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TECHNIQUES FOR THE MEDIATION OF HERITAGE PRESERVATION VS. BUILDING PERFORMANCE

by

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Abstract

In the current climate of urban renewal and architectural sustainability initiatives, one needs to consider if architects have the proper design and analysis tools required to mediate the interests of heritage preservation versus those of building performance. In this investigation, methods of architectural heritage preservation and building performance simulation converge in a case study involving the retrofit of 204 to 214 King Street East in downtown Toronto, a designated heritage building complex and current home of Autodesk's Research Group, an industry leader in CAAD technologies. Using new techniques such as 'Building Information Modeling' (BIM) and 3D Laser Scanning, software such as 'REVIT' and 'Ecotect', and Computational Fluid Dynamics (CFD) simulations performed using the National Institute of Standards and Technology's Fire Dynamics Simulator (NIST FDS), the question of whether architects have the design tools necessary to holistically improve the thermal performance of a building while maintaining its heritage value and its relevance to our culture is examined. The heritage building complex at 210 King Street East is modeled and is analyzed for thermal potential. Based on the results of the analysis, a retrofit design is suggested which attempts to maximize the thermal potential of the building. Finally, the program of the building will be fine-tuned to match the optimized thermal variances within the building, completing a holistic thermal retrofit of the building. This experimental process from data acquisition to retrofit design is documented and used to propose a more generalized set of techniques and procedures, or protocol, for the holistic retrofit of heritage buildings.

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Introduction

In the current climate of urban renewal and architectural sustainability initiatives, one needs to consider if architects have the proper design and analysis tools and techniques required to mediate the interests of heritage preservation versus those of building performance. The ability granted by new technologies to quantify the ecological performance of a building sets the stage for a confrontation between our museological methods of architectural heritage preservation and the ideals of energy efficiency, a confrontation between *artifact* and *organism*. This confrontation is aggravated by current regulations which restrict the direct manipulation of the building envelope, as well as the ad-hoc solutions to energy efficiency supported by those who believe that the path to architectural sustainability is paved with solar panels. At the end of this path is the dark husk of a building, covered in technological debris, irrelevant to society. With the proper tools and techniques however, architects can combat this cultural irrelevance by examining the building holistically, and searching for ways to allow the building to express its full potential. It is through continued architectural evolution that the relevance of heritage buildings will survive not just the ideals of this generation, but of countless more.

In this investigation, methods of architectural heritage preservation and building performance simulation converge in a case study involving the retrofit of 204 to 214 King Street East in downtown Toronto, a designated heritage building complex and current home of Autodesk's Research Group, an industry leader in CAD technologies. Using new techniques such as 'Building Information Modeling' (BIM) and 3D Laser Scanning, software such as 'REVIT' and 'Ecotect', and Computational Fluid Dynamics (CFD) simulations performed using the National Institute of Standards and Technology's Fire Dynamics Simulator (NIST FDS), the question of whether architects have the design tools necessary to

holistically improve the thermal performance of a building while maintaining its heritage value and its relevance to our culture is examined. The heritage building complex at 210 King Street East is modeled and is analyzed for thermal potential. Based on the results of the analysis, a retrofit design is suggested which attempts to maximize the thermal potential of the building. Finally, the program of the building will be fine-tuned to match the optimized thermal variances within the building, completing a simple and holistic thermal retrofit of the building. This experimental process from data acquisition to retrofit design is documented and used to propose a generalized set of techniques and procedures, or protocol, for the holistic retrofit of heritage buildings. After the data acquisition phase which is a common starting point for all retrofits, only the thermal potential of the building is further analyzed in this investigation; however, the principles are applicable to other characteristics of the building as well. The narrow focus on thermal potential simply helps to better highlight the tools and techniques involved in the analysis and design.

The protocol will outline methods, conflicts, and best practices from the initial documentation of the case study to a retrofit design aimed at modifying both the envelope - a very sensitive and overlapping area of interest between building performance and heritage preservation - as well as the interior layout and program of the building. The protocol will be developed by combining existing research in the field with the experience gained from the proposed case study. Each phase of the investigation will raise questions both about the performance and the heritage value of the building, while the key to the success of the overall protocol will be the multi-dimensionality of the *generative datasets* created in the data acquisition and data modeling phases to digitally document the building and evaluate its performance. These generative datasets transform the 3D architectural model from one of data display to one of data discovery, where useful empirical observations can be made from within a digital environment. Explained in more detail

further on, generative datasets are essentially any acquired datasets organized in a format which can be combined with one or more other sets of established environmental datasets to produce new information. This is common practice in many fields such as medicine, geology, and planetary physics.

The purpose of the investigation is not to propose a solution to digitally preserve architectural heritage, but rather a technique to increase our ability to preserve the building's relevance to our evolving culture. The results of this investigation will demonstrate the methods by which new technologies and techniques can be used to visualize and investigate the energetic potential of heritage buildings, thus increasing the longevity of their relevance and, by extension, their existence.

Three primary software programs were chosen to document and analyze the case study: Autodesk Revit, Autodesk Ecotect, and NIST-FDS. Revit is a *Building Information Modeling* (BIM) platform primarily aimed at new construction, and does not yet have the extended functionality required to accomplish the goals of this investigation. However BIM, as explained further on, is compatible with concepts such as data-layering which lend themselves well to the investigation at hand. Revit was used as a database to store material and geometric information about the case study. Ecotect, on the other hand, is a performance evaluating software which can analyze the geometry and materiality of a building and generate visualizations in the forms of graphs and images which describe the performance of the building. Although Ecotect is a valuable tool to gather information about the performance of various materials and geometric configurations, it cannot trace the thermal variances inside the building. This is where NIST-FDS comes in. It is a computational fluid dynamics simulator which was initially developed as a way to trace the progression of a fire through a building, and plan escape routes. Since the simulation of a

fire within a building also traces the thermal variances within a building, it was an ideal tool to diagnose the existing thermal state of the building and assist in the retrofit design process.

The protocol developed in this investigation, and the data which it generates, will allow future researchers the ability to build upon this current investigation and examine other facets of building performance, such as lighting or structural characteristics. Emphasis will be placed on the open-ended and flexible nature of the protocol, as the progression through every phase serves to open up possibilities rather than provide finite conclusions.

Building Information Modeling (BIM) and Generative Datasets

Traditional architectural representation and communication techniques, such as hand drawings, CAD, 3D digital models, and physical models, are techniques which create *inert* data, i.e. visual data which can be duplicated, modified, and disseminated individually, rather than *generative* data, i.e. non-visual data which can be used to generate the representation required. The increasing complexity of modern buildings required an evolution in the way architectural data and its representation was handled, and in the late 1980s new collaborative data standards were developed, such as IGES¹ and STEP². This led to the development in the early 2000s of what we currently know as *Building Information Modeling* (BIM) and the *Industry Foundation Class* (IFC) (Penttila, 608).

Building Information Modeling (BIM) is a multi-dimensional digital modeling process which allows the integration of several layers of architectural data, from the

¹ The Initial Graphics Exchanger Specification served as an open-source format for the exchange of CAD information.

² The Standards for the Exchange of Product Model Data (STEP) is another open-source graphics format.

standard 3D geometric datasets, to the construction and cost schedules, to the program of the building. Often referred to as *Object Oriented CAD*, BIM can be understood as an attempt to integrate all the information required by the building industry into a singular source, i.e. a visually represented authoritative database of architectural information. This graphically indexed database is best formatted according to IFC specifications, which has been endorsed by the International Standards Organization (ISO). Being a non-proprietary public format, the IFC specification allows for a great degree of interoperability and is the specification of choice when attempting to create a generative dataset. Essentially a database of information, BIM datasets can be displayed and interpreted in a variety of ways, from a table of textual information to a fully interactive 3D model. The value of a BIM database in heritage preservation is the manner in which it documents the building. It is not intended to be an archive of data meant to preserve the heritage value of the building specifically – rather it is a descriptive archive of building characteristics which can be used for a variety of purposes, including the development of strategies for the preservation of a building.

The architecture of the BIM database itself has been interpreted differently by various software developers. Autodesk, an industry leader in architectural visualization, has developed a BIM software called REVIT which epitomizes the ideals behind BIM: a centralized database augmented by collaborative efforts. The key behind Autodesk REVIT is the use of a single evolving parent model rather than many independent models which must later be combined. This type of workflow is an essential starting point for the techniques being developed in this investigation, as the existence of an authoritative database of architectural information is essential in the continuing evolution of a heritage building. As building sustainability is not simply a factor of the building's existence and interaction with its environment, but also a measure of the efficiency of the workflow

leading to the building's development, the concept of BIM is a good envelope within which to conduct this investigation as it allows for the future integration of other useful data, such as the structural performance of the building, the carbon footprint, etc., all important aspects of a building's overall sustainability, but beyond the scope of this investigation. However, as the data acquired in this investigation will be formatted into a BIM database, it can be easily used for a variety of other purposes after this investigation has concluded.

Existing Research

In most cases, the application of BIM has been geared mainly towards new architecture, and as such special attention needs to be given to scenarios involving existing buildings, especially heritage buildings, because of their often unique construction. Much research has been conducted regarding the application of BIM to existing buildings for retrofit and renovation, and the use of case studies has been largely accepted as the best way in which to conduct this research, as it allows a scenario-based investigation into the functional successes and limitations of the BIM cycle. One of the primary limitations of Revit identified in this investigation is the absence of a wide range of simulation engines which can allow a more in-depth empirical analysis of the building. While Revit already provides unprecedented integration of the components of a building and their characteristics, it does not yet allow for an analysis of the interaction of these elements. For this type of analysis, co-operation between several different types of software is required.

Research into BIM for existing buildings has had various objectives, from the purely visual purposes of heritage preservation to the more data-intensive renovation projects, however these studies have largely been performed as unique case studies with a unique workflow. As observed by Penttila in this 2007 study on the BIM process for modern historic buildings, "each [BIM] renovation project tends to be unique by its nature, hence

categorization of buildings, projects or renovation methods is more difficult than it is in new building projects” (Penttila, 2007). In this investigation, the specific methods and techniques required to deal with unique situations in renovation projects will exist as optional paths within a framework built of overall procedural similarities applicable to all projects. The actual retrofit design will be kept simple in order to focus on the techniques themselves, and what they can teach us about sustainable retrofits to heritage buildings.

There are three main phases to the development of a standardized protocol for the retrofit of existing buildings: *data acquisition*, followed by *data modeling* (BIM) and finally *data visualization*. While this can be accepted as a general and perhaps obvious guide, the specifics within each of these three phases, from acquisition to modeling to visualization, are largely unresolved, with research projects often being targeted at developing technologies and techniques within each of these phases. Furthermore, the development of each of these phases can continue indefinitely without the boundaries of a well-defined investigation. It is thus important to ensure that data being generated in any of these phases is documented in such a way as to allow future investigations to build upon it, rather than be hindered by it. Although this concept seems logical and simple, experience will show that this is not normally the case. Existence of ambiguous data will restrict solid conclusions that can be drawn from any 3d model, leading to a waste of resources in verifying the acquired information. It will be a key requirement, therefore, that this investigation create a beginning rather than an end in terms of the holistic modeling of the case study.

Data Acquisition

Research in data acquisition from existing architecture is usually centered on three main data-types: laser scan (point-cloud) data, photogrammetric data, and direct

measurement data. Each has their particular strengths and weaknesses, and current studies attempt to determine the best combination of these three forms of data acquisition, and their related technological components, for any given situation.

