TopoBIM: Web-based Spatial Topology for Early Design Participation

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TopoBIM is a 3D web-based viewer for BIM data that facilitates the capture of stakeholder knowledge related to project requirements and constraints in early design. The software provides an interface for viewing 3D models and data for selected room types and adding topological annotations. The use of topological representation is proposed as a method for facilitating knowledge capture, allowing decisions about the details of plan layout to be deferred and widening the potential for participation in the early stage design process. Topological representation is widely employed in the engineering disciplines, but is not commonly used as a means of capturing schematic information in early design.

TopoBIM is proposed as a methodology and workflow for the introduction of topology in early design, and as an example of lightweight, bespoke software that informs design by allowing stakeholders to perform specific tasks using BIM data, without the constraints and limiting complexity of BIM authoring environments.

Keywords: Early design, Topological representation, Participation, BIM, Knowledge capture

INTRODUCTION

The early stages of architectural design are characterized by limited information, rapid cycles of design development, and input from multiple client, consultant and stakeholder groups. The need to capture detailed, structured building information in early design is particularly important in building types such as hospitals that involve complex dependencies between space organization, equipment, and building environmental services. Obstacles to stakeholder participation in the early stages of building design include the need to master complex design software; the challenges for stakeholders of working with architectural representation; and the cost of software licenses (Kassem et al. 2012). The current project addresses challenges to stakeholder participation in early design through the development of bespoke software for web-based creation and editing of building information.

This paper describes an application of bespoke, web-based software as a means of providing access to building information in early design and capturing input from stakeholders regarding building requirements and constraints. The project proposes the use of topological representation as an effective and accessible method for a wide range of stakeholders to view building information and describe programme requirements and constraints. While topological rep-
BIM IN EARLY DESIGN
Building Information Modelling (BIM) is a design process involving the production of detailed 3D models with associated project data. The use of BIM is rapidly becoming industry standard practice in the UK, with all companies tendering for public sector contracts required to implement level 2 BIM, which mandates the use of open data formats and recommends a series of data drops documenting project development at key stages in the design process. Data Drop 1 occurs concurrently with the preparation of the project brief and documents the requirements and constraints gathered during a period of consultation with stakeholders.

A significant limiting factor in the effective implementation of BIM is its use in the early stages of design. There are multiple obstacles to the use of currently available BIM authoring software in early design; two of the most pressing issues can be summarized as the complexity of the interface and the limitations of the underlying data model. The BIM user interface is designed to enable the production of highly detailed ‘virtual buildings’ by expert users, and currently available software does not offer task-specific interfaces to limit this complexity for stakeholders or managers who need access to a limited subset of the tools or data available in the application. In early design a limited range of tools are needed for modelling, data management and analysis, and providing the full range of functionality to every user can invite error through misuse of an unfamiliar interface.

In early design there is an opportunity to inform decisions by providing simplified access to BIM data. A promising model for providing access to BIM data at this stage of design is the use of bespoke software applications such as those proposed by Derix (2010) who writes “Where lightweight computational simulations exist that can be assembled into integrated hybrid workflows, design intentions for implicit architectural properties can gradually emerge through the empathetic coupling of heuristics. The lightweight applications must be limited in functionality (parsimonious) and visualize in real-time the intentions of the simulation as it searches, to render its heuristics transparent.” We have built on this proposal for a collection of simple, lightweight applications that together provide the designer with diverse views of complex phenomena. Also important is the modularity of these applications, which must allow easy data exchange between each other as well as with BIM authoring software.

In addition to simplicity and modularity, we propose that transparency should be an essential requirement for software development and workflow in early design. Resnick et al. (2000) discuss the importance of making software less opaque (i.e. understandable) to its users in response to the ubiquity of what they call ‘black boxes’: tools whose form and function offer few clues about the rules informing their design and operation. Most architectural software is a black box, due both to proprietary protection of source code and to an overwhelming complexity that limits understanding to experts who themselves understand only a subset of the software and its functionality. In contrast to this, transparency is the principle that software and the workflows it enables should be understandable to non-experts in its inputs, outputs and basic rules of operation. The input and output file formats for our application are human readable, allowing (in principle) for the creativity and intuition of the designer to play a role in their analysis and use (Raymond 2003).

