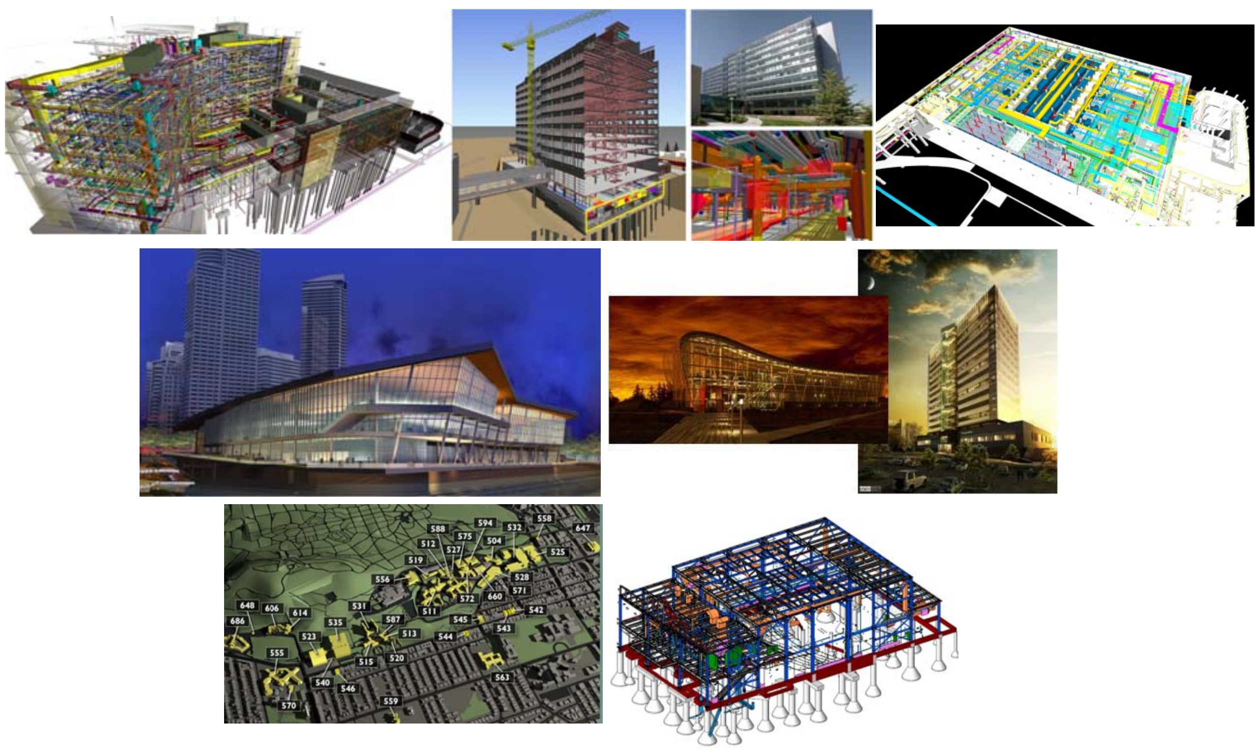
BUILDING INFORMATION MODELING (BIM)

'BEST PRACTICES' PROJECT REPORT

An Investigation of 'Best Practices' through Case Studies at Regional, National, and International Levels

NOVEMBER 30, 2011



This project was funded by:

Alberta BIM Centre of Excellence (ACE)

Productivity Alberta

Western Economic Diversification

EXECUTIVE SUMMARY

Building Information Modeling (BIM) involves a new approach to project delivery that focuses on developing and using an information-rich model of a facility to improve the design, construction and operation of a facility. Many projects have now successfully implemented BIM with significant benefits, including increased design quality, improved field productivity, cost predictability, reduced conflicts and changes, and reduced construction cost and duration to name a few. However, successful implementation of BIM requires drastic changes in the organization of work that cannot be achieved without redefining work practices, which might explain the slow adoption rate, particularly in Canada.

The mandate of this research project was to investigate BIM 'best practices' for the Canadian industry to better understand what is working and what might be the obstacles. The research team identified seven projects at regional, national and international levels and analyzed these projects along three dimensions: Technology, Organization and Process. It is our belief that successful implementation of BIM requires a balance between these three dimensions. We also investigated existing BIM guidelines and standards to see how other countries are driving BIM adoption and measuring the return on investment.

The following highlights some of the 'best practices' identified along the three dimensions:

Technology	• Owner: specify clear, complete, and open requirements. • Owner/Project Team: determine uses/purposes of the model. • Owner/Project Team: determine the scope of the model and the level of detail of the modeling effort required to support each purpose.
Organization	• Owner: rethink the organizational structure/practices for managing its construction projects and real estate portfolio. • Owner/Project Team: early involvement of all key disciplines is essential. • Owner: implement the appropriate incentives to enable collaborative BIM.
Process	• Owner/supply chain: devise and agree on shared goals regarding what is expected to be achieved. • Supply chain: devise and agree on a BIM execution plan. • Supply chain: clearly define roles and responsibilities including handoffs between disciplines.

This report demonstrates that although BIM is quite new in the Canadian landscape, there already exists an abundance of information (guidelines and standards) from other countries, which we can leverage to advance BIM adoption in Canada. The UK initiative, in particular, provides an excellent example of a thoughtful, deliberate and well-resourced process that the government initiated to investigate the appropriate application of BIM for public projects, and to develop a long-term strategy for how to help the industry make the transition to this new way of working.

Our intent with this report was to first capture the essence of these international efforts to make sense of and document how BIM is changing our industry; and second, to make knowledge tangible through the description of cases that outline some or many of these best practices while also presenting lessons learned. There are still major challenges ahead, particularly in terms of procurement and education. To reap the full benefits of BIM, contracts encouraging collaboration and partnership such as Integrated Project delivery (IDP) should be adopted. Proper training at the university and professional levels has to be initiated. BIM has to be built around trust and sharing. The government of Alberta is leading the way in Canada in its initiatives to support its industry in

adopting BIM, involving universities to participate in this process. Additional efforts are needed to develop a strategy for driving BIM adoption, continue to document emerging best practices in Canadian BIM projects, and to develop and formalize tools to help industry measure their performance and maturity in using BIM.

AUTHORS AND CONTRIBUTORS

This report was authored by a team of researchers at the University of British Columbia and École de Technologie Supérieure. Principle authors include:

Sheryl Staub-French, PhD, PEng
Associate Professor
Department of Civil Engineering
University of British Columbia

Daniel Forgues, PhD
Associate Professor
Department of Construction Engineering
École de Technologie Supérieure

Ivanka Iordanova, PhD
Postdoctoral Fellow
Department of Construction Engineering
École de Technologie Supérieure

Amir Kassaian
Graduate Student
Department of Civil Engineering
University of British Columbia

Basel Abdulaal (Capital Theatre)
Graduate Student
Department of Civil and Environmental Engineering
University of Alberta

Mike Samilski (Vancouver Convention Centre Project)
Graduate Student
Department of Civil Engineering
University of British Columbia

Hasan Burak Cavka, MASc (Research Centre (R2) Project)
Graduate Student
Department of Civil Engineering
University of British Columbia

Madhav Nepal, PhD
Graduate Student
Department of Civil Engineering
University of British Columbia

ACKNOWLEDGEMENTS

We acknowledge the following people and organizations for their assistance in the production of this report:

- Geoff Glotman, Glotman-Simpson Structural Engineers (Vancouver Convention Centre Project)
- Jim McLagan, Canron Western Constructors, Ltd. (Vancouver Convention Centre Project)
- Dan Sadler, PCL Construction (Vancouver Convention Centre Project)
- Jean Thibodeau, InteliBuild (Hong Kong International Airport)
- Diane Leclerc, MBA, InteliBuild (Hong Kong International Airport)
- Steve Beaulieu, InteliBuild (Hong Kong International Airport)
- Normand Hudon (Coarchitecture
- Sébastien Vachon, Senior Technician, Technical Team Leader (Coarchitecture)
- Dominic Dubuc, ArchiDATA (Université de Montréal)
- Geneviève Tremblay ArchiDATA (Université de Montréal)
- Jean-Philippe Cyr, Direction des Immeubles of the Université de Montréal
- Robin Bélanger, Direction des Immeubles of the Université de Montréal
- Allan Partridge, Group2 Architecture Engineering Ltd. (Capital Theatre)
- Scott Cameron, Supreme Steel LP (Capital Theatre)
- Monaj Mistry, Stantec (Capital Theatre)
- Derek Cunz, Mortenson Construction (Research 2 (R2) Project)

TABLE OF CONTENTS

1 INTRODUCTION

There are great opportunities for improving productivity in the construction industry. Over the past four decades, construction labour productivity has remained relatively stagnant and has not kept pace with the increasing productivity found in other industries (Teicholz 2004). In contrast, other industries, such as manufacturing, have achieved efficiencies through the innovative use of technology (e.g., increased automation, information systems) and through new and improved business practices (e.g., collaborative agreements, concurrent engineering, and supply chain management). In comparison, facility planning, design, and construction practices have remained relatively unchanged.

Building Information Modeling (BIM) has the potential to significantly change the way projects are delivered. BIM involves a new approach to design, construction, and facility management in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format (BIM Handbook 2009). It is said that BIM has the potential to revolutionize the project delivery process – changing the way facilities look and function, the way they are designed and constructed, and ultimately how facilities are maintained.

Many projects have now successfully implemented BIM, demonstrating significant benefits: increased design quality, improved field productivity, cost predictability, reduced conflicts and changes, less rework, increased prefabrication, and reduced construction cost and duration. This results in a faster and more cost-effective project delivery process, and higher quality buildings that perform at reduced costs (Hardin 2009; Eastman et al. 2008).