A recent study by A. Georgopoulos et al. published in the January 2009 issue of the International Journal of Architectural Computing (IJAC) examines contemporary data acquisition technologies through a case study involving the churches of Virgin Mary Podithou in Galata and St., George Nikoxylitis in Drousiha. Using different but parallel data acquisition techniques for each subject, they evaluated the accuracy, reliability of the data, and time and cost of one versus the other. Although the point cloud data was found to be the most accurate with a differential of $\pm 2.5\text{mm}$ vs. the $\pm 10\text{mm}$ range of the photogrammetric data, they observed that the preferred method of data acquisition depends on the complexity of the object, the accessibility of the surrounding area, and the technical requirements for the final result (Georgopoulos et al., 2009). However, as this current investigation isolates the initial purpose of the data acquisition, namely the performance-based retrofit of an existing heritage building, more concrete recommendations can be made.

A 2008 study by Yusuf Arayici from the School of Built Environment at the University of Salford, UK focuses on the acquisition of data for BIM purposes using laser scanning technology. Their case study, the Jankin House in East Manchester, is used to demonstrate a process by which point cloud data can be directly used to generate BIM elements (Arayici, 2008). Although in a formative phase similar to this current investigation, and still requiring manual intervention and adjustments, their research suggests the future possibility for the use of point-cloud data as a viable data-mine for

geometrical BIM datasets, a required starting point for any type of holistic analysis of a building.

Other data sources include archived plans, construction notes, old and current photographs, building permit applications, and other such data which must be comparatively analyzed and accepted or rejected according to their accuracy and value. This labor intensive process produces a large amount of architectural ambiguity which is resolved and integrated in the data-modeling phase.

The use of these data acquisition techniques for the purpose of generating BIM elements will be discussed and explored further in this investigation through the case study.

Data Modeling

Data modeling involves the transformation of acquired raw data into a database with a graphical interface. Issues in data modeling are predominantly related to the proper definition of data families, data categories, data types, and the data itself. For example, a data family would be [wall], a data category would be [material], a data type would be [2x4 stud wall], and the data itself would be [8'x20'] (height x length). The process of data modeling is incredibly intensive and time-consuming, especially for existing buildings. It is in this phase that the IFC specification shows its worth; the standardization of the method of categorization of architectural datasets though a non-proprietary specification is invaluable to maintain an open atmosphere of collaboration between all parties involved, and to allow institutional, industrial, and governmental groups to participate fully in the development of reliable datasets.

A 2007 study by Hannu Penttila et al. focused on questions of value and methodology through a case study involving the Department of Architecture of the Helsinki University of Technology. Their stated objective was "to demonstrate the possibilities of

model-based methods within renovation and restoration.” (Penttila et al., 2007) They suggest the adoption of an ‘*inventory model*’, intended to be “the container for all building inventory, survey, and measurement data” (Penttila et al., 2007) in order to address the specific additional needs of significant historic buildings where the integration of additional survey and measuring data is essential for successful renovation. This type of data-layering is a property of the BIM concept which will be essential to the future development of the techniques used in this investigation. Their observations relating to the BIM process were that model-based renovation design needs to be started earlier than when using traditional methods, that the early project phases are more expensive, and that the design work, traditionally done after project launch, must be started before in order for the BIM-based validation for the project to be a factor of decision. The implications of this type of workflow, and how it affects the protocol suggested in this current investigation, will be examined in greater detail in following sections.

Looking forward in a 2004 study, Magdy Ibrahim suggests that “BIM CAD systems would either become super containers for information about building elements, or a referential model that points to the information when needed” (Ibrahim et al., 2004). The protocol being suggested by this investigation will take both of these possible futures into account and suggest their complementary rather than exclusive roles in BIM systems for existing buildings.

Data Visualization

The field of architectural visualization has witnessed a great deal of research activity in recent years. Moving beyond the traditional 2D and 3D digital representation, multi-dimensional visualization software developers such as Autodesk and high-end visualization hardware developers such as IBM have invested a great deal of money and effort into

acquiring datasets to test their visualization solutions. For example, in 2006 IBM collaborated with the Carleton Immersive Media Studio as well as other partners in order to test their collaborative design solution called DCV (Deep Computing Visualization), which allows for remote and local designers to interact via a 3D model. This is one important reason why industrial and institutional interests must work together to develop these solutions, as the design possibilities and the digital materials available to architects in the near future will be entirely the fabrication of the technology developers. The possibilities offered by software and hardware developers will be shaping our future design decisions.

The function of visualization software and hardware is to interpret and display existing datasets, which makes the formatting of the dataset of critical importance to the success of the visualization solution. This is yet another reason why the continued use and development of the IFC specification is of such importance, and why the development of protocols oriented toward the creation of generative datasets must be pursued.

Of additional importance is the validity of the dataset itself. The protocol suggested by this investigation places great importance on the validation of the dataset generated in the acquisition and modeling phases (production phases), in order to ensure that the data presented by the visualization solution is actionable data, i.e. highly-reliable and coherent visual information that can motivate action by investors, architects, governments, etc. Of specific interest in this investigation is the actionable information generated by feeding the datasets through performance simulations, which can help in making real-time decisions about the best retrofit options available.

Traditionally, simulations are not run by the architect or designer. Engineers usually perform the simulations and pass along relevant data and recommendations to the architects. (Kieferle et al, 2008). In a paper on simulation technologies, Kieferle et al. stress

the importance of immediate feedback in minimizing the gap between design and simulation; a requirement which is critical in the ability to design retrofits to heritage building where the architect must simultaneously make decisions on heritage value and building performance. Although Kieferle's research involves tangible user interfaces, the BIM database being developed in this investigation is similar in that it allows the rapid manipulation of building properties in order to effect changes in the simulation results; a method which allows an iterative process of design and simulation resulting in a retrofit which is informed by both heritage and performance characteristics.

210 King Street East

Figure 1: View of the south façade of the Adam Brothers Harness Manufacturing Company Building (204 King Street East) at the northeast corner of King Street East and Frederick Street. (Image from "Reasons for Designation – 214 King Street East")

"The property at 204 King Street East is worthy of designation under Part IV of the Ontario Heritage Act for its cultural heritage value or interest, and meets the criteria for municipal designation prescribed by the Province of Ontario under the three categories of design, historical and contextual value." (City of Toronto, Reasons for Designation³).

³ <http://www.toronto.ca/legdocs/mmis/2007/te/bgrd/backgroundfile-4842.pdf>

These are the first few lines in the statement of “Reasons for Designation” released by the City of Toronto relating to the subject of our case study, 204 to 214 King Street East (collectively referred to as 210 King Street East in this investigation). The historic warehouses were built between the 1930s and 1960s, and cover a total of 145,000 square feet of office space. The architecture firm Kuwabara Payne McKenna was responsible for the 1997 renovation and integration of the warehouses, from 204 to 214 King Street East. Except for 210 King Street East which was damaged by a fire, the remaining three warehouses are designated heritage buildings, requiring that the original features of the building be preserved. The building meets criteria for heritage designation for its “Renaissance Revival design... characterized by the horizontal division of the walls with applied Classical detailing”, its association to Toronto architect George M. Miller, a prolific Toronto architect at the turn of the 20th century, and by “[anchoring] the west end of a group of buildings that maintains the continuity of the block east of Frederick Street through their shared materials and setback” (*City of Toronto, Reasons for Designation*). Although the 210 King Street East building is itself not a designated heritage building, it serves as a central entrance to the amalgamated heritage building complex.

Figure 2: Buildings which make up the 210 King Street East complex. 204 King is referred to as building 1, 210 King is building 3, and 214 King is building 4, with the infill building in the back referred to as building 2.

The primary reasons for which 210 King Street East was chosen for this case study and for the development of the protocol are as follows:

- The building was recently renovated (1997) according to current heritage preservation regulations, which would allow a direct comparison of the performance improvements generated by this investigation.
- The problem of ambiguous data existing so soon after a renovation took place would strongly support the creation of authoritative data sets for use in any future renovations for heritage buildings.
- Extensive Laser Scan Data was very recently acquired for the building which would allow for the analysis of its place in the documentation of the building.

While the criteria for heritage designation and the process of selection and evaluation of heritage buildings, what can be called the *conservation* of heritage architecture, is not at question in this investigation, the *preservation* of architectural heritage, i.e. the methods used to ensure the longevity and integrity of the cultural value of a building, is of principal interest. This investigation observes that at a time of increased eco-consciousness, methods of preservation based on the assumption that the cultural value of a building is diminished by altering its superficial, (and often performance-inhibiting) characteristics can only continue to the detriment of our ability to preserve that same value. As the cost of energy increases along with public intolerance for the wasteful use of resources, our cosmetic approach to preservation will need to be augmented by more holistic and decisive methods targeted at the building envelope and its inhabitation. These methods will need to satisfy two criteria if they are to be successful – they must significantly enhance the performance of the building, and they must strengthen the heritage value of the building. As public support for the continued maintenance of a heritage building is derived from its degree of relevance to its cultural environment, increasing the relevance of the building will in turn strengthen its heritage value. The success of this investigation will be

measured by the success of the methods and techniques developed to enhance the energetic potential of the building, and preserve and augment its cultural relevance.

The building envelope is the most crucial element in the conflict between building performance and heritage preservation, for it acts both as the face of the cultural heritage it represents as well as the primary thermal regulator for the building. The beautifully articulated facades of a heritage building may harbor some of the architectural values of the time in which it was built, however its thermal permeability can cause huge energy inefficiencies and damage its ability to survive in a culture which increasingly alienates inefficiency, putting its very existence at risk and thus defeating the purpose of heritage preservation.

In the Ontario Heritage Foundation's manual of principles and practice for architectural conservation, Mark Fram warns of the threat of "ill-conceived modern improvements" (Fram, 9) and their ability to destroy architectural heritage. He continues to write that "this threat of modern improvement is the darker side of heritage conservation". This philosophy of heritage conservation is steeped in the notions that architecture is no different from museological artifacts and that preservation entails a complete removal of the artifact's ability to evolve, one of the qualities which give it the character we are trying to preserve. In his book on Canadian Heritage Preservation, Jokinen recognizes this point by stating that "the idea that historic buildings must not be altered seems inconsistent with the very history one is trying to preserve" (Jokinen, 11). Although the two authors use the notions of conservation and preservation interchangeably, methods of conservation are not the same as methods of preservation. The idea that architecture which is slated for conservation must be cut off from the passage of time denies the very nature of what conservation entails, namely the extension of the useful life of a building of interest.

Methods of preservation of heritage architecture must encourage its continued evolution rather than arrest it.

This investigation seeks to find a compromise to this conflict through the development of holistic techniques for performance-based retrofits to heritage buildings, aimed at proposing an alternative method of preservation which would allow historic buildings a new and more prominent place in our culture, and re-establish their ability to evolve.

Objective

This investigation will bring together research that has been conducted on the subject, as well as new techniques, technologies, and software, in order to design a protocol for the performance-based retrofit of heritage buildings. The design protocol will be based on the principle that optimization of the building's potential will contribute to the preservation of its relevance through time, and as a result, its continued existence.

Figure 3: Basic procedural protocol for performance-based retrofit.

In this investigation, the case study was designed to expose the procedural intricacies in retrofitting a heritage building from acquisition of architectural data to retrofit design.

Certain core issues of current design methodologies will be addressed:

- Utility of ambiguous and conflicting architectural data from existing datasets
- Inability of traditional methods of architectural modeling to diagnose the ecological potential of a building
- Inability to make concrete performance or sustainability claims prior to retrofit design

In addition to addressing the above issues with current methods, the developed design protocol and the generative datasets created through its adoption must meet the following requirements:

- Must deliver actionable datasets
- Must eliminate ambiguous data and deliver data within a context of accuracy vs. acquisition method
- Must allow collaborative input while generating singular data
- The dataset must be multi-dimensional, i.e. it must contain data from more than one source
- The dataset must be generative – i.e. it must be able to meet flexible representation requirements
- Must include a system of trust and accountability

The necessity for the involvement of industrial, institutional, and governmental organizations in the development of generative architectural datasets is an essential part of a protocol where the quality and viability of the datasets are extremely important. The concept of a 'trust score' as described in a 2005 publication on building simulation by Hand et al., will be central to establishing the level of accountability required for a publicly held architectural dataset, and will be evaluated based on the credibility of the author organization, benefit to the dataset archive, benefit to the software developer, and validation from user groups (Hand et al, 2005).