The design brief is a document produced in the earliest stage of building design as a record of client requirements, project objectives, building programme, sustainability goals, and other project constraints and parameters. In highly complex building types such as hospitals the preparation of the design brief involves input from a range of stakeholders
Figure 1
Diagrammatic representation of the Diagnostic Imaging department in a hospital, showing the level of detail used in RIBA stages 0 and 1. The diagram indicates connection and adjacency without specifying precise plan layout. Image source: Bryden Wood Limited.

Figure 2
The topoBIM user interface. On the left is a browsable IFC tree structure, and on the right are the editing controls and visualization options. Image source: Authors.
with expertise in a particular aspect of the building’s construction or operation, information which is compiled into a document that can then be used as the basis for cost, feasibility, carbon, and other types of analysis. This stage of design typically corresponds with the development of diagrammatic plan layouts indicating required circulation, connection and adjacencies between spaces (see Figure 1); and massing models displaying building geometry and site configuration. In the United Kingdom this stage of design is referred to as Royal Institute of British Architects (RIBA) stages 0 and 1, and corresponds to a suggested data drop that includes a list of spaces in the building and a summary of requirements and constraints including finishes, mechanical and electrical services, equipment and furniture for each room or room type.

The design brief is developed in consultation with the client organization and panels of building users, operators, community groups and other stakeholders. The document outlines a set of requirements that become the basis for subsequent stages of design, and which can be used to check that the design specifications are consistent with client and stakeholder requirements. This consultation typically takes place in meetings with representatives of the various stakeholders, and can then be organized as a written summary and Data Drop using the COBie (Construction Operations Building information exchange) format. It is also common to prepare Room Data Sheets (RDS) that summarize the requirements of each room in the facility.

The limitations imposed by software often arise through the interface, but can also result from an underlying data model that fails to allow for the storage of necessary information. By providing a structured format for building data, the Revit data model or data exchange formats like the IFC (Industry Foundation Classes) eliminate ambiguity by limiting the possibilities for unstructured extension. This is a benefit unless the data that needs to be stored has no place in the structure. For example, the information needed for automated checking of compliance with green building standards such as LEED or BREEAM is imperfectly captured by proprietary BIM authoring environments such as Revit, and also by exchange formats such as IFC or COBie, requiring the use of external databases to enable the storage of data required for this particular application (Biswas et al. 2013). Similarly, topological relationships between objects in the BIM model are not captured by the IFC data format and must be automatically inferred (Krishnamurti et al. 2014) or manually added as an external data source.

**TOPOLOGICAL REPRESENTATION**

The term ‘topology’ is used to refer to graph theory, a method for describing relationships between objects. Graphs consist of a collection of objects, referred to as nodes or vertices, and pairwise connections or edges. In architecture graphs have been used to represent relationships of adjacency and connectedness between rooms within a building plan (Langenhan et al. 2013) and spaces or streets within the city (Hillier et al. 1983, Vasku 2013). Topology has been used extensively in artificial intelligence research to support the automated production of optimal space layouts using expert systems, evolutionary algorithms and other approaches to finding optimal configurations with a given set of constraints (Liggett and Mitchell 1981, Eastman 1973, Jo and Gero 1998). In these applications parametric relationships have been used as a formalization of design rules and topology as an abstract representation of relationships (for example of adjacency and connectedness) in the architectural plan. This application of topology for automated space layout is intended as an extension of human design capabilities, replacing the most repetitive work of a technical draftsman in order to allow designers to focus on more complex tasks (Eastman 1973).