Because BIM is a revolutionary technology, most people are just beginning to understand how to use it. What we do know is that to maximize the benefits of this technology, a variety of organisational, procedural and technical issues have to be addressed. BIM requires drastic changes in the organization of work with the client and within the supply chain, as well as major modifications in the legal relationships and sharing of responsibilities. This cannot be achieved without redefining work practices.

The mandate of this research project was to investigate BIM 'best practices' for the Canadian industry to better understand what is working, and what the obstacles might be. The research team identified seven projects at regional, national and international levels to serve as 'representative' BIM projects. We analyzed these projects along three dimensions: Technology, Organization and Process. It is our belief that successful implementation of BIM requires a balance between these three dimensions. These case studies demonstrate the various ways that work practices are evolving to leverage BIM in the delivery of projects, the different ways that BIM projects are being organized to maximize the benefits of BIM, and the benefits and challenges that may be encountered when implementing BIM.

1.1 Definitions and Context

The term 'Building Information Modeling (BIM)' has come to mean different things to different people. We view BIM as both a *product* and a *process*. We define BIM in a way that is consistent with the National BIM Standard (NBIMS), which defines a Building Information Model (BIM) as (Figure 1 shows a graphical representation of this view):

> *"a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward."* (NBIMS 2007)

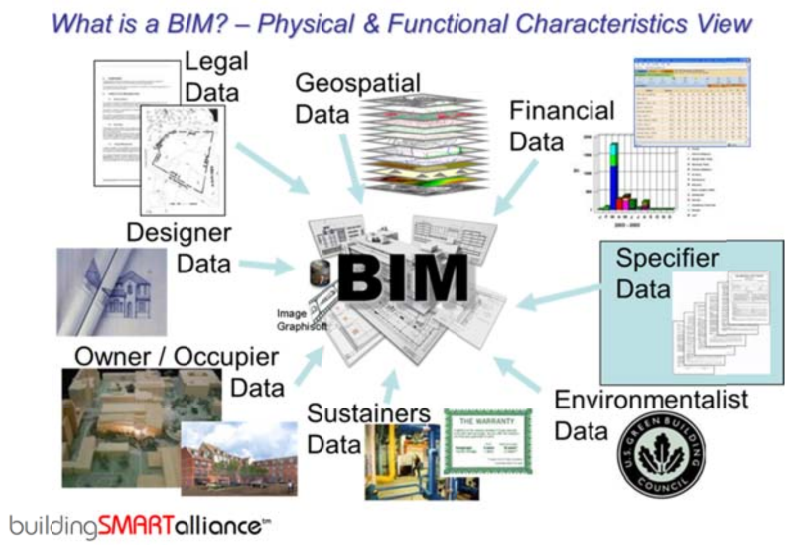


Figure 1: BIM Defined in terms of Physical and Functional Characteristics (buildingSMARTalliance)

BIM can also be defined as a process – the process of Building Information Modeling. From this perspective, BIM can be defined as:

> *"a new approach to design, construction, and facility management...BIM is not a thing or a type of software but a human activity that ultimately involves broad process changes in construction."* (BIM Handbook 2008)

> *"a process focused on the development, use and transfer of a digital information model of a building project to improve the design, construction and operations of a project or portfolio of facilities."* (BIM Project Execution Planning Guide 2009)

To qualify as a 'BIM', a model needs only two characteristics: (1) a 3D object-based representation of a facility, and (2) information or properties about the objects. Figure 2 shows the kinds of information that may be represented in a BIM throughout the project life-cycle.

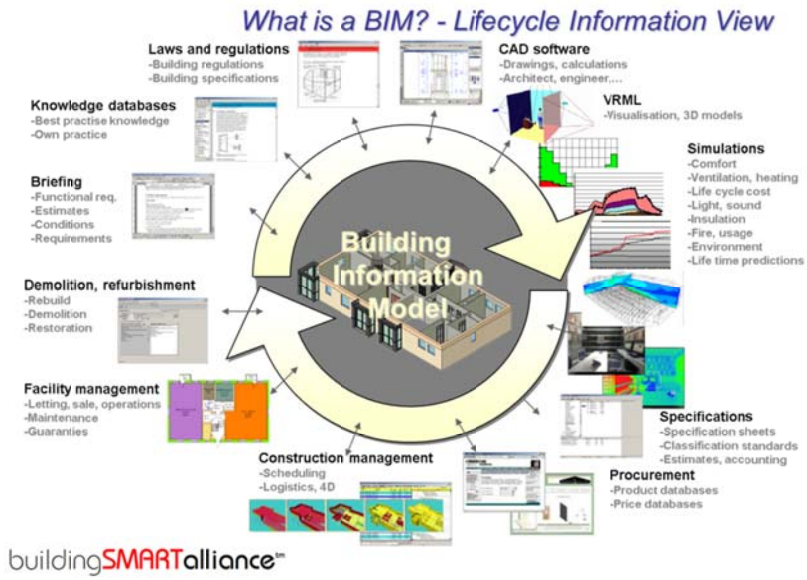


Figure 2: Information that may be represented in a BIM based on a Lifecycle View (buildingSMARTalliance)

Integrated practices and Integrated Project Delivery (IPD) are terms that are being used to describe the trend toward greater collaboration between members of a project team throughout the project delivery process. IPD is defined as:

> *"a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction."* (Integrated Project Delivery: A Guide 2007)

IPD principles can be applied to a variety of contractual relationships, and in the United States, IPD agreements are increasingly being used on BIM projects. The fundamental principles of IPD include (from Integrated Project Delivery: A Guide 2007):

1) Mutual respect and trust
2) Shared risk and reward
3) Collaborative innovation and decision-making
4) Early involvement of key participants
5) Early goal definition
6) Intensified planning
7) Open and enhanced communication
8) Appropriate technology
9) Virtual organization and leadership

Figure 3 graphically shows the differences between a traditional and integrated project delivery process. This figure illustrates the significant changes in the sequencing, timing and involvement of the different project participants, which is summarized below:

"Input from the broader integrated team coupled with BIM tools to model and simulate the project enable the design to be brought to a higher level of completion before the documentation phase is started. Thus the Conceptualization, Criteria Design, and Detailed Design phases involve more effort than their counterparts in the traditional flow. This higher level of completion allows the Implementation Documents phase to be shorter than the traditional CD phase, and the early participation of regulatory agencies, subcontractors, and fabricators allows shortening of the Agency review and Buyout phases. The combined effect is that the project is defined and coordinated to a much higher level prior to construction start, enabling more efficient construction and a shorter construction period." (Integrated Project Delivery: A Guide 2007):

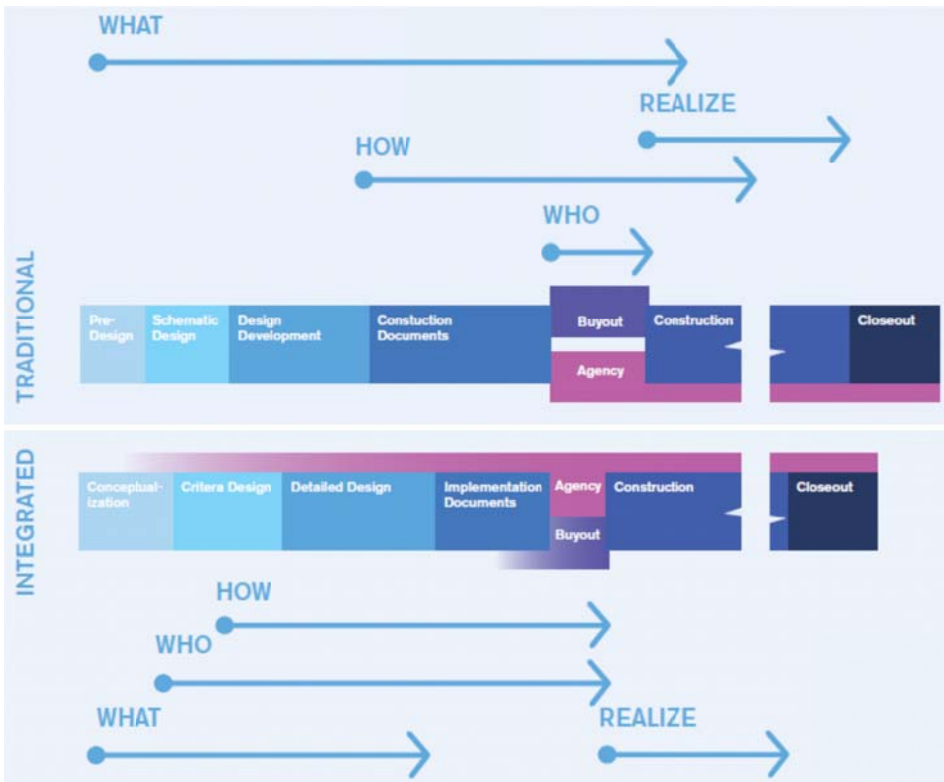


Figure 3: Differences between Integrated and Traditional Project Delivery (AIA California Council 2007)

Figure 4 shows the "MacLeamy Curve", which was first introduced in the Construction Users Roundtable's "Collaboration, Integrated Information, and the Project Lifecycle in Building Design and Construction and Operation" to illustrate the significant changes that occur in an integrated project delivery (Construction Users Roundtable 2004). In this approach, design decisions are made earlier in the process when the opportunity to influence positive outcomes is maximized and the cost of changes is minimized (AIA California Council 2007).