This investigation will begin with an evaluation of the performance of 210 King Street through the data acquisition, data modeling, and initial data visualization phase. Interactive data visualization will then allow for the development of a retrofit strategy aimed at improving the building's thermal potential. The end result will be a retrofit design which will allow the building to not only improve its energy efficiency but also its relevance and, by extension, its heritage value.

Data Acquisition

The data acquisition phase is one of the most complex phases of the BIM process for existing buildings due to the large amounts of ambiguous data generated in this phase. Surprisingly, although the building in our case study was recently renovated and digitally documented in 2D CAD, geometric ambiguities were present throughout the data acquisition process, leading one to contemplate the inefficiency of the data acquisition protocol currently used for the retrofit and renovation of existing buildings. In this investigation, the data acquisition phase will result in the creation of an authoritative BIM dataset for the case study which can be used by anyone for a multitude of purposes. One of these purposes, namely the analysis of the thermal potential of the building, will be followed through to result in a retrofit design. With the architectural datasets acquired in this phase, other avenues can be pursued in future research. The true flexibility of the BIM dataset is this generative ability; the ability to combine an existing dataset which describes a building with a variety of other datasets in order to gain a clearer, more holistic understanding of the building.

The data acquisition phase is the first phase of any retrofit project – it involves the gathering of both existing data and empirical data in order to set the stage and formulate a strategy for action. *Figure 4* illustrates the interplay between the various sources of architectural data and methods of data acquisition. In the case of heritage buildings, the amount of ambiguous data gathered will be extensive, due to the many authors and many techniques for data acquisition that have been used over the lifetime of the building. This ambiguity can only be resolved by validation of the data available through authoritative or empirical data sources. The validation of existing data is best left to the data modeling phase, where final decisions on the accuracy of the data need to be taken. The process of

validation however can cause interdependency between data acquisition and data modeling as it is often necessary to re-acquire data which causes unexpected ambiguities during the modeling phase.

Figure 4: Various Sources of Architectural Data

Sources of Architectural Data

Ambiguous data create a great deal of inefficiencies in the process of digital documentation, and need to be moderated before an authoritative dataset can be established. The importance of an authoritative dataset cannot be overstated in developing efficiencies in heritage preservation and building performance. An authoritative dataset which provides actionable information can mean the difference between the approval and rejection of a proposed retrofit plan, while helping to decrease the data-gathering cost involved in the preliminary phases of design and construction and all future design and construction phases involving this particular building.

An effective protocol would provide a methodology to eliminate ambiguities for existing buildings. Much of these ambiguities are a result of the various sources of architectural data available for existing buildings, therefore the protocol must include methods for consolidating, testing, and storing an authoritative set of architectural data that is both accurate and trustworthy.

For our case study, the available data included the architectural data from the Kuwabara Payne McKenna architecture firm which designed the 1997 retrofit to the group of buildings, CAD plans which later proved to have a large degree of inaccuracy, and hand-drawn plans which were used for permit applications were obtained as an initial source of architectural data. While the CAD plans were not of high accuracy and poorly detailed, the hand drawings were significantly more useful for their detailing and measurements. However, since both the inaccurate CAD drawings and the seemingly more accurate hand drawings were sourced from the same firm, the trustworthiness of the information was deemed relatively low. This meant that the drawings needed to be validated by other means before they could be used as a viable source of data: either they had to be verified by another source of existing data, or they had to be validated by empirical methods of data acquisition. The validation of this data is essential as it supports the validity of all the information spawned by its interactions with other datasets.

Figure 5: Revit model of previously existing inert (uncategorized) data for 210 King Street E.

Another source of data was a BIM model created previously by architecture students at Carleton University. Darcy Charlton, Melissa Wakefield, and Siavash Zanjani created a Revit model as requested by Autodesk for their Digital 210 King project, intended to create a BIM dataset of their building for further research. This model, shown in *figure 5*, was an excellent 3D model, but contained mostly inert data without reference to data sources, and as such could not be used to create a generative data model for the purpose of building performance simulation or retrofit design. It did however point out a crucial difference between Building Information Modeling and traditional 3D modeling. In traditional 3D modeling, it is the appearance of the model which lends it utility. In BIM, the appearance is secondary to the proper selection and categorization of building materials and their order of construction. An improperly formatted BIM database is no more useful than a 3D model. A properly formatted one, on the other hand, can be examined to discover material details, costs, construction schedules, permeability, etc. This initial model was a good first attempt and was studied carefully in order to learn more about some of the potential data acquisition and modeling problems which may lie ahead. Issues such as a discrepancy between the number of floors in the acquired CAD drawings and the number of

floors in the Revit model led to the examination of various parts of the building more carefully.

Finally, some existing photography of the heritage building complex was made available, and turned out to be a very useful source of cross-reference material used during the data modeling phase.

None of the existing sources of data provided an unambiguous collection of architectural data, and as such, the data acquisition phase was largely dominated by empirical data acquisition methods used to validate existing data or to create whole new datasets.

Trust Scores

The concept of trust scores was described by John Hand et al. in their 2005 paper on improving the quality of data available to simulation programs. The idea is that data gatherers would be evaluated by their peers or other organizations based on the utility and validity of their data. This would allow anyone to choose their data sources based on the quality of the data. For example, datasets generated by organizations which have a financial stake in the success of the data would not be as trustworthy as non-profit organizations whose datasets have been evaluated by peers and found to be accurate. (Hand et al., 2005) Datasets generated by one organization and then assembled by another would also have a high trust score. The concept of trust scores is essential to a protocol whose intention is to create authoritative datasets which make it easier and more efficient for existing buildings to evolve. Without reliable documentation, the undertaking to retrofit existing buildings would require constant data acquisition, a large labor inefficiency in the retrofit process. An authoritative dataset for heritage buildings would greatly increase the ability to re-enforce the relevance of heritage buildings over time by developing a compounded set of

measurement, geometric, environmental, efficiency and other information relevant to the continued preservation of the building.

According to Hand et al., several factors affect trust scores for data (Hand et al., 375):

- Technical credibility of the author organization
- Benefits (financial or otherwise) to the data provider
- User confidence in the data

These factors allow the suggestion of the following preliminary guidelines for the creation of trustworthy datasets:

- Information regarding the method of data acquisition must always be saved in the BIM database along with the data acquired, in order for users to make informed decisions about the accuracy and precision of the data sets.
- The group responsible for the data modeling must not be entirely composed of the same group responsible for the data acquisition, as a conflict of interest may arise if the acquired data does not match the modeling requirements.

Although the above guidelines are not mandatory as high initial trust scores can overcome the negative tendencies of some workflows, they provide an indication of circumstances where acquired data can lose its credibility.

Of key importance in determining trust scores is the number of individual groups involved in the development of architectural data. There are four major groups that interact with the development and use of architectural data: Governmental groups, institutional groups, industrial groups, and user groups. The more groups involved in the creation and validation of the data, the more trustworthy the data becomes. It will be essential for this protocol to identify possible points of entry for each of these groups in the creation of authoritative architectural data sets.

Another requirement for a high trust score would be that every step of the protocol should be undertaken by a group other than the one which completed the preceding step. This removes the tendency for groups to embellish data to meet financial or scheduling requirements and favors the integrity of the data set created. Although this will not always be possible, its occurrence should be seen as a positively contributing factor to the trust score and the viability of the data.

Empirical Data Acquisition

Current methods of empirical data acquisition include photogrammetry, laser scanning, photography, and various forms of direct measurement. Each method has its benefits and drawbacks, and their utility will largely be determined by the characteristics of the data they generate. As our purpose is to evaluate building performance and design a retrofit, of primary importance is the accuracy of the data and the precision of the method used. An additional consideration when developing a more widely applicable protocol is the expense of each method, the effort required, and the trustworthiness of the data acquired. All of these factors must be mediated by the protocol if the datasets generated in this investigation are to be of use to other analyses, or if the protocol itself it is to be of use for the retrofit of other heritage buildings. Of these factors, the trustworthiness of the data acquired is the only factor which does not qualify only the method, but those implementing the acquisition method as well.

Of importance when considering methods of data acquisition is the question, "How do we obtain the data accuracy required for the project with the least cost/effort possible?" This is always a determining factor when making a data acquisition decision.

Figure 6: Relative strengths and weaknesses of various methods of data acquisition.

Photogrammetry:

Photogrammetry involves the generation of 3D co-ordinates through the stereographic matching of two or more high-resolution photographs. One of the benefits of photogrammetry is that the data acquisition phase is fairly expedient, as it simply requires one to take convergent photographs of the building for data-mining later on. Hundreds of photographs can be taken and used in the data modeling phase to generate the 3D geometry required to document the building. The major drawback of photogrammetry is that, although theoretically it could generate precise and accurate geometry, in practice the consistent accuracy and precision of the method are relatively low when compared to other methods, which means that the resulting geometry, although superficially accurate, can vary by several inches or even feet when comparing the results of two teams of data modelers. For this reason, photogrammetry is not a good solution for retrofit design purposes, and was not used for data acquisition in our case study.

3D Laser Scanning

Laser scanning technologies are constantly undergoing improvements both in the resolution of the acquired point cloud data and the software used to manipulate them. Laser scanner use beams of light to create a dense cloud 3D coordinates. This Point Cloud Data representing the building can then be visualized in through software. Research in laser scanning for building renovation has shown the utility of laser scanning in building renovation. Both the accuracy and precision of laser-scanning is quite high, as is the expense involved. However, the effort involved in gathering point cloud data is relatively low when being performed by experienced professionals.

In a project conducted by Marko Rajala and Hannu Penttila regarding the renovation of a building in Helsinki, point cloud data was extensively used to document the building, and to generate a 3d model which could then be used for the purpose of renovation design (Rajala, Penttila, 270). In this research project, the point cloud data was used for the creation of a 3d model of the building. It is important to note, however, that the point cloud data acquired in the Rajala and Pentilla project was used as a source of coordinate data for the creation of a 3D vector model, rather than assuming the role of the 3D model itself. The result is two distinct and as of yet incompatible sets of architectural data – the point cloud data, which is essentially a list of 3D coordinates, and the 3D model, which is a list of mathematical equations and properties. It is necessary, in the case of heritage buildings such as 210 King Street East, that the link between these two types of data is maintained, and that the trust score of the group involved in translating the point cloud data into vector data be recorded, if an authoritative architectural dataset is to be developed. This link will be discussed in the *Data Layering* section further on.

In this current case study, laser scanning data for the 204 to 210 King Street building complex was acquired by Autodesk Research for a different project. The research being performed by Autodesk would make it possible to use laser scanning information to directly validate acquired data, and generate vector data. The development of software that would allow point-cloud data to be translated into usable floor plans would be an invaluable tool in the development of an authoritative source of geometry for a particular building. Although there would be a great deal of expense involved, the data generated by laser scanning would speed up the process of data validation and data modeling, and could serve as a secondary environment for data acquisition, after the building itself.

*Figure 7: Assembled point-cloud data for the 210 King Street East complex.
Image courtesy of Autodesk Research*

Figure 8: Each color represents a different laser scan session. Point cloud data was assembled by Autodesk Research. Image courtesy of Autodesk Research.

Figure 7 & 8 show the point-cloud data acquired by Autodesk Research for their study. The top floor of the building is clearly visible and it can be seen how new software designed to manipulate point cloud data may aid in the creation of BIM datasets. Autodesk validated the point cloud data to a small margin of error, demonstrating the ability to assemble point cloud data from several laser scanning sessions into a coordinate model with high accuracy.