Topology has also been explored as a link between qualitative, human-readable design representations of design information and their corresponding quantitative, machine-readable data formats. Topological representation has been proposed as a
simplified form of design communication analogous to sketching in its capacity to focus on a limited set of relationships within the building (Medjdoub and Yannou 2000). Topology can equally be used as a link between human-readable design representation and a machine-readable data format through the automated or semi-automated translation of architectural drawings into topological data structures (Langenhan et al. 2011).

In this project our intention has been to use a topological representation as an intuitive abstraction of spatial requirements in the hospital that can be understood and used by stakeholders in the design process to capture knowledge related to the design and operation of the hospital. It is convenient in terms of data storage and visualization that this information is also machine-readable, but we have deliberately avoided automated data analysis in favor of manual evaluation and processing of the information collected using our interface, assisted by visualization.

**TOPOBIM USE CASE**
TopoBIM is a 3D web-based viewer for BIM model data (geometry and semantic information) that facilitates the capture of stakeholder knowledge related to project requirements and constraints for the design brief in RIBA stages 0 and 1. The software provides an interface for loading 3D models and data for selected room types, and the ability to define (directed or undirected) connections between rooms. Each group of connections occupies one layer, and using multiple layers it is possible to define different types of connection between the same rooms (see Figure 2).

The interface deliberately avoids the complexity of BIM authoring environments such as Revit: although a virtual building model with a high level of detail is required in later stages of design, this level of detail can prove distracting and unnecessarily time-consuming in early design when the knowledge needed to produce a detailed model is not necessary or indeed available. We have chosen graphs as a type of representation that allows design requirements and constraints to be defined without specifying the kind of precise spatial information required to produce a plan layout. For example, the software allows one to select the rooms required in a given hospital department and then determine the sequence in which these rooms would be encountered by a particular user of the hospital. The captured information can then be exported as an adjacency list to software such as Gephi, an open source tool that provides access to multiple algorithms for graph visualization and analysis (Bastian et al. 2009). Most importantly, the information captured from stakeholders can inform the development of the design brief. Although the graph information is both human readable and machine readable, we have focused in this project on the manual process of capturing and evaluating the data required for producing the design brief.

The use case considered in this paper is a hypothetical consultation with stakeholders in the design of a private hospital. The first application of topoBIM with a client is currently underway and will be reported in future work; in this publication we report a hypothetical use case describing the tests conducted within Bryden Wood Limited during the process of developing the software. In this initial use case we have envisioned the use of the software to support the preparation of design briefs for hospitals and other building types involving complex dependencies between space organization and equipment. Directed graphs have been used as a simple and direct means of representing multiple, overlapping requirements while making use of data from past BIM projects as a starting point in the design process (Langenhan et al. 2013). Nodes represent rooms, which can be selected from a library of relevant room types exported in IFC format from BIM models for past projects (see Figure 4). Because room types in hospitals and other institutional building types are often standardized, and because Room Data Sheets are a standard format for communicating building data to clients and stakeholders in early design, there is a benefit at the design briefing stage.
in using the room as the principle unit of design and analysis. Each room model contains semantic information and geometry for the room itself and associated furniture and equipment, allowing users of the software to inform design proposals with plausible assumptions about the requirements for standard room types. The following is an outline of the proposed topoBIM workflow.

Each participant in the consultation process receives a link to an instance of topoBIM pre-loaded with a set of room models specific to a given department in the hospital (see Figure 3). A collection of rooms can then be selected from this list by the user and loaded into the 3D viewer. Each room appears as a simplified volume with associated equipment and furniture (see Figure 4). Multiple 3D layouts are available in the interface. Directed connections can be added by clicking on two rooms in the

Figure 3
The topoBIM workflow. Source: Authors.
desired sequence. Connections occupy user-defined layers that can be used to represent any type of information about the relationship between rooms in the department. Each user will be able to create layers to capture information, assigning their own name to identify each category of information. For example, a nurse or other medical professional could choose to add information to layers representing the desired adjacency of rooms and the flow of patients and staff, with separate layers for inpatients and outpatients. Rooms such as operating theatres are associated with a complex constellation of rooms and circulation patterns for staff and patients, and one of the hypotheses that will be tested in the implementation of this project is the effectiveness of topological representation as a means of visualizing and capturing these relationships, with a separate graph for each type of information.