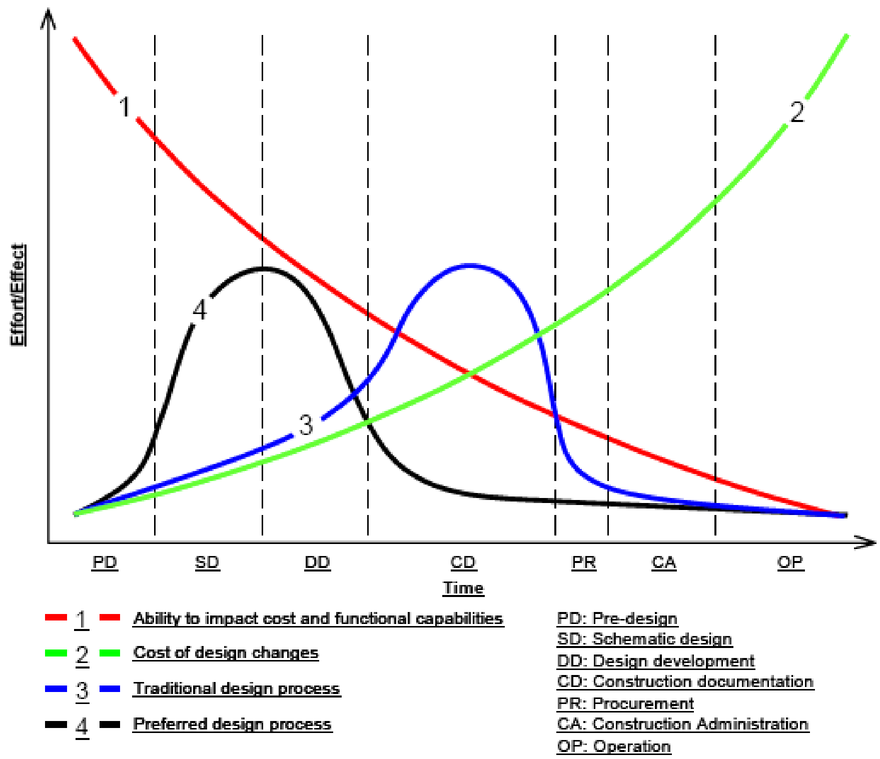


Figure 4: "Mcleany Curve" illustrating that effort and decision-making is shifted earlier in the design process in an Integrated Project Delivery (Construction Users Roundtable 2004).

As will be demonstrated in the case studies, project teams that employ a more 'integrated' project delivery process are better able to maximize the benefits of BIM.

1.2 Research Objectives and Approach

There were two main objectives for this research project:

- Review different industry sectors including owners, architects, engineers, MEP's, as well as different types of building construction including industrial and residential builders, and manufacturers to see how BIM has successfully applied and what challenges and barriers have arisen.
- Investigate best practices through case studies at regional, national, and international levels.

The research team completed this work in four parts, as outlined below.

1) *Identify case studies that represent best practices*
The intent was to identify case studies that adequately represent sufficient diversity across: (a) the different industry sectors (e.g., owners, architects, engineers, etc.), (b) the different regions (regional (Alberta), national, and international), (c) different project phases (from concept through operations), (d) different scales of projects (in terms of size, complexity, and function), and (e) different uses of BIM (e.g., energy analysis, constructability, fabrication, etc.). Our mandate was to provide a minimum of three Canadian case studies and two International case studies.

2) *Investigate BIM guidelines and standards.*
   This part of the research: (a) investigated BIM guidelines and standards that exist within different regions of the world that have demonstrated leadership in BIM adoption, and (b) identified relevant industry publications that provide guidance in BIM implementation and assist with the evaluation of BIM project execution for the case studies considered.

3) *Develop a framework for analyzing case studies*
   Based on the research completed in step (2), we developed a framework for analyzing the case studies. The intent of the framework was to establish a consistent and thorough method for evaluating each BIM Project.

4) *Analyze case studies using the framework developed in (3):*
   Each BIM project identified in step (1) was evaluated based on the framework developed in step (3). For the international case studies, we relied extensively on existing publications since much has been written about these projects. For the Canadian case studies, significant effort was made to write up the BIM projects selected.

1.3 Selection of Case Studies

To select the BIM projects to study, our intent was to identify projects that captured a broad range of 'best practices' that had significant impacts on the project life-cycle.

To identify Canadian projects, we spoke to several practitioners that have experience on BIM projects, reviewed the literature, attended the Insight BIM Forum and other BIM events to learn about on-going and completed projects, and talked to a variety of people in our network. For international projects, we focused on projects that pushed the extent and depth of collaboration, highlighted the benefits across the entire lifecycle, and demonstrated novel project delivery approaches that incentivized all members of the project team to collaborate with BIM.

For the Canadian case studies, the intent was to provide a minimum of one regional case study from Alberta and a minimum of two other case studies from across Canada. However, the challenge was that there are almost no written case studies of BIM projects in Canada, although several projects have been presented at different venues. In contrast, many BIM case studies have been written up for international projects, particularly in the US. Therefore, we were constrained by the short term accessibility of data and access to project participants for the 4-month research project duration.

Table 1 shows the seven BIM projects that were selected for this study. Each case study will be described in detail in Section 5.

Table 1: The seven BIM projects studied to identify 'best practices' at regional, national and international levels.

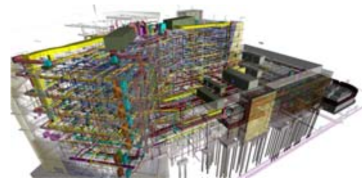
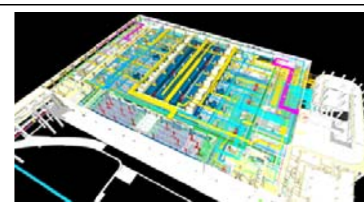
International	1	Sutter Medical Center Castro Valley (United States)	
	2	University of Colorado Denver Research 2 (R2) (United States)	
	3	Hong Kong International Airport - Cathay Pacific Cargo Terminal (Hong Kong)	
National	4	Vancouver Convention Centre (British Columbia)	
	5	University of Montreal (UdeM) (Quebec)	
	6	Biotechnology building for GlaxoSmithKline (GSK) Inc. and Headquarters for Caisse Desjardins (CD) (Co-architecture, Quebec)	
Regional	7	Capitol Theatre (Edmonton)	

Table 2 shows the different phases covered by the BIM projects selected. As stated previously, we wanted to select projects that demonstrated 'best practices' throughout the project life-cycle.

Table 2: Coverage of BIM Projects selected across Project Phases

Feasibility	Concept Development	Design Development	Design Documents	Pre-construction	Construction	Operation
	Sutter Medical Center Castro Valley (United States)					
	University of Colorado-Denver, Research 2 (R2) (United States)					
	Cathay Pacific Cargo Terminal (Hong Kong)					
	Vancouver Convention Center (British Columbia)					
						UdeM (Quebec)
GSK & CD (Quebec)						
	Capitol Theatre (Alberta)					

Legend		
International	Canada	Regional

1.4 Constraints and Disclaimers

The mandate for this project was to "investigate best practices through case studies at regional, national, and international levels." Because BIM is relatively new, particularly in Canada, we use the phrase 'best practices' with hesitation. A 'best practice' is considered as a proven method or technique that consistently performs a task with superior results when compared to others means. In this report, we have tried to identify those 'methods or techniques' that have enabled organizations and/or project teams to leverage the benefits of BIM, while also documenting the challenges. We are not claiming that the projects studied are the 'best' BIM projects.

2 RELEVANT BACKGROUND

This section describes relevant background on different aspects of BIM implementation and planning. Specifically it describes:

- BIM Standards and Initiatives
- BIM Guidelines and Execution Plans
- Uses of BIM
- Levels of BIM
- Impact of BIM

2.1 Canadian Efforts: BIM Standards and Initiatives

In Canada, there are two organizations focused on driving BIM adoption: the Canada BIM Council (CanBIM), and the Institute for BIM in Canada (IBC).

2.1.1 Canada BIM Council

The Canada BIM Council (CanBIM) was established in 2009 to advocate and support the entire AECOO business community to effectively deploy BIM. The following summarizes the mission, strategy and goals of CanBIM (CanBIM website, accessed Nov. 2011):

CanBIM's Mission

- *Serving as the business voice of Canada's BIM community.*
- *CanBIM represents, supports and advocates on behalf of the entire AECOO and educational community to build a positive business environment for the effective deployment of BIM, not only for our member firms, but for all engaged in utilizing BIM in Canada.*
- *Our Mission is to provide our professional, educational, construction, fabrication and supply chain members a collective voice dedicated to BIM. We provide our members with advocacy, learning opportunities and best practices for BIM in a Canadian context while maintaining connectivity with our international partners.*

CanBIM's Strategy

- *Our strategy for executing our mission is to*
- *Foster an environment of open collaboration and communication with all industry stakeholders.*
- *Align our organization with professional organizations focused on making BIM the standard*
- *Assist in any way possible to produce tangible working methodologies that allow BIM to develop as a standard.*

CanBIM's Goals

- *We plan to implement our strategy by achieving the following operational goals:*
- *We will host Regional Sessions throughout the year where we will discussion and decide upon key issues relating to BIM.*

- *We will grow our membership and professional affiliations for the purpose of collaboration and communication with a wider audience.*
- *We will continually improve upon the delivery of relevant and current information to our membership and interested stakeholders.*

CanBIM membership comes from all parts of the industry from Builders, Architects, Engineers and Consultants to Facility Managers and Vendors. CanBIM is a registered not for profit entity run by a volunteer Board of Directors. The council uses annual membership dues to develop documentation, maintain the web portal and host events relating to BIM.

Members are encouraged to participate on subcommittees and contribute to on-going projects organized by the sub-committee leaders. The CanBIM board meets monthly or as required. The membership is invited to meet four times a year during our Regional Sessions. The goal of the Regional Sessions is to host a local forum to discuss Industry issues related to BIM and other technologies. The intent is to share knowledge across the country, as well as setting priorities for the development of standards, guidelines and best practices in BIM. The Regional Sessions are also a great opportunity to have your firm's voice heard in a public setting to help steer the consensus on how this technology will be implemented in the industry.