Photography

The primary role of photography in BIM is for material and textural data acquisition and general documentation. It allows for the resolution of some ambiguities that may present themselves in data acquired by other methods. Photography can be seen as the more accurate 2D visual representation of the subject, and can be used to estimate proportions or document materiality and color. Even though it cannot be data-mined very accurately, it is still one of the most indispensable and efficient data acquisition methods as it allows modelers the ability to verify the proportional accuracy of their measurements and help in determining material and color properties.

A large photographic archive will also permit the use of photogrammetric modeling should the need arise. As with point cloud data, photographic data should be layered into the BIM database and graphically indexed, allowing for quick access to several types of acquired data for the same point of interest in the building.

Figure 9: Photograph of two timber beams meeting the brick wall of Building 2

Figure 10: Basement doorway which required photographic documentation – Building 1

***Figure 11: Basement wall joint between Building 1 and Building 2.
Notice the layers of stonework and brickwork.***

Figure 12: Measuring the width of the brick wall in Building 1 through the window.

Direct Measurement Techniques

Direct measurement techniques from digital surveying to simple tape measures are by far the most accurate and viable data that can be gathered from a building, however the effort required is extremely high. It is not feasible to construct a protocol to digitally document a building based solely on direct measurement techniques as this would take a considerable amount of time and expense. Instead, key measurements are taken using this method in order to validate data acquired by other means. For example, direct measurements can be used to determine the accuracy of an existing dataset or the precision of a laser scanner. If it can be verified through direct measurement that a data acquisition method is both accurate and precise, then this method can be trusted to yield a very reliable data set which can, in the case of data ambiguities, be seen as the authoritative source.

Direct measurement was extensively used in the data acquisition phase for this case study, as the ambiguity in the existing datasets was extensive.

Data Acquisition Results

The ambiguity of the existing data prompted a lengthy data acquisition process. For example, the CAD drawings and the final plans acquired from the architecture firm responsible for the 1997 renovations did not match. As more information was not available on the reasons for the discrepancy, validation through direct measurement was required in order to determine which of the two sets of measurements was more accurate. This difficulty can be avoided in the future if the BIM framework included a table for recording the methods by which data was acquired, and descriptions of the margin of error for the acquisition method.

Figure 13: Example of ambiguities present in existing architectural data.

After several points of direct measurement validation it turned out that the final drawings which were submitted to the city were more accurate than the CAD plans, and the entire set of CAD plans was put aside. Where the final drawings did not provide measurements, direct measurements were taken from the site. The majority of structural measurements were acquired from the column grid as recorded in the drawings for tender submitted by in 1997, as well as one unexpected space in the building: the stairwells.

An Architectural Core Sample

The emergency stairwells were the most revealing spaces in the entire building (*Figures 10, 11, 12*). In these spaces, it was possible to measure the floor heights and the wall thicknesses. It was possible to determine the material composition of the walls, the window insets, and the manner in which the East wall of Building 1 and the West wall of Building 2 were joined. It was the most densely concentrated accumulation of architecturally relevant data in the entire building, and yet it was a rarely visited space. It served as an architectural core sample of the building's construction, an invaluable space for data acquisition as it was the joint between the horizontal and vertical planes of the building.

One characteristic of historic buildings which is well reflected in the stairwells is the very direct way in which the building allows us to interact with its core elements and structure. There is no drywall covering the brick, no hidden inner structure to deduce – the wall reveals its floor connections, its sectional strength, its massive nature, everything is laid bare in this one space. Fram describes how the uniqueness of heritage buildings is not singularly visible to trained professionals, but that “anyone who is willing to learn the discipline of observation can see and record these qualities” (Fram, 34). The story revealed by a historic façade to the learned observer, and the one revealed by the stairwell space to a

layman, can be seen as completely different but equally enriching. It can be seen that the façade of a heritage building may hold significant heritage value, however the stairwell spaces, for example, host a time-capsule of architectural data on construction methods, materiality, mass, proportion, and rhythm which cannot be experienced on the façade. The heritage value of a building is not just skin deep. The story of the materiality of the façade, for example, can only be experienced by interacting with the façade with more than our eyes. A retrofit which serves to explore the full potential of the materiality and space of a heritage building will serve to enrich its heritage value more than would be possible by selectively extracting it away from the process of architectural evolution. Rather than removing from the flow of architectural evolution a building which has been recognized as having heritage value, it can be redirected along a path of architectural exploration, where our desire to learn more about the building is reflected in the continued transformation of the building along this new evolutionary path.

Issues with Data Acquisition for 210 King

As it was impossible to obtain unambiguous sources of existing architectural data describing the heritage warehouse complex, empirical data gathering techniques were used extensively. This process had a significant impact on the development of the protocol.

Originally, it was assumed that the data acquisition phase would precede the data modeling phase. However, the direct measurement data gathered was entered into the BIM in real time. In other words, the BIM database served as a storage container for all the empirically gathered architectural data. This made sense as it would provide a visual representation of gathered data and would allow the data acquisition phase and the data modeling phase to run concurrently. This concurrence was only achieved with data acquisition through direct measurement. Data acquisition through laser scanning had to be

completed before any modeling could take place since the data acquired from laser scanning is segmented into sessions which are assembled later on. *Figure 8* identifies the various laser-scanning sessions by color. The multiple sessions were only assembled by Autodesk after all the laser-scanning was completed.

Another issue was the accuracy of the measurements. When measuring walls composed of rough brick and stone, the possibility of high accuracy is at question. Estimates needed to be made for several measurements which had a possible error range of ± 2 in. For building performance analysis, this is well within allowable tolerance; however for the integrity of the dataset, the margin of error needs to be recorded. The best way to address the issue would be to allow every coordinate in the BIM database to have a corresponding author, method of acquisition, and margin of error field that could be viewed. This would allow users of the data set to evaluate for themselves whether or not the data set meets their accuracy requirements based on the proposed use of the data. This simple addition can transform a perceived inaccurate and useless dataset into a useful tool simply by knowing the parameters affecting the accuracy of the data.

Data Acquisition Recommendations

- Associate all data with an author, a measurement technique, and a margin of error.
- Associate groups of datasets with updatable trust scores.
- Use the BIM database as a storage medium for empirically acquired data
- Update Revit software to include the option to store multiple datasets which describe the same geometry or material.

Data Acquisition Protocol

Figure 14 illustrates the data acquisition protocol for laser scanning. Of importance is the manner in which the task from acquisition to validation is divided up between industrial and institutional workgroups, in an effort to increase the overall trust score of the

final point cloud dataset. A similar division of labor should be applied to all other forms of data acquisition, such as photogrammetry, direct measurement, etc. in order to maintain high accuracy and trust scores.

Figure 14: Interaction of contributing groups in the validation of point-cloud data.
FARO: A manufacturer of 3D laser scanners. They acquired the point cloud data referred to in this investigation
CIMS: The Carleton Immersive Media Studio

There are two main reasons for this occurrence. Firstly, there seemed to be no better way to store the data acquired through direct measurement than in the BIM database itself. The choice was between making a whole new set of plans, sections, and elevations to compete with the existing data, or to simply enter the authoritative data as it was gathered directly into the BIM database. This was by far the more efficient and logical method, and would not have been possible with traditional 3D modeling techniques or software. One major limitation of the software used, however, was that possible types of data which could be indexed were limited. REVIT does not yet contain a feature allowing the layering of many types of acquired geometric data.

The second reason for the concurrency of the data acquisition and data modeling phase was that the utility of a software designed as a tool for new building design and construction has not been established for heritage building modeling. It was simply not known exactly how successful the attempt to create a BIM model of a heritage building would be. Except for the assumptions formed at the start of the case study, the resolution of data required was unknown, the amount of data required was unknown, and the ability of the software to model unique situations was unknown. From the very beginning, the linear relationship between the data acquisition phase and the data modeling phase had broken down into a dialogue between the two, where a software-related inconsistency would drive a burst of data acquisition which would then result in a compromise solution between the actual reality of the building and the software approximation. It was necessary to develop a compromise which would satisfy the resolution of the software and the need for an accurate digital description of physical reality. Due to the diverse nature of heritage buildings and the varied skill levels of the data modelers who might be working on them, the concurrency of data acquisition and data modeling cannot be assumed to be resolved based on 'lessons learned' from this experience. The concurrency of these two phases must be built into the

protocol if it is to be of use. Furthermore, the utility of Revit in recording acquired data from direct measurements is unparalleled as it allows not only the visualization of data as it is collected, but its collaborative features allow more than one individual to participate in the data collection without fear of redundancy.

Considering the various strengths and applications of each method of data acquisition, the most evident solution to this problem is a layered approach to digital architectural documentation, and involves the layering of acquired data in the BIM database, whose retrieval is facilitated through graphical indexing. What this implies is that a user interested in information about a particular detail would be able to navigate visually to that detail in the 3D representation of the BIM database and would have access to all the acquired data about that detail as well as information on the methods of acquisition and their margin of error.

Data Layering

Data layering is a scalable concept that lends itself well to the desire for an authoritative digital description of architecture. Recognizing that accuracy is a relative concept which is entirely dependent upon purpose of the data, it is necessary to allow multiple digital descriptions of singular elements to exist in the same modeling space. These alternate descriptions, such as point-cloud data, photography, video, etc. can exist as a link to external resources within the BIM database, similar to the method which REVIT uses to index 2D CAD drawings. These additional resources would be helpful when users require more than just a mathematical description of the element being examined, or when an assessment of the acceptable geometric or textural accuracy for a project is required.

Figure 16: Possible BIM Data Layering for Heritage Buildings

Another benefit of data layering is its ability to merge seamlessly into the dialogue between data acquisition and data modeling, and potentially make the process of generating a performance model easier. If laser scan data was obtained early, it could be used as a data mine for the occasional direct measurement which must be verified. In the Rajala and Penttila study, the point cloud dataset and the 3d vector model were two distinct descriptions of the building. In order to be of use in the creation of an authoritative dataset, the point cloud data and the 3d vector model would have to be linked together, to allow the point cloud data to serve as a repository of unmeasured data, similar to photographic documentation, where one can search for previously unknown or overlooked architectural data such as wall thicknesses or mullion patterns. This could help to break the dependency between data modeling and data acquisition, leading to a more streamlined workflow and a fewer number of site visits.

Figure 17: Point Cloud Data can help to break the dependency between data modeling and data acquisition.

Indexing and Retrieval

Data modeling in REVIT is more involved than traditional 3D modeling. It is in effect a form of multidimensional modeling, as it records more than the simple 3D geometric data associated with surfaces. REVIT models contain the geometry, materiality, construction phase, etc. of building elements. This is an invaluable tool in the creation of a protocol for heritage building retrofits; if expanded, it would allow the storage of various forms of information relating to a particular building in a single database of internal properties, or links to properties, that can fully describe a building. Multidimensional modeling would essentially create a map of the building to which data could be added infinitely, and it would store and categorize the data according to purpose, quality, trust score, and utility. This categorization, augmented by graphical indexing, would allow the authoritative database to serve the user with all the information available on a particular building, allowing it to be

easily retrofitted and updated in the future, and contributing to its lifetime performance and longevity.

Interpretation of Ambiguities in Acquired Data

In the development of an authoritative source of architectural data for a specific building, numerous ambiguities in acquired data must be resolved. The simplest and most effective way to resolve these ambiguities is by direct physical measurement. Often, these methods of validation are not possible because of circumstances beyond our control, such as access restrictions. In cases like these it is essential for the existing data sources be associated permanently with the data they have provided. For example, it is essential for all architectural data to be stamped with the acquirer's profile and the method of acquisition. In this way, we will be able to determine, from the existing sets of ambiguous data, which is more trustworthy based on the trust score of the author as well as the tools used for data acquisition.

