Building Information Modelling and the Documentation of Architectural Heritage: Between the 'Typical' and the 'Specific'

S. Fai, M. Sydor
Carleton Immersive Media Studio (CIMS)
Carleton University
Ottawa, Canada
sfai@cims.carleton.ca, mikael.sydor@gmail.com

Abstract— **One of the greatest challenges to using Building Information Modelling (BIM) for the documentation of architectural heritage is in overcoming the propensity of the software toward standardization. Most BIM applications are optimized for industrialized building systems where even a minor deviation in geometry or dimension between like elements is considered problematic. Heritage buildings, on the other hand, are more typically constructed of unique elements that, while sometimes similar, can never be assumed to be identical. For example, two Corinthian capitals from the Temple of Mars Ultor may be similar, but they are not the same. In this paper, we discuss a novel method for developing a BIM for a unique vernacular building in eastern Ontario, Canada. Constructed anonymously in two discrete stages during the last half of the 19C, the builders employed both stacked log and an idiosyncratic balloon frame construction. Both types of construction are far from the standard assemblies found in commercial BIM software. In discussing the construction of the model, we will outline the integration of detailed survey data, including pointcloud, with a library of 'typical', but parametric, construction details under development by our research group. While the survey provides an accurate geometrical record of the building under discussion — including structural deformations — the library is used to develop the specific assemblies and is based on, and fully indexed to, 'typical' details culled from construction manuals available in Canada during the late 19C.**

Keywords—**architectural heritage, parametric modelling, building information modelling, Canadian Architecture, laser scanning**

I. Introduction

A. Context: Cultural Diversity and Material Imagination in Canadian Architecture (CDMICA)

The research put forward in this paper is part of a two year (2011-2013), inter-disciplinary Partnership Development Project, funded by the Social Sciences and Humanities Research Council of Canada (SSHRC). The objective of the project is to develop a prototype for a BIM centred, cross-platform web application that supports the culturally nuanced documentation and dissemination of knowledge related to the materials and methods of construction specific to built heritage in Canada. The time frame for the study is 1825-1925 — a period of intense and diverse immigration into the country. The CDMICA database is comprised of three data sets:

1. a reference library of over four hundred digitized building and construction manuals dating from the period under study;
2. a BIM library of 'typical' building details, with parametric components, assembled from, and indexed to, sources in the reference library. The library is compatible with the industry foundation classes (IFC) data model;
3. twenty BIMs developed from survey data acquired by the CDMICA team, representing diverse and unique examples of ethno-cultural methods of construction adapted to the Canadian context.

B. BIM for the documentation of architectural heritage

Today, in North America, government agencies [27] [29], professional associations [23] [30], and corporate architecture/engineering practices [25] [27] are actively promoting Integrative Project Delivery (IPD) and the adoption of BIM as the common platform for the co-ordination of design, construction, and life-cycle management. In this context, we argue that it is not a question of *if* BIM should be adopted for the documentation, conservation, and rehabilitation of heritage properties, but *how*. We need only look back to the transformation brought about by CAD in the 1990's, to appreciate the impact that new forms of architectural representation have on contract documents, project delivery, and design. Architectural heritage must be considered within the larger framework of the architecture, engineering and construction (AEC) industry.

While not yet prevalent, the use of BIM for managing built heritage is growing. An early advocate, Hannu Penttilä, offered a case study that evaluated the advantages of BIM for the retrofit of buildings of significant historical and cultural value in 2005 [19]. In 2008, Yusuf Arayici, anticipating the inclusion of intangible heritage assets within the context of BIM, argued for its adoption for existing buildings in order to move beyond "rote 3D visualization" through the incorporation

978-1-4799-3170-5/13/$31.00 ©2013 IEEE

of multifunctional, intelligent, and multi-representational data [1]. In 2010, Attar et al., saw the potential of BIM for the retrofitting of heritage buildings for increased energy performance. More recently, Fai et. al. have explored the use of BIM for the integrated modelling of built heritage at multiple scales — including town planning [10].