Videos from the meetings, open discussions and the presentations, etc. are hosted online as a resource for the community. Similar to the Regional Sessions, the CanBIM web site is also intended to be a portal to host discussions and technical developments.

CanBIM also has a Memorandum of Understanding (MOU) with buildingSMARTalliance to share both material and human resources to foster a pan-American approach to BIM. CanBIM has a seat on the Technical Committee, Planning Committee and Board of Direction for NBIMS, an initiative of buildingSMARTalliance that will be described in the next section on International Efforts.

2.1.2 Institute for BIM in Canada

The Institute for BIM in Canada (IBC) was founded in 2010 to *"lead and facilitates the coordinated use of Building Information Modeling (BIM) in the design, construction and management of the Canadian built environment. IBC's priorities include an awareness program, a practice manual, a bibliography of useful resources, and a full environmental scan/assessment on the use of BIM in Canada and internationally."* (Institute for BIM in Canada website, accessed Nov. 2011)

The following summarizes the terms of reference for the organization, including its authority, mission and objectives (Institute for BIM in Canada website, accessed Nov. 2011):

Authority

- *The Institute for BIM in Canada (IBC) is a joint national organization having the sole authority to endorse its products, services, positions and policies.*
- *Marketing, education and promotion of IBC approved documents and suggested practices are the responsibility of the Institute in collaboration with its constituent organizations.*
- *The IBC may receive inquiries, make recommendations, and distribute information to improve BIM related procurement/contracting practices, as it deems appropriate.*

Mission

- *To lead and facilitate the coordinated use of BIM in the design, construction and management of the Canadian built environment.*

Objectives

- *To define collaborative approaches and solutions as between stakeholders in the BIM environment.*
- *To develop and recommend "best practices" policies, tools and procedures to support BIM utilization.*
- *To educate the industry about trends and developments relative to BIM in Canada*
- *To communicate its activities to the industry at large.*

The IBC recently completed an Environmental Scan of BIM Tools and Standards, which is a report that is publicly available on their website. This report provides a quick overview of the tools and technologies commercially or freely available in the market to support BIM implementation efforts. They are now working on a BIM Practice Manual. (IBC website, accessed Nov. 2011)

2.2 International Efforts: BIM Standards and Initiatives

BuildingSMART International (bSI) is "a *neutral, international and unique not for profit organisation supporting open BIM through the life cycle*." (bSI website, accessed on Nov. 2011) They have regional chapters in Europe, North America, Australia, Asia and the Middle East. Figure 5 shows a world map highlighting specific chapters of buildingSMART, as well as the regions that were studied in more detail for this project (shown circled). BuildingSMART has developed a common data schema that makes it possible to hold and exchange data between different proprietary software applications. This buildingSMART data model standard is defined by Industry Foundation Classes (IFC), which is in the process of becoming an official International Standard ISO/IS 16739. According to bSI:

> *"'Open' is the key to the real value of our buildingSMART standard. IFC can be used to exchange and share BIM data between applications developed by different software vendors without the software having to support numerous native formats. As an open format, IFC does not belong to a single software vendor; it is neutral and independent of a particular vendor's plans for software development. For this reason, we say that our organisation – buildingSMART – is 'the home of open BIM'."*

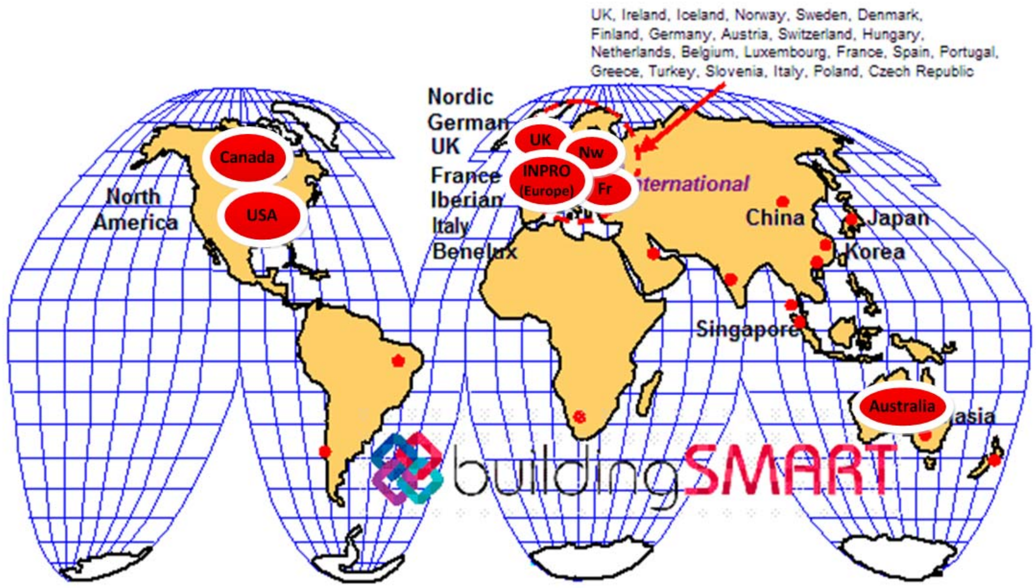


Figure 5: Countries whose BIM guides were studied in the context of this project (indicated with red ellipses on the World map).

The buildingSMART alliance™ (bSa) is a member of the bSI and is focused on "*helping to make the North American real property industry more efficient by leading the creation of tools and standards that allow projects to be built electronically before they are built physically using Building Information Modeling*." (bSa website, accessed on Nov. 2011) The bSa is responsible for developing the National BIM Standard (NBIMS) for the United States. The goal of NBIMS is to establish *"the standards needed to foster innovation in processes and infrastructure so that end-users throughout all facets of the industry can efficiently access the information needed to create and operate optimized facilities."* Recently, the Institute and the Alliance signed an agreement to develop Open BIM Standards with the Canadian BIM Council. The intent is to work collaboratively on a National BIM Standard that will be adjusted for country-specific issues to create a National BIM Standard - Canada. (bSa website, accessed on Nov. 2011).

For this research, we investigated relevant BIM standards and guidelines, and identified relevant organizations that are BIM advocates within the different regions. Figure 6 shows the different organizations that are working to develop BIM standards, promote the use of BIM, and provide BIM education and information for the different industry sectors for the regions we analyzed.

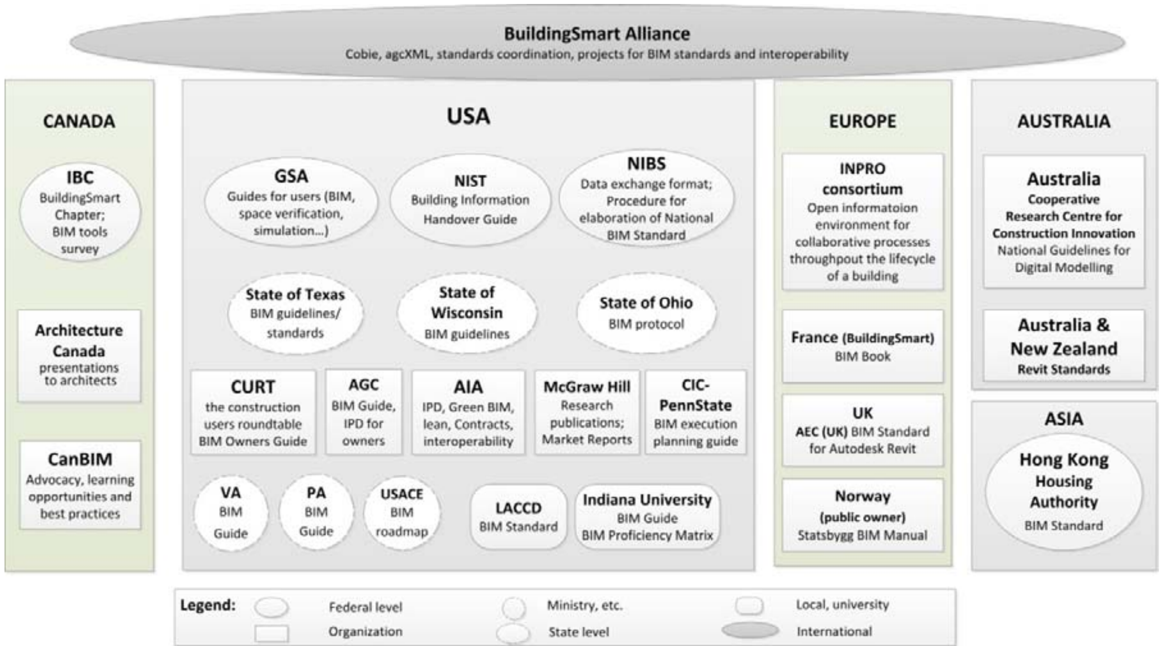


Figure 6: BIM Standards and Guides studied in this research and organizations involved from the different regions studied.

Table 3 shows the different themes and topics of the different guides shown in Figure 6. This table shows the breadth of coverage of these guides in terms of addressing important issues related to the three dimensions of our framework – technology, organization and process. We recognize that these are incomplete but our intent here is to provide a summary of existing BIM guides and a reference that can be used to better understand all the various BIM-related documents.

There is a growing trend within certain regions to develop BIM standards and guides. In general, we found guides mostly prepared by public owners, industry advocates and universities. Some guides are developed by large consortiums of public owners and private companies. The scope of influence of these documents varies from multinational (INPRO) and federal (GSA, NIST, NIBS), through country and state (in the USA) levels, to local levels (Los Angeles Community College District (LACCD) Guide).