Parametric Design and Heritage Value

There is a concept called *parametric design* which is exploited in Revit. Parametric design involves the association of variable parameters to building elements which, as a result, are either locked at a constant value, or constrained to other building elements, changing with respect to them. This unique method of design has some interesting heritage repercussions when used to model existing buildings. For example, in a situation with concrete walls surrounding a floor slab, we could envision two parametric solutions. The first one would constrain the walls to the floor, meaning that the geometry of the floor will determine the position of the walls. This would ensure that the walls would always border the floor. This also mean that if the building were built on this solution, the floor slab would

have to be poured first, and the walls would then be poured to match the geometry of the floor slab.

The second parametric solution would see the floor constrained to the walls. This means that the position of the walls would determine the geometry of the floor. This would ensure that the floor would always border the wall, and achieve the same visual result as the first parametric solution. There is one difference, however; the walls would have to be poured first, and the floor slab poured after, an opposite to the construction process suggested by the first parametric solution. Thus, the parametric process of modeling is based on methods of construction, and the creation of a parametric BIM dataset for heritage architecture provides the opportunity to deduce a variety of historical information embedded within the building. This is why modeling an existing building with Revit is akin to attempting to understand the design intentions of the architect. Creating a BIM database for existing buildings is, in effect, the same as retracing the construction and design logic behind the building.

Material Composition

Careful attention needs to be paid to the material composition of the building envelope. The performance of the envelope is directly related to its material composition, and as such it is essential to model the wall section as accurate as possible. In our case study, the wall section is primarily 3 to 5 course brick on a stone and concrete foundation.

Figure 18: Wall Sections from East and North Walls of Building 1, acquired from the emergency stairwell.

Figure 19: Wall section for wall shared between Building 1 and Building 2 (BLDG1 East Wall)

Order of Construction

*Figure 20: Building 1 east wall view from the emergency stairwell.
Notice the stonework sandwiched between two layers of brickwork.*

The above photograph tells us that building 1 was built first, and that building 2 was an infill project. It is a sectional view of the wall shared by building 1 (left side of photograph) and building 2 (right side of photograph). The stonework on the right side suggests that this was once an exterior wall for building 1. As described previously, the order of construction plays an important part in the creation of a BIM dataset. This evidence can be indirectly recorded in the BIM database through the parametric constraining of the east wall of building 1 to the west wall of Building 2. Although this does not affect any thermal simulation results, the information could be useful for structural simulations or future renovation planning.

Data Modeling Results:

Upon conclusion of the data modeling phase, a BIM database was created which contained the majority of the information gathered from the data acquisition phase. Various challenges were overcome or circumvented during the modeling phase leading to both software-oriented and procedural recommendations.

Figure 21: Resulting BIM database from the data modeling phase

Figure 22: South elevation view of 210 King Street generated from BIM database

Figure 23: Structural Framing of 210 King Street (Bearing walls not shown) – an investigation into the structural efficiency of the building could be started with the same BIM model that was built to test thermal efficiency.

The primary success of the data modeling phase was the categorization of the majority of acquired data into the BIM database. Although some categories of acquired data could not be integrated into the BIM database, such as the laser scan data or the photographic documentation, the heritage building was nonetheless successfully documented as a database of properties and values. Structural members needed to be categorized by their materiality and specifications. Walls were categorized by their purpose as interior or exterior walls, their load-bearing capabilities, their materiality, etc. Every element was categorized not just by their dimensions and position but by their purpose and specification. This is one of the strengths of the BIM process as it provides a flexible and accessible description of the building. The result is the beginning of an authoritative architectural dataset which can be geometrically and materially explored and manipulated. One large difference between a BIM model and a traditional 3D model is that the BIM model is a database of information, while the traditional model is simply an aesthetic construct. If proper care is taken to build the BIM database, the information contained within it can reveal hidden details about the building that can influence decisions very early in the design process.

Software limitations

The major software-related limitation encountered during the data modeling phase, was REVIT's inability to store a large variety of acquired data. It was possible to store wall types, materiality, dimensions, and interdependencies in a graphically indexed fashion, however point cloud data or photography could not be stored in that fashion. It was possible, however, to creatively use some of the features of the program to overcome some of these limitations. For example, 'callouts', which are intended as links to detailed cad drawings of specific details, could be used to store graphically indexed photography, however as this was not the intended function of the callout, some features which would

have been useful in viewing and indexing photography were absent. Many other software-based limitations exist, as is the norm with most CAD programs – there is always space for new features. It is the procedural limitations, however, that are more interesting to discuss.

Procedural Limitations

Software programs are a set of rules and guidelines within which a user operates. No combination of keys or clicks will make the software do something beyond its programming. In a sense, the software designers are now the creators of our architectural design tools, a fact which may go unnoticed during the design and construction of a new building, as it is easy to move from the digital world to the analog world. However when an existing building is being modeled, we are attempting to describe the analog world in a digital environment. This reproduction is never fully accurate, and the modeler must make several often arbitrary decisions in order to complete the model. It is within this series of decisions that procedural errors are made, the most common of which is the proper categorization of architectural elements in the BIM database. There are many ways to represent a building as a BIM database; doors can be defined as windows and still appear to be doors, structure can be modeled one stud at a time, or be simply represented within a wall definition, not physically modeled but existing in the database as a property of a specific wall type. How do we know which way is the right way? While there are numerous way in which to represent a building as a BIM database, there are significantly less ways to do it correctly, and it cannot be said that there is only one right way. However some guidelines can help to make the right distinctions during modeling.

The first thing to remember is to create a BIM model in the same sequence as a building would be built. This means that the roof does not get modeled before the floor slab or the walls, and the foundation and major structural elements should always be defined

first. Second, always constrain every building element to a previously defined element, never to a subsequently created element. This ensures that the BIM datasets are linked in the order of construction and will more accurately represent the building. Third, wall units are composed of multiple layers of materials, and these materials should not be modeled as individual elements; instead they should be defined as properties of the wall itself. This type of composite object is better suited for export to simulation software, as these software often represent a thick wall as a flat plane with the properties of a thick wall. Defining a BIM wall with multiple objects would be interpreted as several walls sandwiched together, an inaccurate description of the existing wall. Lastly, the model should be tested with simulation programs like Ecotect often during the modeling phase, to catch any inconsistencies as early as possible.

Preparing the data for visualization

The final stage of the modeling process is to prepare the data for visualization. This process involves some trial and error as the workflow between Revit, Ecotect, and NIST-FDS is not entirely seamless. Ecotect uses only a fraction of the information present in a BIM database for the purpose of visualization and simulation, and NIST-FDS uses a different coordinate-based script to analyze the internal thermal variances. The proper interpretation of the BIM dataset by Ecotect and NIST-FDS is essential in order to get accurate results from the simulations. Effective interoperability of the BIM database created in Revit is still a problem; however this is a software-only limitation and can be overcome in future releases.

As the focus of our case study is the building's thermal performance, only data for the building envelope, the roof, and the floors was exported from Revit. The interior subdivisions and structure are not immediately necessary to get a preliminary idea of the performance of the building. In addition, removing the internal divisions will give us a

better image of the climate within the building, and will allow us to examine the thermal performance of the building as a whole.

Autodesk Ecotect

The first attempt at importing the Revit model of the case study into Ecotect was unsuccessful. The geometry of the building did not conform to the requirements for Ecotect and as such the BIM dataset needed to be optimized for this purpose. The critical elements to be redefined were the windows, walls, doors, floors, and the connections between walls and floors. As Ecotect only uses these elements and all others are ignored, it is essential that these elements be modeled and defined in Revit correctly before working on other details. *Figure 24* shows the Revit gbXML export window, graphically illustrating the geometry being exported for Ecotect analysis. This is an area where the software could be improved. For example, the materiality of the walls did not translate into Ecotect correctly, and it was not possible to define a materiality in Revit which could be read correctly by Ecotect. It was necessary to reconstruct the material in Ecotect itself and apply it to the imported geometry. As this is strictly an inter-operability issue, the duplication of labor (defining materiality in Revit and once again in Ecotect) can be avoided with software updates.

Revit – Ecotect Interoperability Issues

- Material composition defined in Revit cannot be seen correctly
- Complex geometries created in Revit are not translated correctly
- Custom objects created in Revit, arched windows for example, are replaced with rectangular windows in Ecotect.

Figure 25: FDS model initial import from Ecotect

Beyond these initial difficulties, material properties from Ecotect could not be read properly by FDS, and had to be rebuilt once more. At this stage, the material properties of the building have been defined three times; once for Revit, once for Ecotect, and once again for FDS. An optimized software workflow devised for the purpose of performance analysis would have to resolve this problem in order to make the retrofit design protocol being developed in this investigation functional and efficient.

Data Modeling Recommendations

Although the data modeling and acquisition phases can be revisited if necessary based on the results of the simulations, the bulk of these two phases will be relatively completed at this point for the purposes of initial sustainability simulations.

As it became evident that the initial performance analysis for the building had minimal requirements from the Revit model, the protocol displayed in *figure 26* has been updated to reflect this. Given enough manpower, the performance simulations could have

Protocol Overview

Figure 27: Evolution of the retrofit protocol after the data modeling phase.

Data Analysis and Visualization

An analysis of the thermal performance of a building requires both an analysis of the building envelope, as well as an analysis of the thermal variances within the building. Autodesk Ecotect will be used to investigate and measure the thermal potential of the envelope, while NIST-FDS will be used to visualize the thermal variances within the building.

Ecotect Thermal Analysis of Existing Conditions

Current methods for improving the thermal performance of heritage buildings involve retrofits which augment the R-value of the envelope, such as a layer of interior insulation. This allows for minimal aesthetic impact on the celebrated façade of the building. However, an Ecotect analysis of the thermal performance of the envelope shows us some interesting results which help us to see the façade not as an artifact to be frozen in time, but rather as a functional process affecting to the health of an entire organism.

Figure 28: Zones defined by Ecotect for analysis + Daily sun-path diagram for Toronto in December

Figure 29: Zones and sun-path diagram for June in Toronto

Figure 30: Hourly Temperature analysis for hottest and coldest days of the year

There are two sets of Ecotect graphs presented in this investigation which are used to determine the performance of the building envelope: The *Hourly Temperature Graph* and the *Hourly Gains Graph*.

Hourly Temperature Graph for Existing Conditions

The Hourly Temperature graphs in *Figure 30* are representative of the hottest and coldest days of the year, and were chosen in order to get an idea of the most extreme fluctuations in temperature experienced by the building envelope. This is necessary to get a sense of how the material reacts to the various factors such as solar radiation, inter-zonal heat gains and losses, temperature fluctuations, and convective heat flows, which affect the thermal climate of the building.

The hourly temperature graphs are based on three scales and five curves. The scales used are the hour of day on the bottom, the temperature on the left, and the solar radiation on the right. The five curves graphed are:

- Outside Temperature
- Beam Solar: refers to the amount of direct solar radiation affecting the zone
- Diffuse Solar: refers to the amount of reflected solar radiation affecting the zone
- Wind Speed: wind speed is not associated with a scale, however its relative strength is shown
- Zone Temp.: internal temperature of the room in question

The Hourly Temperature graph primarily demonstrates the relationship between the external temperature and the average internal temperature. The upper graph in *Figure 30* describes the hourly temperatures on the hottest day of the year.

The hottest day of the year

In analyzing the graph it can be seen that the internal temperature of the top floors are positively correlated with the external temperature, with indications of a mild capacitance. The internal temperature of the top floors is also generally higher than the exterior temperature by about 5°C to 8°C, indicating that a thermal process, possibly direct solar radiation or inter-zonal heat transfer, is heating up the room. As the Beam Solar curve

appears to positively correlate to the internal temperature of the top floor with a time-shift of about one hour, we can assume that the 5°C to 8°C temperature difference is due the radiation of heat through the envelope (rooftop or exterior walls). The envelope is absorbing heat through solar radiation and radiating this heat into the building, a heat transfer process which appears to take about one hour.

