transforms a genotype into a phenotype (2D or 3D model of the design), followed by defining the representations. The data-files will specify the design constraints and context (i.e., site boundaries, minimum dimensions and distances, number of floors and spaces etc.) (Figure 1a). The results generated are therefore based on routines and data-files. Thereafter, the BIM tool is used representation and amendment. In order to address BIM software compatibility requirements, the results (generated designs by the framework) will be translated into Industry Foundation Class format (Figure 1b). The G-BIM framework will use genetic algorithms for conceptual design and form generation (population of alternatives) this will also benefit from the advanced features of BIM tools for illustration and collaboration (coupled with BIM's parametric change management features).

Conclusion

Construction projects are increasingly becoming more complex, often engaging new business processes and technological solutions in line with clients' requirements. Given the dynamic nature of these changes and increased levels of project complexity, the AEC sector now requires (more than ever before) a myriad of newly skilled professionals, operatives, and interdisciplinary teams in order to meet these new challenges. These needs will however require the industry as a whole to engage the right type (and level) of skill sets and competence to meet these new project requirements and business imperatives. Extant literature has highlighted the need for new skills in BIM and computational design. This paper presented the rubrics for a dynamic and flexible BIM application which covers AEC design requirements for the early stages of design. This included the critical aspects required to support recent (computational) design paradigms, including algorithmic architecture, generative and parametric design - which are capable of providing techniques for exploring and generating design solutions.

This paper critically reviewed seminal literature on AEC tools in order to highlight the existing theoretical and technical gaps that exist on the implementation of BIM tools to support conceptual design. The implementation of such interfaces can lead to new approaches for using generative design. This can help AEC designers explore different design solutions in a risk free virtual environment. However, this is not without its own set of challenges. BIM and generative tools need to be further examined in order to fully exploit the potentials of both. This will require seamless integration (to fully extol the benefits of computational conceptual design). The implementation of such approach could leverage significant benefits. This paper presented a Generative BIM framework with the capability of analysing and optimising design solutions at the conceptual design stage to: provide techniques for exploring and generating design solutions; create models with appropriate information and details needed for the development process; create a generative process capable of controlling the variability of design outcomes (i.e., generating alternatives that differ significantly in terms of overall organisation and configuration), including the generation of designs with the required level of complexity at each stage of the design process. The conceptual framework provides for the exploitation of new concepts in computational design and architecture. The theoretical basis underpinning this research will be used to develop a working prototype. From a research limitation perspective, it is acknowledged that whilst this work is relatively in its infancy, primary data and empirical evidence presented in this paper support these findings. That being said, it is equally important to acknowledge that further studies are needed to develop and validate this framework, using domain experts and focus-groups (development iteration), in order to capture the precise rubrics and parameters needed to shape and further refine this model as a part of the holistic development process.

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