The next sections describe a few noteworthy initiatives in the different regions.

2.2.1 BIM Initiatives in the US

The United States clearly has the most significant breadth of owners requiring BIM, as well as the most significant representation of organizations advocating for BIM. A pivotal point in the adoption of BIM in the US was when the General Services Administration started mandating BIM on all federal building projects starting in 2007. The GSA's mission is to "*help federal agencies better serve the public by offering, at best value, superior workplaces, expert solutions, acquisition services and management policies.*" (GSA Website, accessed on Nov. 2011) One goal of the GSA's National 3D-4D-BIM Program is to provide a significant support service for assisting project teams that are interested in adopting new 3D, 4D, and BIM building technologies. Further, some guides developed by other institutions refer to chapters of the GSA Guides (e.g., the Veteran Affairs (VA) BIM Guide).

Given the significant growth of BIM adoption in the US in the past decade, it is clear that the broad range of organizations advocating, teaching and supporting BIM implementation have had an impact. This transformation witnessed in the US demonstrates the importance of disseminating best practices to support the industry transition to BIM.

Table 3: The different themes/topics discussed in the various BIM guides.

		USA										Europe				Au
		GSA	NIBS	NIST - Dept. of Commerce - Inf. Handover Guide	CIC+PennState - BIM execution panning guide	VA - Veteran Affairs BIM Guide	PA-Port Authority of NY&NJ BIM Standard	Wisconsin BIM standard & Guide for arch. & eng.	Texas - guidelines - standards for professionals	CURT - BIM implement.: owner's Guide	AIA, etc.: IPD for owners	INPRO - Europe	UK	Norway	France	Australia
		federal					other	state		association		other	countries			
	General															
	BIM theory		x									x				
	BIM benefits	x		x	x			x	x	x				x	x	x
	Point of view (owner, professionals, builder)	o,p,b	inst								p					
Technology	Technology (software, infastructure)	x			x	x	x	x								x
	Requirements															
	Modeling requirements	x			x	x	x					x	x	x		x
	(BIM application, hierarchy, objects+prop, precision, layers)													x		x
	Deliverables	x			x	x	x					x	x	x		
	Quality control& perf. Measure	x			x		x					x gates				
	Data															
	Data exchange	x	x	x	x							x	x			x
	Files, names, folders structure					x	x					x	x	x		
	Metadata			x												
	Data interoperability		x	x	x		x					x ifc	x			x
	Sharing, storing data		x		x	x						x reuse	x			x
	Contents of the model by building aspect:															
	architecture	x			x	x						x		x		x
	structure				x	x						x		x		x
	spatial program	x				x			x			x		x		x
	visualisation	x				x								x		x
	building code				x							x		x		x
	4D phasing	x			x	x						x		x		x
	energy performance	x			x	x					x	x		x		x
	sustainability										x				x	
	clash detection				x	x	x					x		x		x
	5d-estimating				x									x		x
	circulation, safety	x												x		x
	Contents by disciplines + landscape, interior, acoustic							x						x		
	Contents by project phases: prelim, concept, dev, exec, constr, oper, recycle															x
	construction					x			x		x lean	x		x		x
	subcontractors, fabricators					x										
	operation (as build)											x		x		x
Organization	**BIM adoption process in company**	x	x	x	x	x				x					x	x
	BIM maturity (matrix, measure,certification)		x				x									
	BIM management (execution plan)				x	x	x			x			x			x
	Planning & impl. of the Guide			x	x											x
	Risk management											x				
	Experience feed-back											x				
	Legal aspects						x					x				x
Process	**Project**															
	Process (projet, bâtiment)	x		x	x	x	x	x	x	x	x lean	x		x		x
	Project delivery mode			x	x	x	x ipd				x ipd	x				
	Collaboration				x		x				x	x	x			x
	Project team	x			x	x						x	x			
	Process of creation of the standard		x										x			

2.2.2 Other Noteworthy BIM Initiatives

The government of the United Kingdom has recently taken significant steps to advance BIM adoption as part of a major governmental strategy to improve construction efficiency and deliver better value for public sector construction. The Government Construction Strategy report was released on May 2011, announcing that the government will require collaborative 3D BIM on all of its projects by 2016. This requirement will be implemented in a phased process while working closely with industry groups to allow sufficient time for the development of new standards and for training. (Cabinet Office, Government Construction Strategy Report 2011)

The decision of the Government Construction Clients Board was based on the report from the BIM Industry Working Group convened by the Department for Business, Innovation and Skills (BIS), which was released March 2011 (BIM Industry Working Group 2011). The key recommendations from the BIM strategy group were:

1) *Leave complexity and competition in the supply chain*
2) *Be very specific with supply chain providers, they will only provide that which is asked for*
3) *Measure and make active use of outputs*
4) *Provide appropriate support infrastructure*
5) *Take progressive steps*
6) *Have a clear target for the "Training Edge" of the industry.*

They also developed a BIM Maturity index (Figure 7) that characterizes the different levels of experience within the supply chain, and also the different approaches to BIM. This maturity index serves as a structured 'learning' progression and BIM evolution process over time. (BIM Industry Working Group 2011)

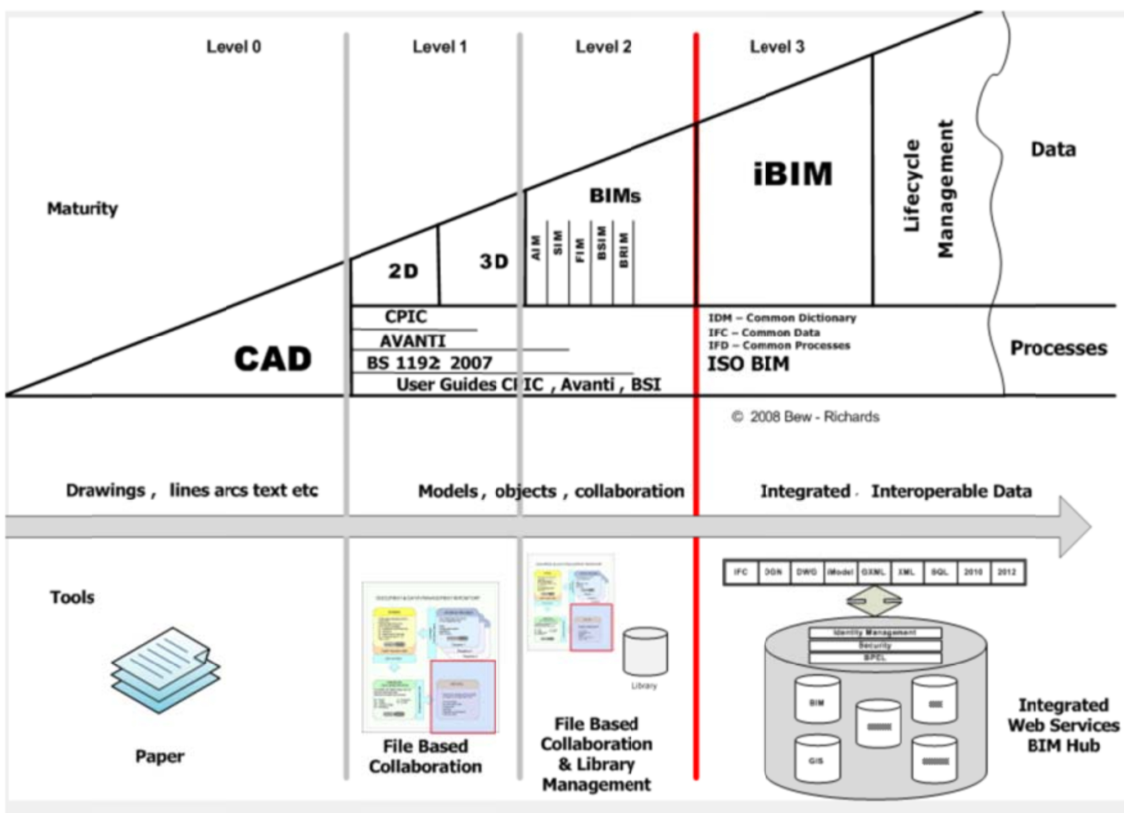


Figure 7: Maturity index illustrating the different levels of experience and approaches to BIM (BIM Industry Working Group of the BIS 2011)

Another noteworthy initiative to accelerate BIM adoption is the Singapore Construction Productivity and Capability Fund program, which supports BIM training and BIM enhancement initiatives. It is a multi-pronged initiative aimed at transforming the Singapore industry to make it more sustainable. The BIM Fund is one of three components stimulating the adoption of technologies to improve the productivity and quality of the end product. It includes a specialist diploma in BIM, which is offered as a 5-month part-time study program. Another interesting characteristic is that this BIM enhancement program proposes a 'Construction Productivity Roadmap' which envisions mandatory BIM submission starting in 2013 (see Figure 8) and ambitious BIM adoption target (80% of the design professionals by 2015). A Construction Productivity and Capability Fund was created to support this process (Figure 9).

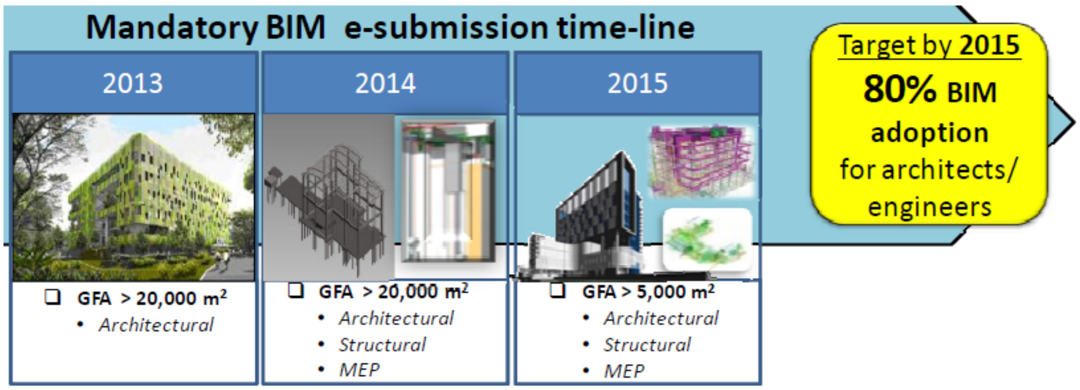


Figure 8: Timeline for mandatory BIM submission in Singapore.