A survey of the current research, however, suggests that two challenges to the use of BIM for the documentation of heritage buildings remain. The first is in the difficulty of adapting the generic assemblies that are packaged with existing BIM software to the idiosyncrasies of traditional building materials and methods of construction. For the manufacturers of industrialized building systems, the economic benefit of developing BIM libraries for their products is obvious — the same components or assemblies may be used thousands, even millions of times without variation. However, for structures built with traditional materials such as fieldstone or rough-hewn timber, each component and each assembly is unique.

The second challenge to the use of BIM for heritage documentation is in representing the structural and material deformations that often characterize older buildings. Again, as a technology optimized for industrialized building, BIM was not developed for modelling the irrational geometry of a century-old house made of logs. At the same time, with increasingly affordable and user-friendly hardware and software for non-contact digital recording, our ability to accurately record these deformations has increased dramatically. In recording architectural heritage, the documentation must include a true record of the building's geometry and the BIM needs to accommodate that geometry.

To address the first obstacle, Arayici proposes a cumulative approach where specific details are modelled for unique, documented cases and then stored to create a library that grows over time [1]. To that end, Murphy et al. offer a novel rethinking of a BIM library — HBIM (heritage building information modelling) — that employs parametric relationships between typical and specific details [17][24]. Their team is developing a library of typical parametric building objects (column capitals, column shafts, etc.) that follow the proportional rules of the classical orders that can be modified, both manually and using procedural modelling, to fit site-specific meshes developed from pointcloud data [18] De Luca et al. and [6] and Garagnani et al. [13] are also exploring this semantic modelling approach. While this method is valuable for documenting the geometry and the character defining elements of a building, further research is required to determine how effective it would be in modelling construction assemblies typical to Canada in the period under study.

Concerning the second challenge to the use of BIM for the documentation of architectural heritage, the process of moving from survey information (including point-cloud data) to geometrical models has been studied in detail. Of note in relation to CDMICA, Canciani et al. propose an expert based system, where shape recognition from the point cloud is tempered by having an "accurate knowledge based model of the building acquired through archive sources." [5] This model can be expanded to include other historical sources that inform the survey and documentation of related buildings. Research into modelling directly from the point cloud in BIM software has included the development of plug-ins for the Revit API. Most are directed at industrial plant processes, however Garagnini et al. have released a plug-in aimed at providing tools "to produce accurate components with precise extensions" for documentation of heritage buildings [14].

II. CDMICA Datasets

A. Reference Library of Building and Construction Manuals

To establish a bibliographical landscape for our period of study, we have assembled a reference library of over four hundred digitized texts relating to methods of construction in Canada between 1825 and 1925. These texts, where copyright permits, will be available online as part of the CDMICA prototype. The library provides a historical baseline of best practises and examples of 'typical' construction components and assemblies. Research into five dominant types of materials (heavy timber, light frame timber, log, stone and brick) resulted in a series of maps that document changes to and variations in typical construction practice over the century under consideration. Based on these maps, each material has a number of 'typical' assemblies reflecting innovations over time, material availability by region, or the availability of mass-produced elements. This exercise also provides the first indication of what parametric components of the assembly will facilitate the transformation from a 'typical' to a 'specific' detail.

B. BIM Library of Typical Assemblies

Using the information mapped from the reference library, typical BIM assemblies are constructed using Autodesk Revit. They are composed of individual parametric components (which contain information regarding materials and relationship to the rest of the assembly.) Depending on the context, they are modelled either with parametric dimensions relative to the assembly, or as adaptive components that can, within their constraints, be assigned to nodes on planes or in a mass (potentially generated from point cloud input). They are modelled in such a way that they could be used as an entire assembly for future modelling, or the individual components could be repurposed where necessary. The composite assemblies are indexed to the reference library using an external (SQL) database to link to the specific page of their bibliographic sources.