From this first graph it can be inferred that a reduction in summer temperatures for the top floors can be achieved by using a thermally reflective rooftop design, and the positive correlation between the exterior and interior temperatures may be lessened with better insulation or a different envelope configuration.

In the same graph, the internal temperatures of the lower floors can be seen to remain fairly steady in spite of the external temperature variations, or the temperature variation of the top floor. The peak temperature for the lower floors is achieved at around 4pm, which the peak external temperatures occur around 12pm. This delayed response to external temperatures can be inferred to be caused primarily by the significantly lesser amount of exposed surface area to both external temperatures and direct solar gains. As the internal temperatures of the lower floors are just slightly higher than the comfort zone, it may be possible to reduce these temperatures with natural ventilation. As the current envelope has no operable windows on any side, adding openings on the north and south sides of the building may help to reduce these internal temperatures enough to bring them into the comfort zone.

It can be inferred from this graph that a reduction in summer temperatures for the lower floors may be achieved with natural ventilation.

The coldest day of the year

The lower graph in *Figure 30* demonstrates the relationship between exterior and interior temperatures for the coldest day of the year. Similar correlations between the internal and external temperatures can be seen. In wintertime, however, it is desirable to increase the internal temperatures. As such, the earlier solution of a reflective rooftop to lower the temperature of the top floor would be detrimental to building performance in the wintertime. The gains for direct solar radiation are beneficial to internal temperatures, and must not be eliminated; however the positive correlation between interior and exterior temperatures for the top floors must be lessened to allow for the full benefits of direct solar radiation.

The lower floors display a similar behavior in the winter as they do in the summer. The insulation of the floors is adequate as it lessens the correlation between interior and exterior temperatures, however the average temperature itself must be raised by 20°C to enter the comfort zone. The best known scenario to increase interior temperature is one that instills a greenhouse effect inside the building to take advantage of the principal heat source in the winter, direct radiation from the sun. The south façade of the building is in direct sunlight all day, and is the best façade for the purpose of creating a greenhouse effect to increase internal winter temperatures.

From this graph, the possibilities for increased winter temperatures has been narrowed to a greenhouse effect on the south façade.

Hourly Gains Graph for Existing Conditions

The hourly gains graphs displays information regarding sources of heat gain and heat loss. It uses two scales, the time of day on the bottom and the heat gain in Watts on the left.

The curves represent heat gains from HVAC, conduction, Sol/Air, Direct Solar, Ventilation, Internal, and Inter-Zonal:

- HVAC: This curve shows heat gain or loss from the HVAC system. As we are analyzing passive performance, this curve is always zero.
- Conduction: This curve heat conduction loads through the fabric of the zone
- Sol/Air: this curve shows heat gains due to solar radiation on opaque surfaces
- Direct Solar: This curve shows heat gains through solar loads on transparent surfaces
- Ventilation: This curve shows heat gains or losses though ventilation
- Internal: This curve shows internal heat gains from lighting, equipment, and traffic. This curve is not used in passive analysis
- Inter-zonal: This curve shows heat gain through adjacent spaces.

The upper graph in *figure 31* describes the hourly heat gains and losses for the typical lower level for the hottest day of the year, while the lower graph describes the same for the coldest day of the year.

The upper graph clearly demonstrates the heat capacitance of the envelope of the lower floors with the typical time shift between the Direct Solar and Sol/Air curves. The Sol/Air curve shows that the 3-layer brick envelope stores solar heat for about 5.5 hours in the summer months. The envelope also demonstrates a relatively large heat conduction during the summer months, and moderate losses from inter-zonal heat exchanges.

The lower graph magnified in *figure 32*, shows large losses in heat through ventilation and conduction in the winter months. This clearly demonstrates the permeability of the envelope. There are also large inter-zonal heat gains overnight, indicating that the lower floors absorb heat from adjacent spaces at night more than during the day.

From this graph, we can infer that a possible way to increase the performance of the envelope is to increase its R-value to prevent gains and losses due to conduction, and to increase ventilation to mitigate solar gains in the summer.

Figure 31: Hourly Gains Graph for Typical Lower Level. Top graph represents summer data, bottom graph represents winter data.

Figure 32: Magnification of lower graph in figure 31 - Winter heat gains and losses for lower levels

Autodesk Ecotect - Elements in Current Model

Model Library Properties Layers Acoustics Advanced Export No Highlight

Walls

- 210King_TripleBrick
- BrickCavityConcBlockPlaster
- BrickConcBlockPlaster
- BrickPlaster
- BrickTimberFrame
- ConcBlockPlaster
- ConcBlockRender
- DoubleBrickCavityPlaster
- DoubleBrickCavityRender
- DoubleBrickSolidPlaster
- FramedPlasterboard
- FramedTimberPlaster
- RammedEarth_300mm
- RammedEarth_500mm
- ReverseBrickVeneer_R15
- ReverseBrickVeneer_R20

Concrete & Screeds

Cellular Bonded

Cement

Cement / Lime Plaster

Cement Blocks, Cellular

Cement Fibreboard, Magnes

Cement Mortar

Cement Panels, Wood Fibre

Cement Plaster

Cement Plaster, Sand Aggre

Cement Screed

Compacted

Calculate Thermal Properties

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Brick Masonry Medium	110.0	2000.0	836.800	0.711	25
2.	Cement	10.0	1860.0	840.000	0.720	35
3.	Brick Masonry Medium	110.0	2000.0	836.800	0.711	25
4.	Cement	10.0	1860.0	840.000	0.720	35
5.	Brick Masonry Medium	110.0	2000.0	836.800	0.711	25

OUTSIDE INSIDE

Delete Element... Add New Element << Add to Global Library Help Apply Changes Close

Figure 33: Ecotect Wall Composition for Building 1 North/West/South walls, floors 4 to 6.

Figure 34: Ecotect Wall Composition for Building 1 North/West/South walls, floors 2 and 3.

Figure 35: Ecotect Wall Composition for Building 1 North/West/South walls, ground floor.

Results from the analysis of the existing building envelope

Our analysis of the building envelope in its current configuration shows us that the use of insulation on the interior of the envelope could help to increase the thermal performance of the envelope by increasing its R-value. An insulation-based retrofit described by Philip Parker, of Read Jones Christoffersen Ltd. In Vancouver is called Dynamic Buffer Zone (DMZ). DMZ is a retrofit technique which helps to eliminate moisture build-up on the interior surface of masonry walls which have been insulated, and involves pumping air between the insulation and the wall (Parker, 2008). Although this solution has been used in various heritage buildings and has been known to be effective, it is still essentially a material modification. Material modifications are often necessary, however in this case the Ecotect thermal simulation shows us that there is still an unexplored thermal potential harbored by the heritage walls of our case study. The full expression of this potential will serve to increase the relevance of the building, and by extension the heritage value of the building, more than would the use of insulation. The measure of the capacitance of the envelope, about 5 hours, allows us to see beyond the simple band-aid solution of insulation towards the thermal potential of the existing material. Strategically selected parts of the envelope could begin to achieve their full thermal potential if they were used as trombe walls, instead of simply serving as exterior walls. This articulation of the façade to explore the dormant potential of the façade's material composition allows us to observe and interact with its materiality in a completely different way than was possible before.

Another possible modification would involve the demolition of infill Building 2 in order to increase light and ventilation to the building. As Building 2 was a later addition, it could be removed without damaging the heritage value of the building. This path would, however, greatly reduce the available office space within the building, and cause drastic

changes to the internal climate of the building. This option will only be considered as a later resort if the internal climate cannot be optimized by other means.

Heritage preservation: implications of altering the facade

Traditional heritage preservation methods would not allow modification to the building envelope simply for performance gains as, in principle, the aesthetic value of the façade outweighs any potential energy efficiency gained from modifying it (Fram, 54). The Ecotect analysis demonstrates, however, that the thermal potential of the south façade would be optimized by transforming sections of the façade into trombe walls. This confrontation between potential optimization of the façade vs. the preservation of its appearance can be resolved by suggesting that the façade be altered in a manner which would not disturb the symmetry or geometric rhythm of the façade. Failure to compromise in this fashion would result in the progressive irrelevance of the building to a culture which increasingly values energy efficiency and sustainability. In this light, the dismissal of potential gains in thermal efficiency in favor of aesthetic value runs contrary to the idea of conservation itself.

Retrofitting the Envelope

Based on the initial analysis of the thermal potential of the envelope, a retrofit involving the transformation of sections of the south façade into trombe wall elements is suggested in *figure 36*.

Figure 36: Possible articulation of the façade – strategically selected sections of the façade are cut out and recessed into the building to serve as trombe walls, exposing the material composition of the façade.

The sections transformed into trombe walls were selected based on a compromise between the results of the Ecotect analysis and the necessity to maintain the essential rhythm of the façade. The south façade was first divided into symmetrical geometric sections which best represented the rhythm of the façade. Sections were then strategically selected based on their location and their ability to capture solar radiation. Several possibilities existed, however the one that presented the best compromise between the aesthetic of the façade and the potential performance improvements were selected.

Ecotect Thermal Analysis of Retrofitted Envelope:

The Hourly Temperature graph in *figure 37* shows us the average temperatures within the building after sections of the south façade were recessed into the building to serve as trombe walls. As can be seen from a comparison of the Hourly Temperature graphs before and after the retrofit, there is a significant spike in the temperature within the building during peak solar radiation, around 11:30am.

What is also interesting, however, is that these new temperature curves correlate almost exactly with the solar radiation curves, which means that the temperature begins to drop immediately as the solar radiation decreases. This tends to indicate that there is inefficiency in the configuration of the trombe walls and their ability to direct and retain heat throughout the building.

These changes will be examined in further detail within NIST-FDS, where we can track the movement of heat from the trombe walls within the building itself. As we have explored one possible solution to maximizing the envelope's ability to thermally regulate the building within Ecotect, the next step is to export the model to NIST-FDS and begin examining the internal thermal variances for a possible modification which could allow for better heat flow throughout the building.

Although the relationship between the thermal properties of the envelope and the climate within the building would have been illustrated much clearer were the CFD engine integrated into the Ecotect software, by evaluating the performance of the envelope at key points in the day and in different configurations, it was possible to get snapshots of the effects of an envelope retrofit on the interior climate. The key is to extract from Ecotect the most important factors which affect internal temperature and feed this data into FDS to see what would happen when conditions were changed.

Figure 37: Thermal analysis after trombe wall retrofit

NIST-FDS Thermal Analysis of Existing Conditions

Figures 37-39 show us which data from Ecotect is required to run the FDS simulations. These values describe not only the materiality of the building, but its energetic reaction to thermal factors, in this case, solar radiation. The solar absorption values along

with the emissivity of the material tells us how much heat the material will generate during the day, while the interior and exterior temperatures helps us to set the initial environmental parameters within FDS before stating the simulations. *Figure 40* shows where the material values acquired from Ecotect are entered into FDS.

Figure 38: Material properties data from ecotect. The Emissivity and Solar Absorption values are useful for describing the material in FDS.