DISCUSSION
In the TopoBIM graphical interface the abstraction of topological representation is used deliberately as a way to defer decisions about detailed aspects of design, analogous to the use of a hand sketching in early design (Medjdoub and Yannou 2000). The use of a 3D interface for representing both rooms and connections was chosen as a means of preserving an understanding of the relative volume and spatial qualities of rooms. The 3D interface also facilitates analytic views that distribute rooms and equipment on the z-axis, for example according to their level in the IFC hierarchy.

The simplicity of TopoBIM in terms of interface and representation is a conscious response to the complexity of BIM software and its representation of complex building types. The project makes use of three types of simplicity to support access to and augmentation of spatial information by clients and other stakeholders in the design process. First, the simplicity of the software itself means that it provides a very specific function, the creation and viewing of topological information, a function not available in industry standard BIM applications which describe geometry and semantic information but not topology. Second, the interface presents a deliberately abstract representation of the building as a topological network which ignores details of spatial layout in order to focus on dependencies and constraints that must be articulated in the design brief prior to specifying a specific design solution (Coates et al. 2005). Third, the software further simplifies the experience of each user by allowing them to focus on only those layers of topological information relevant to their ex-
pertise: for example a surgeon can create and review only connections related to the circulation route for surgical staff in a particular section of the hospital, without the distraction of considering overlapping and adjacent activities within the building.

Currently there is a gap in the BIM-based design process between the BIM authoring environment on one hand, and on the other standard data formats such as COBie and IFC. Both the proprietary authoring software and the open data standards are restrictive in their own way to stakeholder participation, and can benefit from the addition of modular software applications which add specific functionality to the BIM design process. We propose that stakeholder participation can be enhanced when these applications are designed in a way that promotes the overall transparency of the design process, a goal that can be accomplished in part through the use of human-readable (text-based) file formats, parsimonious user interfaces and modularity of functionality and design. The intention is to enable additional opportunities for designers to apply their creativity and intuition in problem-solving, rather than relying on the computer to automate the process of evaluating building data in early design.

The purpose of topological representation in this project is to isolate a specific element of the BIM data model for use by a particular stakeholder. This ap-
proach could allow stakeholders who don't need access to the full BIM model to access only that part which is relevant to their work, and to annotate it with their knowledge of building requirements and constraints.

CONCLUSIONS
This project has focused on the collection of stakeholder knowledge in early design rather than analysis of this information. As discussed earlier there is a long and well-established research trajectory in building performance analysis based on topological representation, and we have deliberately not incorporated analysis in topoBIM. Following the principles of simplicity and modularity described above, our aim in this project has been to provide only the functionality needed to collect information that might not otherwise be recorded and store this information within the BIM model. We anticipate that the analysis and use of this information will become the subject of a future project.

In future work we will investigate the application of topoBIM at multiple scales. Previous research has demonstrated the validity of topological representation for a range of scales including design for manufacture and assembly (DfMA), the whole building and the city. Although our current functional prototype focuses on the scale of a single building oor or department, it can be made to work with these additional scales with minor modification. We will also investigate in future work the modification of existing BIM data formats to include the possibility of capturing topological information such as that produced by our application. One exciting possibility to explore in future work is the integration of topological user annotations in a future version of the IFC.

TopoBIM has been developed as a collaboration between researchers at the University of Sheffield School of architecture and London architecture firm Bryden Wood Limited. The use of topological representation for knowledge capture was developed in a series of projects at Bryden Wood Limited, the most recent of which is described in this paper. Funding for this project was provided by the University of Sheffield through an Impact, Innovation and Knowledge Exchange (IIKE) scheme funded by the Engineering and Physical Sciences Research Council (EPSRC); and by Bryden Wood Limited.

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