C. BIM Models

In order to test the veracity of our 'typical' details and to develop a workflow for transforming the typical into the 'specific', we have undertaken the documentation of twenty heritage buildings of various scales and programs. In addition, the buildings are located in various parts of the country and represent diverse ethno-cultural communities. The heritage recording is guided by Robin Letellier's seminal book, *Recording, Documentation, and Information Management for the Conservation of Heritage Places: Guiding Principles* [16], and employs hand survey (tape, disto, profile gage), laser scanning (Leica Scanstation2 and Leica C10), Leica Total Station, digital photography, and photogrammetry (PhotoScan).

III. Case Study

Twenty buildings have been modelled for *CDMICA* using variations of the techniques discussed in this case study. The case study focuses on a log building with a light frame addition. The log structure dates to the mid 19C and the addition to the late 19C. Two laser scanners were used (Leica C10, ScanStation 2) simultaneously with 16 different interior and exterior set-ups in order to generate a complete point cloud of all eight interior rooms, the exterior facades and the immediate site. The scans have a point density of 1cm at the furthest architectural element in the sightline (usually less than 5m). Each scan is registered to adjacent scans through fixed targets. These targets are also integrated into a Total Station (Leica TS11) survey that is used as a control for the registration of the scans, as well as to tie into existing survey benchmarks for geo-referencing. Leica Cyclone software is used to register all of the scans and the survey data, and to crop and reduce noise. An un-decimated point-cloud in .pts format is exported for use in modelling, visualization and for archival purposes. At this high point density, for the purposes of measurement or visualisation, the point cloud is functionally the same as a mesh model [12].

A. Modelling Process

The point cloud (in .pts format) is inserted directly into Autodesk Revit 2013 [23], relying on the built-in indexing and decimation protocols. This offers a sufficient level of detail (LoD) however alternatives that allow for greater control of this process are being investigated. The points provide the metric information to define the geometry and orientation of the BIM and serve as a template for modelling architectural elements. One of the current limitations of using pointcloud information directly in Revit is not being able to snap directly to individual points; rather Revit interprets a small sample of points and suggests a snapping plane that is perpendicular to the current view [14]. To ensure accuracy, other survey methods — such as photographs, hand measures, and point intensity mapping — are used as a reference.

The pointcloud information can be interpreted by using section planes in both orthographic and axonometric views,. Virtual reference planes are drawn against which the deformation of the built elements can be measured.. Using these planes, parametric families can be placed, aligned and adapted so they match the dimensions, deformation and orientation of the measured built elements. The pointcloud data only records the visible surfaces of the building, whereas the modelling process expresses the materials and methods of construction within the assemblies of the building. Incorporated into each modelled element is a tag that describes whether it has been directly observed or is an informed supposition.

Elements from our typical detail library are incorporated, both for modelling efficiency and to achieve a more semantically rich model. In this particular case study, the observable details are very similar to those modelled for the "Balloon Frame" typical assembly. However, some of the most revealing details, including the sill plate and the floor joists are not directly observable. For the floor, the direction of the deformation and the assembled dimension suggested an orientation and member size that is consistent with the typical detail. Interestingly, the elements that are not typical (rather, are not recommended as a best practise from the period bibliography) experienced a higher level of deformation than those that were. For example, within the framing for the roof, the rafters that are joined with a ridge beam had a maximum deflection of 1.9cm (¾") while those without a ridge beam had a maximum deflection of over 5.1cm (2").

The intent of the BIM is to document the building with a very high LoD related to the assemblies, such that detail drawings can be extracted and used for further study. The modelling process also documents the structural deflections in a manner beyond simply (and sometimes misleadingly) creating a meshed skin that doesn't reflect the composition of the assembly. Lastly, there is an imperative to document the nature of the materials and methods of construction as part of the CDMICA mandate. (see fig. 1)