HOURLY SOLAR EXPOSURE											
Toronto, Ontario - Canada											
Object: 4 (14.841 m²) (Azi: -180.00 °, Alt: 0.00 °)											
Date: 20th July											
Hour	BEAM (W/m²)	DIFFUSE (W/m²)	SUN ANGLE	SOLAR SHADE	REFLECT (W/m²)	INCIDENT (W/m²)	W	ABSORBED (W/m²)	W	TRANSMITTED (W/m²)	W
0500	24	116	>90.00	100%	0	58	861	29	426	0	0
0600	148	170	>90.00	100%	0	85	1262	42	624	0	0
0700	252	210	>90.00	100%	0	105	1558	52	771	0	0
0800	344	242	88.28	0%	0	131	1949	65	965	0	0
0900	410	286	80.79	0%	0	209	3096	103	1532	0	0
1000	451	309	73.74	0%	0	281	4167	139	2063	0	0
1100	468	304	69.51	0%	0	316	4687	156	2320	0	0
1200	460	307	67.67	0%	0	328	4872	163	2412	0	0
1300	402	294	68.90	0%	0	292	4329	144	2143	0	0
1400	342	240	68.28	0%	0	247	3659	122	1811	0	0
1500	225	215	76.70	0%	0	159	2363	79	1170	0	0
1600	131	170	84.84	0%	0	97	1436	48	711	0	0
1700	36	106	>90.00	100%	0	53	787	26	389	0	0
1800	10	23	>90.00	100%	0	12	171	6	84	0	0
TOTALS					0	2372	35198	1174	17423	0	0

Figure 39: Properties of a small section of the south façade. This data allows us to pick which sections of the south façade are ideal for transformation. The 'Absorbed' column describes the amount of solar radiation absorbed by the façade. This value is a result of multiplying the incident solar radiation by the absorption value for the material.

Figure 40: The values in Figures 37-39 were manually extracted from Ecotect and used to define the simulation parameters for the building in NIST-FDS.

Once the building was properly scripted, the FDS software was able to trace the thermal dynamics within the building. FDS is based on an orthogonal analysis grid and is limited to only rectangular objects. This means that spaces which contain non-rectangular objects, such as floors or walls with openings, have to be subdivided and redefined into groups of rectangular volumes.

Figure 41: Orthogonal FDS analysis meshes used to measure thermal variances.