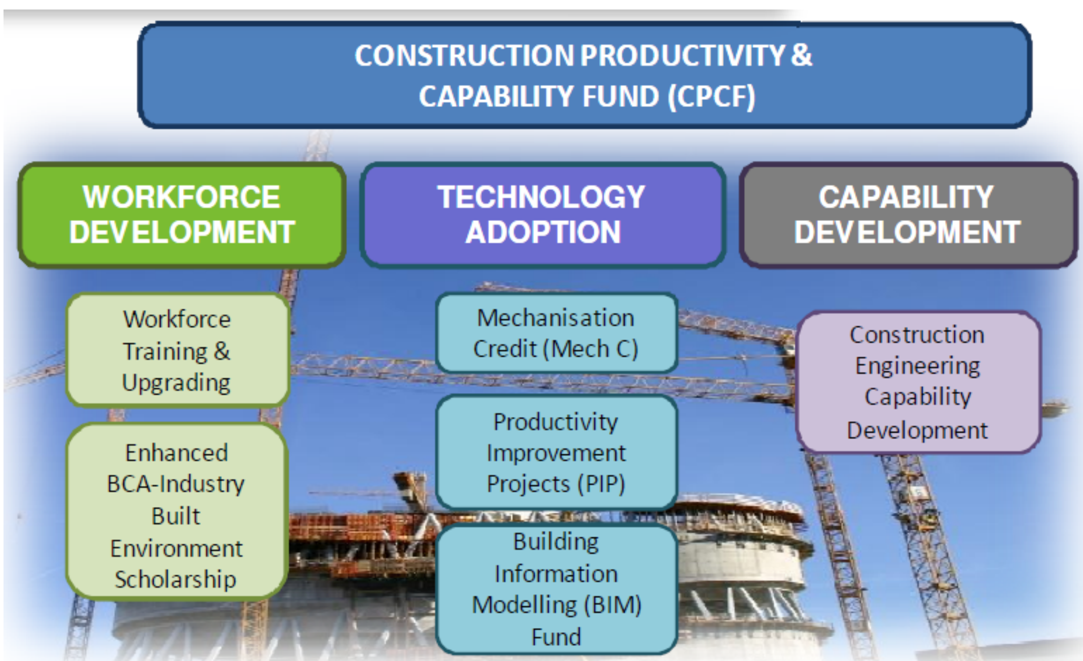


Figure 9: Processes supported by the Construction Productivity and Capability Fund in Singapore.

2.3 BIM Guides and Execution Planning

Several government- and industry-led efforts from around the world have developed different guides or manuals to facilitate BIM implementation. However, few have gone as far as Penn State and the GSA in the US, or the Australian CRC in defining best practices in BIM design and execution planning. For this reason, this section provides some highlights on these initiatives.

2.3.1 US BIM Guides

The Computer Integrated Construction Research Program at Penn State University developed the BIM Project Execution Planning Guide —a buildingSMART alliance project (CIC 2010). This guide intends to provide a practical manual that can be used by project teams to design their BIM strategy and develop a detailed BIM Project Execution Plan (or the 'BIM Plan'). The BIM Plan outlines the overall vision along with implementation details for the team to follow throughout the project to effectively integrate BIM into the project delivery process.

This guide outlines a four-step procedure (see Figure 10) to develop a detailed BIM Plan. The four steps consist of identifying the appropriate BIM goals and uses on a project, designing the BIM execution process, defining the BIM deliverables, and identifying the supporting infrastructure to successfully implement the plan.

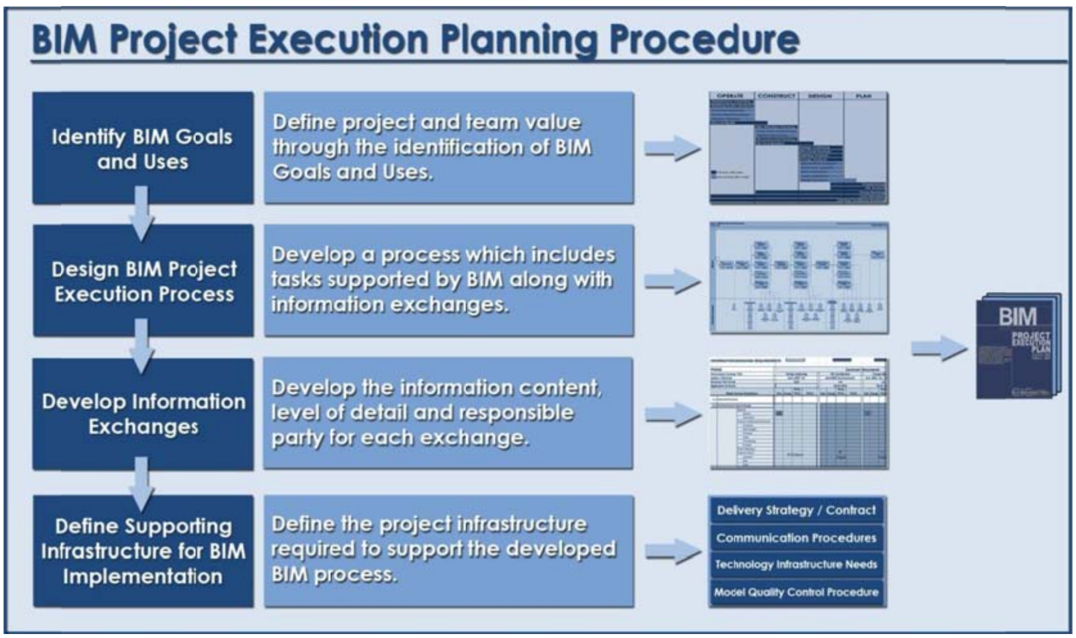


Figure 10: The BIM Project Execution Planning Procedure developed by Penn State (CIC 2010)

The General Service Administration (GSA) National 3D-4D-BIM Program (GSA 2011) provides general guidelines for integrating 3D, 4D, and BIM technologies into the existing project delivery process for GSA-administered projects. GSA is developing the following BIM guide series to support the adoption of 3D-4D-BIM technologies on GSA-administered projects and beyond, and for assisting project teams that are interested in adopting these new digital technologies.

- Series 01 - 3D-4D-BIM Overview
- Series 02 - Spatial Program Validation
- Series 03 - 3D Laser Scanning
- Series 04 - 4D Phasing

- Series 05 - Energy Performance and Operations
- Series 06 - Circulation and Security Validation
- Series 07 - Building Elements
- Series 08 - Facility Management

Figure 11 highlights the steps and iterations that are recommended by GSA for technology adoption on a specific project.

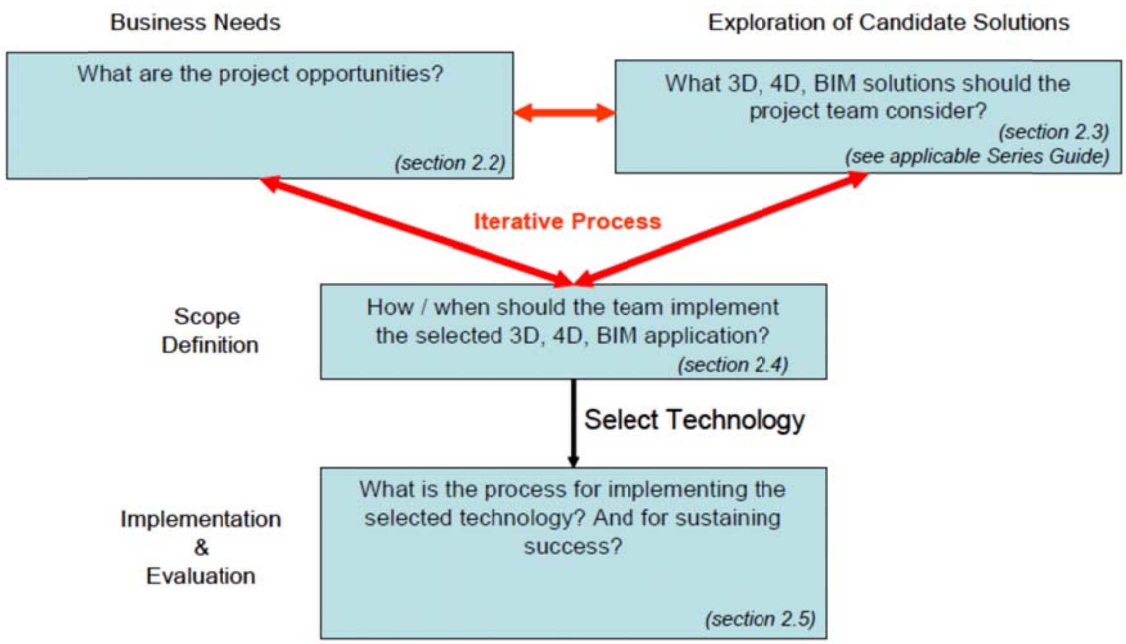


Figure 11: Process for adopting 3D, 4D, and/or BIM technologies (www.gsa.gov.bim)

The GSA recognized that there are a number of opportunities that may be available on a project or project areas where 3D-4D-BIM technologies may be applied (Figure 12). The GSA encourages all GSA projects to deploy technologies at strategic project phases in support of specific project opportunities, taking into account a number of considerations: 1) the experience of the project team, 2) the maturity of the technology, 3) the resource availability (e.g., funding), 4) information exchange between team members, 5) the procurement of 3D-4D-BIM services, 6) timing of adoption of technology during the project life-cycle, 7) contractual language, 8) ownership and rights in data, 9) roles and responsibilities, and 10) metrics for measuring the success of digital technologies.