IV. Conclusions

In their *BIM Handbook*, Eastman et. al. acknowledge that building information modelling software typically defers to "…generic objects based on standard onsite construction practices that are appropriate for early stage design." [8, p.241] The further specification of those "generic objects" is accomplished through manufacturer or custom libraries. Because manufacturer libraries are not available for most buildings designated as heritage and custom libraries can be expensive, this characterization of BIM has caused some to question whether it is an appropriate technology for the documentation of architectural heritage. In this paper, we have mapped out one possible solution to the challenge of creating custom BIM libraries for the documentation of heritage buildings and integrating those libraries into the data gathered from a contemporary building survey. We argue that by remembering the difference between what is similar and what is the same, it is possible to re-imagine the relationship between 'typical' and 'specific' within a BIM environment. The analogous relationship that exists between a 'typical' and a 'specific' architectural detail has somehow been overshadowed by our obsession with precision. The builders and construction manuals used in our reference library, resonating with the Renaissance treatises that preceded them, show us what is possible. Our survey shows us what is. Because BIM details are parametric, we are able, with relative ease to move between those two points, not so much to create a 'better' model, as to help us reflect on what created the distance between those two points. For further information, and access to the aforementioned digital BIM library, please visit: www.cims.carleton.ca

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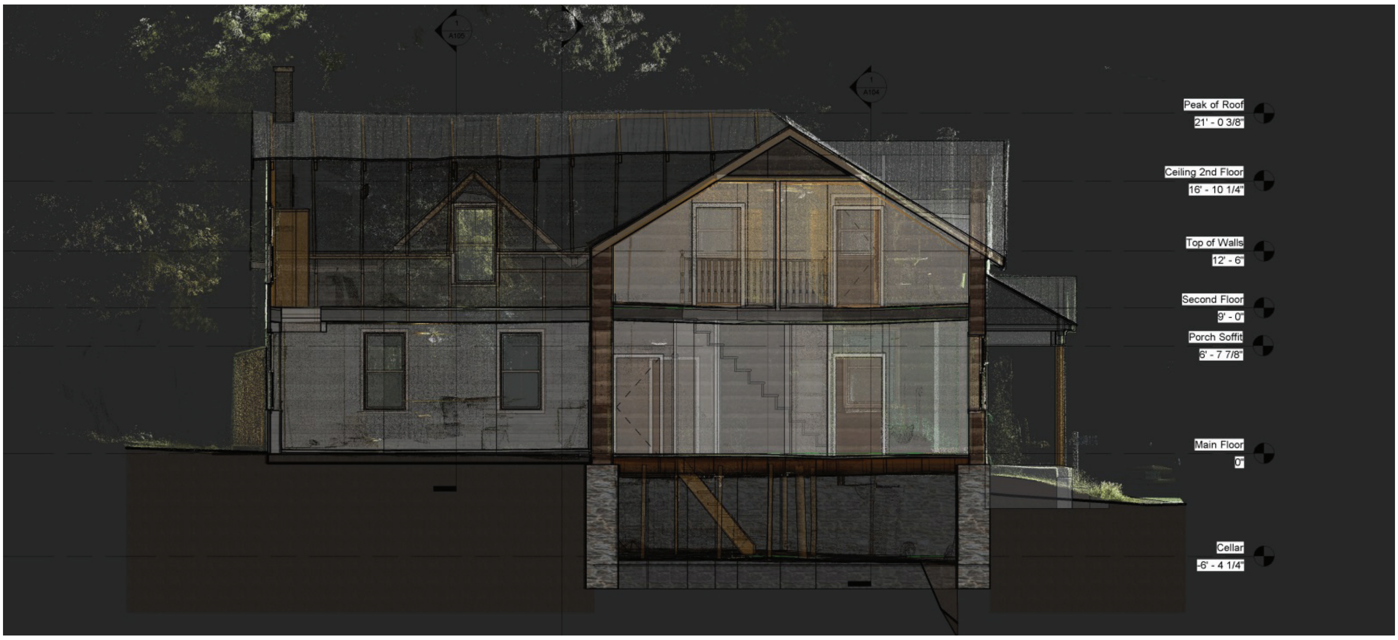

Fig. 1. Longitudinal Section in Revit 2014 showing / Frame Building BIM and pointcloud.