FDS Analysis Meshes

As opposed to creating a single fine mesh covering the entire set of buildings, the FDS analysis mesh was split up and adjusted to fit the resolution requirements of various parts of the building. Each wall and stairwell space was enclosed in a fine mesh, while open spaces were enclosed in coarser meshes. This allowed for a greater level of detail when examining thermal interactions close to the walls, and a more general picture of the climate in the open spaces. *Figure 41* depicts the set of meshes created for the analysis for 210 King Street. The scripting of the coordinates of the meshes must be done manually for accuracy. *Figure 42* shows the coordinate matrix for the analysis mesh used in this investigation. All objects in FDS are scripted in a similar fashion.

```

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```

Figure 42: FDS script defining the analysis grid for the case study.

The two scenarios of the hottest and coldest days of the year were used to analyze the thermal performance of the existing interior. Within these two scenarios, simulations were run for the peak and lowest solar radiation levels of the day. These three snapshots (figures 43 – 45) of the thermal climate within the existing building help us to understand the thermal behavior of the building in general terms, and allow us to propose some modifications to both the envelope and the internal spaces which could lead to performance improvements. We can observe from the simulation results that the thermal currents within the building are minimal, that each level is fairly isolated, and that the vertical space of the emergency stairwells does not play a significant role in the thermal regulation of the building. The images show the expected results; the building loses heat at night due to poor insulation, and gains heat from heat absorbed through the envelope.

Figure 43: FDS – Hottest day of the year. North-South section of building 1. Slice: X_0
 The building is gaining heat from the southern façade and the rooftop. The coldest area in the building is the north stairwell, while the hottest area is on the top floor and the top of the stairwell.

Figure 44: FDS – Hottest night of the year. North-South section of building 1. Slice: X_0
 Cold walls cool the interior of the building overnight. The first areas to cool down are the top floor and the lower north stairwell.

Figure 45: FDS – Coldest day of the year. North-South section of building 1. X₀
The building is gaining heat from the façade and rooftop. Coldest area is the north starwell, while the warmest areas are the top floor and upper stairwell. This is somewhat similar to the summer daytime thermal map.

The thermal map of the coldest night of the year is similar to that of the warmest night of the year. In both circumstances the temperature within the building is higher than the temperature outside the building right after sunset. This results in a similar thermal pattern emerging on both nights.

Retrofit Proposal

As can be seen from the thermal snapshots of the building in its existing state, the thermal climate within the building is stagnant. Heat produced by the walls through solar radiation and conduction does not circulate efficiently within the building and instead accumulates at the ceiling, causing a drastic horizontal temperature gradient on every level. The vertical spaces within the building, such as the stairwell and elevator shafts, do not make use of their potential stack effect to increase the dynamics of the thermal climate. The primary cause of this stagnation is a lack of openings anywhere on the building. Existing thermal regulation of the building is completely controlled by the HVAC located on the roof (effects not included in the simulations). Without these systems, the only airflow within the

building is due to the movement induced by heat gain or loss through the solid material envelope of the building.

The integration of passive natural ventilation retrofits within the building could resolve the thermal stagnation within the building and reduce the work required by an HVAC system. In the summer months, natural ventilation could be used to cool the building and facilitate the outflow of heat. In the winter, natural ventilation between the interior vertical and horizontal spaces could aid in the proper distribution of heat created by trombe walls within the building during the day, while channeling this heat to the appropriate places at night.

Based on these observations, the proposed retrofit will therefore consist of: the creation of horizontal and vertical openings within the building, facilitating the redistribution of warm air; the transformation of sections of the warm south façade into trombe walls; the perforation of the cold north façade to allow for the entry of cool air; and finally the redevelopment of the interior program to harmonize with the natural thermal currents within the building.

Figure 46: Basic trombe wall configuration used for the south façade of the buildings.

NIST-FDS Thermal Analysis of Retrofit

The retrofit suggested previously is based on observations from the FDS simulation of the existing condition. Its primary goal is to establish a more dynamic thermal flow within the building in order to fully express the thermal potential of the building. The combined results of these retrofits are displayed in the images below. When compared to the simulation results from the existing condition, the effect of retrofits can be clearly seen. A drastic change in the thermal dynamics within the building has resulted in a retention of heat within the building during the winter, and a more efficient cooling mechanism during the summer.

The first step is to visualize the effect of the trombe walls on the interior thermal climate. Based on these observations, it can be then determined how best to continue. The heat absorption of a south-facing trombe wall was measured in Ecotect for both winter and summer conditions. This information was then manually entered into FDS as a property of

the trombe wall. The simulations were then initiated. The following sets of thermal images are the results obtained from FDS.

Figure 47: Winter Day - North Elevation Y₁₇

As can be seen from this thermal slice taken just behind the northern facades of buildings 1, 2, and 3, thermal segregation is occurring for a variety of reasons. At (1) in figure 47, the heat buildup on the 4th floor is due to the addition of the trombe wall on the southern façade for the 4th floor of building 3 as well as heat flowing from the top floor of building 4 (not pictured). At (2), we can see that the building 2 remains cooler much longer than the rest of the building as there is no direct source of heat within building 2 other than the rooftop. At (3), we can see that the build-up of heat in the northern stairwell of building 3 is due both to the heat gain through the roof due to solar radiation, as well as heat leakage into the

stairwell from the top floor. We can clearly see that the roof has a dramatic effect on the climate of the top floors.

Figure 48: Winter Day - South Elevation Y.7

In this west-east thermal slice taken seen behind the southern elevation, we can see a few areas of thermal activity. At (1), the heat created by the façade through the absorption of solar radiation is travelling across the ceilings and floating up to the top floor via the main staircase in building 3. This results in extra heat being trapped at the top floor. At (2), we can see that building 4 is thermally stagnant, and that the heat generated in buildings 1 and 3 affect its climate minimally. At (3), we see that the lower 2 floors seem to show a slightly greater heat build-up than the above floors, with the exception of the top floor.

Figure 49: Winter Day – South Elevation Y.14

The above slice is taken right behind the south façade, directly in front of the trombe walls. We can see in all cases (1-5) that the trombe walls act as vertical channels of heat, sucking up the cold air from below and pumping out hot air at the top. At (1), we can see that this effect in fact keeps the lower floor cool while increasing the heat in the upper floor. A similar process occurs at (2) and (5), the other multi-level trombe walls. At (3) and (4), however, the single level trombe walls simply increase the heat on the floor they are on. Just above (3), the thirds floor of building 3 stays colder as no trombe wall activity reaches this floor.

Figure 50: Winter Day - West Elevation X.19

This thermal slice is taken along the north-south axis of the building, through the emergency stairwell and lower trombe wall of building 1. At (1), we can see the thermal activity caused by the trombe wall. At (2), we see that the emergency stairwell is subjected to heating through the roof, however the rest of its vertical space is unaffected by the heat within the building. This space could possibly be used as a thermal chimney during the summer. In the winter, however, this minimally used space does not need to be heated.

Figure 51: Winter Day - West Elevation X.

This thermal slice clearly illustrates the significant difference between the climate in building 2 at (2) and the climate in building 1 and 3. The vertical activity of the highest trombe wall can be seen at (1). In rearranging the program for the habitation of the building, this type of temperature variance can help to define programmatic boundaries.

Figure 54: Winter Day - Level 2 plan Z_5

In figures 52 and 53, it can be seen that the trombe walls are providing heat in the winter months, and remain cool in the summer months, changing the internal climate noticeable. There is still a buildup of heat within the northern stairwell space which will need to be resolved. The plan view shown in figure 54 maps out a typical lower level, with the highest temperature found in building 1 at (1), and the lowest in the northern stairwell at (2) and building 2 at (3). Temperature increases in areas (4) and (5) are moderate.

Figure 55: Winter Day - Level 4 plan Z₁₅

Figure 56: Winter Day - Level 6 plan Z₂₃

The 4th floor plan in *figure 55* shows an interesting reversal of thermal climate from the lower floors, where building 4 at (3) is significantly warmer than the rest of the complex. This is because the 4th floor of building 4 is in fact the top floor, and solar

radiation absorbed by the rooftop material is heating up the area. By comparison, buildings 1 and 3 are cooler, and building 2 at (1) is the coolest space on this level.

Figure 56 is the thermal map for the top floors of buildings 1,2, and 3. At (1), the thermal currents induced by the trombe wall can be plainly seen. At (2), the upward movement of warm air through the main staircase can also be easily seen as a ring of warm air. This initial condition evolves to the point where, as can be seen at (1) in *figure 57*, building 2 becomes the warmest space on the top floor, because of its contained space and the heat from the rooftop.

Figure 57: Winter Day - Level 6 plan a few hours later Z₂₃

The impact of the trombe wall retrofit on the thermal map of the building can be easily seen when comparing the existing thermal maps with the ones generated after the initial retrofit. The results for summer days are very similar to the ones generated for winter days, with the some notable exceptions summed up in *figures 52* and *53*. It shows

that the configuration of the trombe walls helps to reduce the summer heat gain relative to the winter heat gain. In terms of air movements within the building however, the results are very similar.

Based on *figure 53*, which is a north-south thermal map of a typical summer day, one possible solution for a summer retrofit would a natural ventilation path through the north stairwell and out the southern facade. This will allow the venting of heat from the building, as shown below.

Figure 58: proposed retrofit based on results in figure 53. Heat is vented through the stairwell.

A thermal analysis of the combination of our winter trombe walls and our summer ventilation can be seen in the following images. As can be seen by the thermal map, the natural ventilation mechanism proceeded opposite to plan, however achieving the same effect.

Figure 59: Summer Day - West Elevation X_0

Figure 60: Summer Day - North Elevation Y_{17}

As these thermal maps show, the natural ventilation mechanism is forcing the hot air into the northern starwell to be vented out the roof, while cooler air comes in from the southern façade.

Program Analysis: Existing vs. Retrofitted

The existing program in the building, i.e. the location of the offices, the lunch room, and the bathrooms are indicated in *figure 61*. The existing configuration was a function of the spatial arrangements and lighting levels within the building, and had nothing to do with the thermal climate within the building. By mapping out the temperature variances exposed by our FDS analysis of the building, we can begin to see a cyclical movement of temperature within the building. Were the program of the building designed to make use of these thermal variances, the energy required for HVAC systems would decrease even more.

Figure 61: Typical existing program.

There are many possibilities for tuning the program of the building to match with its climate, however all are based on the marriage of thermal comfort and the activity taking place. The first step was to map out the thermal cycles within the building, based on our

thermal slices from FDS. The following is what we now know about the building' thermal cycle:

Winter Cycle

Morning

- 4th floor of building 4 (the top floor) starts to warm up. Some of the warm air floats into the 4th floor of building 3, warming it up as well.
- Top floor of building 1, 2, and 3 (6th floor) begin to warm up.
- All lower floors of building 2 remain cool throughout the morning
- Building 4 has marginal heat gains throughout the morning.
- Warm currents begin to rise from the face of the trombe walls.

Afternoon

- Warm currents are steadily flowing around the trombe walls.
- Most of building 1 is several degrees higher than the outside temperature
- Lower floors of building 1 are the warmest areas on those floors.
- Top floors of buildings 2 and 4 are the warmest spaces in the building before the sun goes down.

Evening

- As the building materials cool down, the heat trapped within the building will begin to move out. At this point if all the vents are closed, the building will react similarly as it does at present, slowly losing heat through the envelope over the course of the night.
- The top floors of all buildings as well as the stairwell will begin cooling down first, followed by the lower floors.

Summer Cycle

Morning

- 4th floor of building 4 (the top floor) starts to heat up. Some of the warm air floats into the 4th floor of building 3, heating it as well.
- Top floor of building 1, 2, and 3 (6th floor) begin to warm up.
- All lower floors of building 2 remain cool throughout the morning.
- Building 4 has marginal heat gains throughout the morning.

Afternoon

- Trombe walls are inert.
- Most of buildings 1 and 3 are being cooled effectively through natural ventilation.
- Lower floors of building 1 are the warmest areas on those floors.
- Top floors of buildings 2 and 4 are the warmest spaces in the building before the sun goes down.

Evening

- As the building materials cool down, the heat trapped within the building will begin to move out. At this point if all the vents are closed, the building will react similarly as it does at present, slowly losing heat through the envelope over the course of the night.
- The top floors of all buildings as well as the stairwell will begin cooling down first, followed by the lower floors.

Based on the above observations, it can be generally stated that in the winter months, the daily activities within the building should flow from the center of the building towards the envelope, and that the reverse is true of the summer months. *Figures 62 – 63* indicate the preferred program flow in winter and summer. These conclusions would indicate a free-flowing program with moveable program elements. For example, there would be a summer kitchen and a winter kitchen; morning work areas and evening work areas.

Figure 62: Program flow during winter months.

Figure 63: Program flow during summer months.

This type of dynamic compartmentalization of space could be achieved by detaching the interior walls from the envelope and creating moveable wall sections. With the help of FDS simulations, these sections could then be used to define open or closed spaces, and to essentially trap and retain heat in specific parts of the building. A moveable wall design could be created with apertures in the top and bottom to allow for thermal regulation of closed compartments, and to manipulate the flow of heat through the building. The mapping of the effects of this type of manipulations would only be possible through an FDS simulation. *Figure 64* shows a simple wall design which could be used to manipulate heat flow and compartmentalize space. *Figures 65 and 66* show potential spaces within the building which lend themselves well to the creation of interior buffer zones. Buffer zones are areas of near-constant temperature and can be created by the proper seasonal positioning of the interior moveable wall elements.

Figure 64: A simple sketch showing the essential components of a hanging moveable wall with upper and lower operable openings to allow for thermal regulation.

Figure 65: Highlighted area shows potential for a cool air buffer zone

Figure 66: Highlighted area shows potential for a warm air buffer zone

A cool air buffer zone can be created in the area marked in *figure 65* by using the cool air trapped within the stairwell space. Apertures between the stairwell and the building can be designed to siphon off warm air from within a compartmentalized space. A warm air buffer zone can be created in the area highlighted in *figure 66* by trapping the heat flowing from the top floor of building 4 into the 4th floor of building 2. *Figure 55* shows the heat building in the top floor of building 4.

These new configuration would have people arrange their daily schedules to be more in tune with the climate of the building itself, creating a closer bond between the building and its inhabitants. This new intimacy can lead to a new appreciation for the building and its history, strengthening its relevance to our culture by intimately interacting with our current goals and aspirations. The inhabitants begin to identify with the building as an organism, not an artifact, and the character of this organism is revealed to us through our negotiation of its thermal variances. This intimacy is an entirely new dimension to the building which is not visible on the façade. The retrofit design proposed in this investigation very minimally alters the existing heritage value of the building, while adding an entirely new dimension to our appreciation of the building's character.

Final Protocol

Figure 67: Final protocol design

Figure 67 shows the framework of the protocol developed in this investigation. As can be seen, data modeling and data interpretation run concurrently, with validated point cloud data contributing to the accuracy of the model. The first phase of data modeling involved the mapping of the overall geometry of the space, and the material properties of

the bounding elements. This information can then be used for initial simulations while the second data modeling phase was underway. This second phase involves the addition of the remaining architectural elements and their material properties. This model can then be used for aesthetic visualization, or further simulation if necessary. The third data modeling phase would involve the addition of specific details of interest, such as ornamental detailing, structural connections, textures, etc. and can be used for digital reconstruction, documentation, presentation, etc. The final result of this process is a heritage building whose cultural relevance has been safeguarded by its re-integration into the flow of time.

Conclusion

The purpose of this investigation was to develop a set of design and analysis tools and techniques required for architects to examine heritage buildings holistically within a design environment, and propose retrofits which would best express the hidden potential of the building. The thermal potential of the case study, 210 King Street East, Toronto, was examined through a three-part process of data acquisition, data modeling, and data visualization. The techniques used within and around the software associated with each of these three parts formed a generalized protocol for the retrofit of heritage buildings which suggests that the cultural relevance of the building would be enhanced by exploring the potential of the building. Rather than attempting to cosmetically freeze the building in time, it was suggested that the building be allowed to evolve to its fullest potential.

According to the 'reasons for designation' for the 204 King Street East portion of the complex, the south façade was one of the primary reasons for which the building achieved heritage designation. As the simulations have demonstrated, the potential increases in thermal performance can be great if the south façade were thermally articulated, and the interior was retrofitted to allow for natural ventilation.

There are two main observations which support the perforation of the façade as a method of re-enforcing the heritage value of the building. The first is based on the difference between a heritage façade, and a heritage building. The protected façade provides only a 2-dimensional impression of its materiality and character. To truly experience the facade, we must be able to see its full character, not simply its face. Its character consists of all the properties and qualities which give the façade its personality. This, of course, includes its aesthetic qualities, but it also includes its thickness, its thermal properties, its mass, its texture, etc. As this investigation was focused on the thermal

properties of the building, the retrofit which was suggested served to fully express the thermal properties of sections of the façade in a manner that could be fully experienced by the inhabitants of the building, as well as the community outside.

The second observation is that the heritage value of architecture is not best preserved by the museological and artificial preservation of the building, but rather by the preservation of its relevance in our communities. Heritage architecture which continues to have relevance in our evolving cultural landscape is the only architecture which will continue to foster support. This observation is in disagreement with Mark Fram's view that the aesthetic contribution of an unblemished façade to the richness of our architectural inheritance far outweighs any contribution that could be made by altering it, however it is this very principle that will eventually cause the demise of heritage buildings as they lag behind the sustainable heritage buildings of the future, and gradually lose their relevance and, by extension, their function in our communities.

Existing software would have to be improved in terms of interoperability in order to facilitate the type of retrofit described in this investigation. At present, it is a challenge for an architect to accomplish a holistic analysis of an existing building due to the numerous technical challenges. Although the concept of BIM as it functions in Revit has great potential as a platform for the documentation of heritage buildings, it does not yet contain certain essential features such as data layering or trust scores to allow for the effortless and efficient examination of an existing building.

The techniques presented in this investigation are largely guided by the ideals of efficiency and accountability. Inefficient work flows are unsustainable by nature, and no data which cannot be verified to originate from a trustworthy source should ever be used as a basis for action. These techniques, together with the tools used to acquire, model and

visualize the building, were organized into an efficient protocol which would perpetually maximize the utility of the data to the architect and everyone else. This protocol for the sustainable retrofit of heritage buildings can be used as a guide both for similar projects as well as for software developers looking to create a self-contained program specifically for the holistic examination of existing buildings. If some future software were developed which could easily allow the workflow suggested in this investigation, we would finally be able to understand our heritage buildings, and architecture in general as organisms rather than simply as artifacts.

This investigation made use of 3 different tools, namely Revit, Ecotect, and FDS, and combined them around a BIM database nucleus. Although the methods required to combine them point to many problem areas, the overall result is one which benefits us in a few different ways. First, it allows anyone to use this investigation as a reference for a similar project, or as a starting point for more in-depth research. Second, it validates the workflow and demonstrates the methods by which performance simulations can be brought into the design process. Third, it provides a valuable scenario around which to base future software features. Beyond these more practical benefits, this investigation also demonstrates how we can see heritage architecture through the eye of material potential rather than only aesthetic potential, and allow a building to evolve beyond the imposed 'artifact' status which keeps them frozen in time.

Postscript

Current research in retrofits for heritage buildings has dealt with similar interoperability issues as explored in this investigation, often focusing on a specific portion of the protocol presented here. There has been research into the use of 3D laser scanner for vector data acquisition instead of point-cloud data acquisition. There has been research on the effective use of photogrammetry for data acquisition and modeling of heritage structures around the world. There has also been very advanced research and simulations conducted on structures, envelopes, moisture penetration, and all manner of other issues relating to heritage building and new constructions. The uniqueness of this investigation is in the workflow developed for the purpose of holistically examining heritage buildings, and designing a retrofit which could maximize the energetic potential of the building. The interoperability issues encountered and the software limitations resulting from the combination of existing pieces of technology will hopefully drive the improvement of our digital design and analysis tools, allowing the architect the ability to make design decisions based on different sets of data not previously available.

In continuing this investigation, the next steps would be to develop a design for the compartmentalization of the spaces within the building. Developing a set of digital methods and techniques to subdivide internal spaces for the purpose of manipulating heat would be an invaluable investigative tool for determining efficient sets of activities and circulation routes for all seasons. The integration of these additions into the existing BIM dataset for the building will provide the benefit of this information to future designers. Through the evolution of the BIM dataset for 210 King Street East, the heritage value of relevance of the building can be better preserved by continually suggesting points of entry and change for the building.

Another path forward would be to integrate the mechanical systems into the BIM model in order to visualize the efficiency of the system and design changes which would enhance the natural ventilation possibilities described earlier. Further, the structural frame of the building could be analyzed for the addition of levels or the removal of bearing walls.

On a larger scale, the envelopes of the adjacent buildings could be modeled and used to simulate the exterior conditions beyond the boundaries set by this investigation. The effects of high and low pressure weather systems can be used to further open the building to natural means of ventilation, heat gain, lighting, and other sustainable design strategies.

It would be also be essential to further develop the relationship between point cloud data and a vector-based model, or to propose a new method of design through visualization based on 3D points. Either way, the ease with which point cloud data can be acquired is increasing, and a method of integrating this data into the design process is required.

Future research can be focused on improving existing software so that many of the recommendations made in this investigation can be implemented within a single software environment. The datasets created in this investigation can also be used to analyze characteristics of the building such as the structural efficiency of the building, natural lighting, water conservation, etc. Finally, the creation of an online library of heritage architecture datasets might one day facilitate the dissemination of large datasets to interested parties. The dataset created in this investigation is only a first attempt at describing a heritage building within a framework which can allow for simulation and design to proceed side by side.

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