Technology	Project Area		Improvements in:
3D Laser Scanning	• As-built Information	• As-Constructed Information	• Quality • Accuracy • Coordination • Efficiency
3D Geometric Models	• Site • Architectural • Structural	• MEP • Fabrication/Construction Tolerance	
Design and Construction Coordination	• Coordination between disciplines	• Clash Detection	
4D Models	• Project Phasing • Tenant Phasing	• Construction Sequencing • Traffic Studies	
BIM Models	• Site • Architectural – Space – Zone/Circulation	• Structural • Mechanical • Equipment Information • Maintenance Schedules	
BIM-analysis Applications	• Program/Asset Management • GIS • Energy Analysis • CFD Analysis	• Acoustic • Cost Estimating • Equipment Inventory • Facility Management	

Figure 12: 3D-4D-BIM applications or project areas identified by the GSA (www.gsa.gov.bim)

2.3.2 Other Noteworthy BIM Guides

Other countries have also taken initiatives at the national level to promote BIM. For example, in Australia, the National Guidelines for Digital Modeling have been developed to assist in and promote the adoption of BIM technologies in the whole Australian building and construction industry (CRC for Construction Innovation 2009). The guidelines are supported by six case studies including a summary of lessons learnt about implementing BIM in Australian building projects.

According to these guidelines, three areas of current practice, namely technology, policy, and process will be affected by BIM implementation. While the technology and policy implications are also urgent, the process implications are the most pressing for the industry to address. The technology and policy implications are framed by how new BIM tools are employed and new modes of practice emerge using new processes (CRC 2009). Digital modeling will result in changes in design, construction, maintenance and operation processes. The focus of the National BIM Guidelines in Australia is on the process implications of BIM implementation. There are four major BIM implementation stages as identified in the guidelines (see Table 4).

Table 4: Different stages of BIM Implementation (Source: CRC 2009)

Stage	Subdivisions	Remarks
0-2D Documents	0A Manual Drafting	Pre-BIM stage; still the predominant mode of practice; not the focus of the guideline.
	0B CAD 2D Drafting	
1-Modeling	1A 3D CAD Modelling	First stages in the adoption and use of BIM; represent part of the industry which is implementing BIM. Most practitioners are currently at stage 1B; major focus of the guideline.
	1B Intelligent 3D Modelling	
2-Collaboration	2A One-Way Collaboration	

	2B Two-Way Collaboration	
3-Integration	3A Local Server	3A and 3B stages describe technologies and processes hosted on model servers. These model servers are yet to be implemented in the Australian industry, but are currently being used for research at UNSW and QUT.
	3B Web-Based Server	

The guidelines specifically provide, in the context of Australian Building and Construction Industry, modeling requirements and challenges of BIM implementations, particularly for Intelligent 3D Modeling (Stage 1B) and Collaboration (Stages 2A and 2B). The guidelines stress on the need for carefully setting up the BIM project definition and execution plans for BIM implementation. These major decisions essentially involve ‘who?’, ‘what?’, ’why?’ and ‘when?’. The interrelated questions that need to be worked out according to these guidelines are:

1) Who is involved and their responsibilities? For whom are the models intended?
2) What models are required? What range of discipline models is needed, and if an aggregate model is to be created, why is it required?
3) When are they required? At what project stage are the models needed?
4) What data is needed in the models and at what level of detail?
5) How will the models be exchanged and in what format?
6) Who is managing the process? Is there a need for a project BIM manager?

This section highlights a few initiatives that have been developed by different organizations that are owner- and industry- driven to facilitate the adoption of BIM.

2.4 Uses of BIM

BIM can be used to support a variety of functions throughout the project delivery process. Identifying how BIM will be used and/or what functions it will support are key considerations on every BIM project. Figure 13 shows the most frequent BIM-related activities identified in a survey of the US industry (McGraw-Hill 2008).

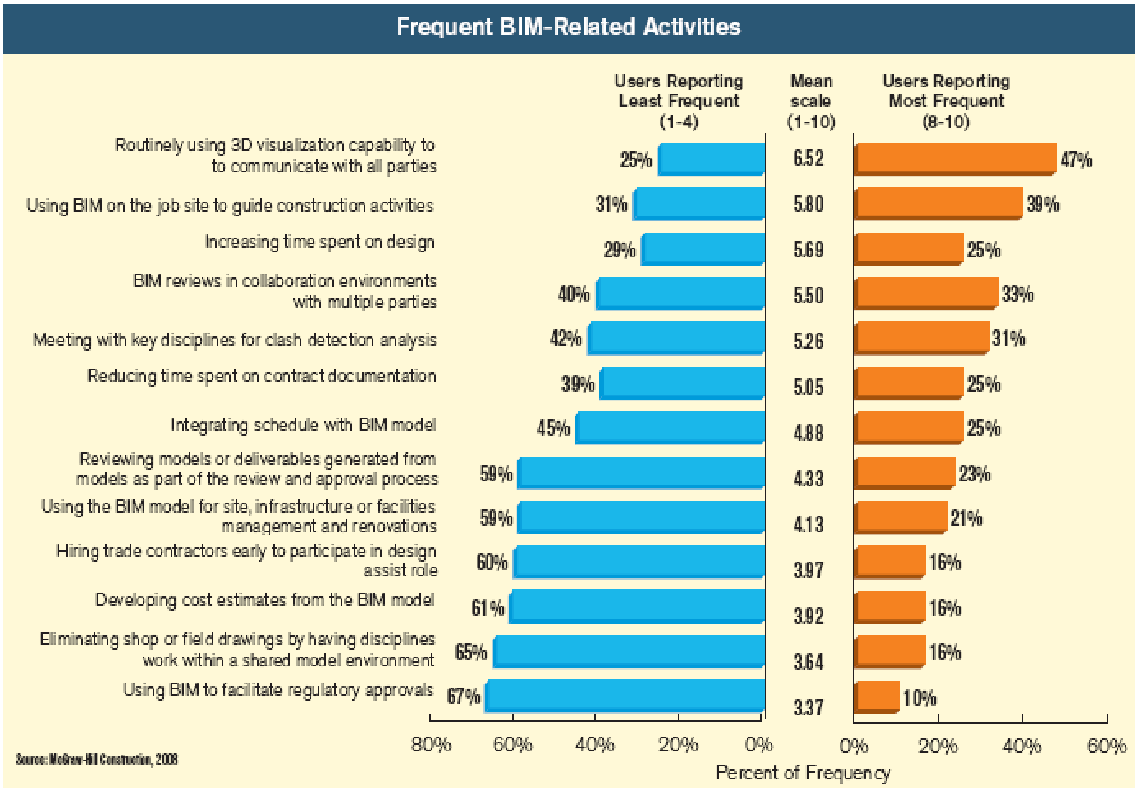


Figure 13: Most frequent BIM-related activities identified in a survey by McGraw-Hill (2008)

One of the major drivers of BIM expansion is the increasing ability of specialized analysis tools to extract data from design models and perform valuable analysis, such as quantity take-off, scheduling, estimating, energy analysis, etc. (Figure 14).

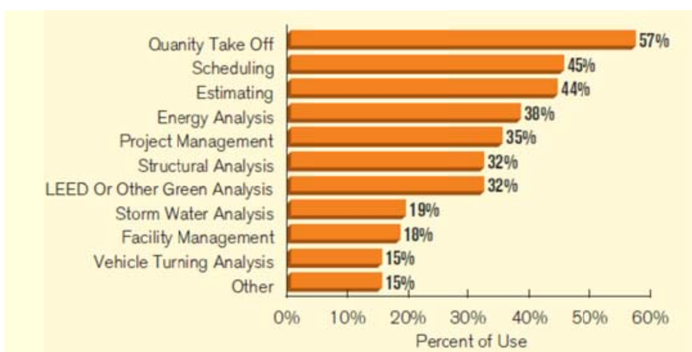


Figure 14: Use of BIM Analysis Tools identified in a survey by McGraw-Hill (2008)

The Computer Integrated Construction research group at Penn State University has also identified potential uses of BIM when developing their BIM Execution Planning document discussed previously. Specifically, they identified the following 25 uses of BIM and provide templates to help users understand the requirements for implementing each use (Computer Integrated Construction Research Program 2009):

1) Maintenance Scheduling
2) Building Systems Analysis
3) Asset Management
4) Space Management / Tracking
5) Disaster Planning
6) Record Modeling
7) Site Utilization Planning
8) Construction System Design
9) Digital Fabrication
10) 3D Control and Planning
11) 3D Design Coordination
12) Design Authoring
13) Energy Analysis
14) Structural Analysis
15) Lighting Analysis
16) Mechanical Analysis
17) Other Eng. Analysis
18) LEED Evaluation
19) Code Validation
20) Programming
21) Site Analysis
22) Design Reviews
23) Phase Planning (4D Modeling)
24) Cost Estimation
25) Existing Conditions Modeling

We evaluated the uses of BIM for each of the projects studied.

2.5 Levels of BIM

An important consideration when implementing BIM on a project is the 'level of BIM', which really tries to answer the question of *how far do you go*? It is critical that the scope and level of detail to be modeled is properly considered and that all parties are clear on what is expected of them. The American Institute of Architects (AIA) have grappled with this issue and developed the E202 BIM Protocol document that is meant to provide a practical tool for using BIM across the project. Specifically, the intent of the E202–2008 BIM Protocol document is to answer the following questions (from AIA website):

- Who is responsible for each element of the model and to what level of development?
- What are authorized uses for the model?
- To what extent can users rely on the model?
- Who will manage the model?
- Who owns the model?

Figure 15 shows the E202 Model Element Table that is included as part of this BIM protocol document and identifies (1) the level of detail (LOD) required for each Model Element at the end of each phase, and (2) the Model Element Author (MEA) responsible for developing the Model Element to the LOD identified.

§ 4.3 MODEL ELEMENT TABLE

Identify (1) the LOD required for each Model Element at the end of each phase, and (2) the Model Element Author (MEA) responsible for developing the Model Element to the LOD identified.

Insert abbreviations for each MEA identified in the table below, such as "A – Architect," or "C – Contractor."

NOTE: LODs must be adapted for the unique characteristics of each Project.

Model Elements						Conceptualization		Criteria Design		Detailed Design		Implementation Documents		Construction	
						LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA
				D5090	Other Electrical Systems	100		100		100		300		500	
E	EQUIPMENT & FURNISHINGS	E10	Equipment	E1010	Commercial Equipment	100		200		300		400		500	
				E1020	Institutional Equipment	100		200		300		400		500	
				E1030	Vehicular Equipment	100		100		200		300		500	
				E1090	Other Equipment	100		100		200		300		500	
		E20	Furnishings	E2010	Fixed Furnishings	100		200		300		400		500	
				E2020	Movable Furnishings	100		100		200		300		500	
F	SPECIAL CONSTR. & DEMO	F10	Special Construction	F1010	Special Structures	100		200		300		400		500	
				F1020	Integrated Construction	100		100		300		400		500	
				F1030	Special Construction Systems	100		100		300		400		500	

Figure 15: A portion of the AIA - E202 Element Model Table developed by the AIA and included in the E202 BIM Protocol exhibit.

As shown in the E202-Model Element Table, the AIA define 5 levels of BIM with increasing level of detail from Level 100 thru Level 500. Figure 16 graphically shows these 5 levels of detail along with their definitions from AIA (graphic from http://allthingsbim.blogspot.com/2008/12/aia-bim-protocol-e202.html).

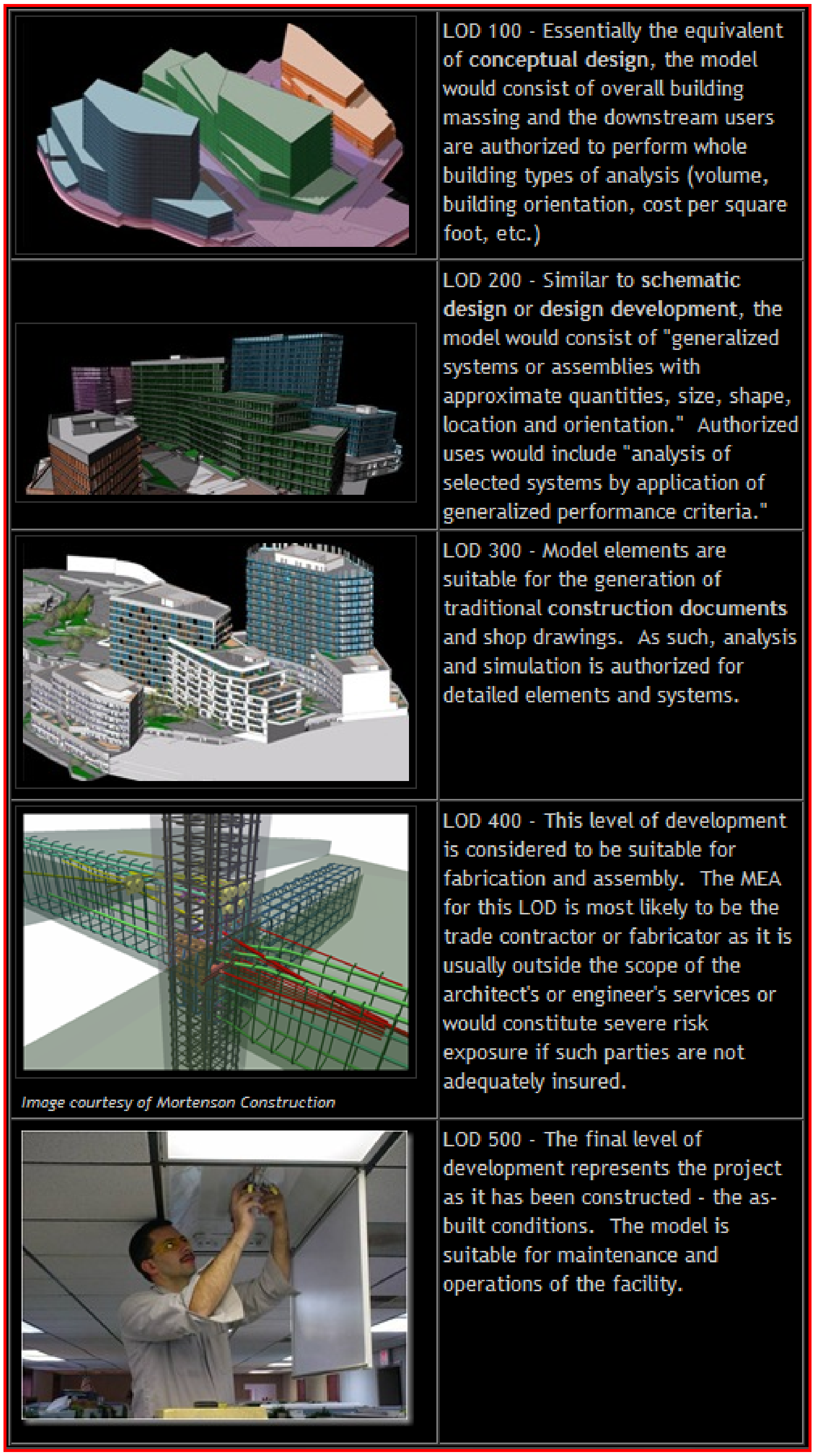


Figure 16: Levels of Detail defined by the AIA in their BIM Protocol Exhibit (graphic from http://allthingsbim.blogspot.com/2008/12/aia-bim-protocol-e202.html)

DPR Construction, a contractor in the United States with extensive BIM experience, defines 4-levels of BIM (from http://dpr-review.com/fall-winter-2010/story/the-four-levels-of-bim).

- Level 1: A tool primarily used to communicate design intent and help owners evaluate alternative designs at the beginning of a project and visualize an end product.
- Level 2: Models created by design teams that include mechanical/electrical/plumbing (MEP) systems at a higher level done during the coordination phase to reduce requests for information (RFIs) and changes in the field during construction, as well as site logistics.
- Level 3: Includes detailed models created by MEP subcontractors that are merged with the designers' models to produce fabrication-level MEP models. Level of detail also allows for very detailed 4D sequencing of the building process, 3D as-built models, and the ability to pull accurate quantity trends directly from the models.
- Level 4: Integrates substantially more stakeholders into the process from the early design stage to provide input and review, test the constructibility, and determine the best materials and methods for design and construction, in accordance with the project's budget, schedule and quality. Level 4 BIM results in the creation of a model that incorporates such fine details as seismic and gravity hangers, metal framing systems, and detailed models of components like rebar. These models can be used to produce permit documents and shop drawings, pull material quantities, produce accurate model-based estimates, perform cross-trade prefabrication, and produce actual installation drawings.

We used these references in analyzing the level of BIM implemented in the projects studied.

2.6 Impact of BIM

The return on investment (RIO) for BIM was researched in McGraw-Hill's "SmartMarket Report on Building Information Modeling: Transforming Design and Construction to Achieve Greater Industry Productivity," (2008):

- The surveyed companies, who actively track their return on investment from BIM, say they are getting returns of 300% to 500%.
- 82% of respondents believe BIM is having a positive impact on their company's productivity.

In a follow-up survey by McGraw-Hill in 2009, they sought to identify the key areas where BIM is contributing the most value. Figure 17 shows the top rated ways that respondents found that BIM saves time and/or money (McGraw-Hill 2009).

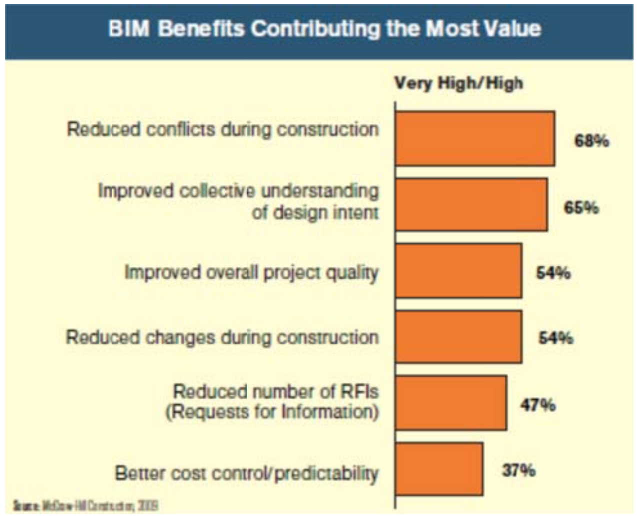


Figure 17: The top BIM benefits that were rated as contributing the most value (from McGraw-Hill 2009)

Many BIM users also see a significant internal business value of BIM (Figure 18). They see it as a way to get a leg up on the competition by marketing new business to new clients, offering new services and maintaining repeat business with past clients. Moreover, BIM creates efficiencies which mainly come from reducing and avoiding rework, reducing conflicts and changes during construction, and through clash detection (McGraw-Hill 2009).

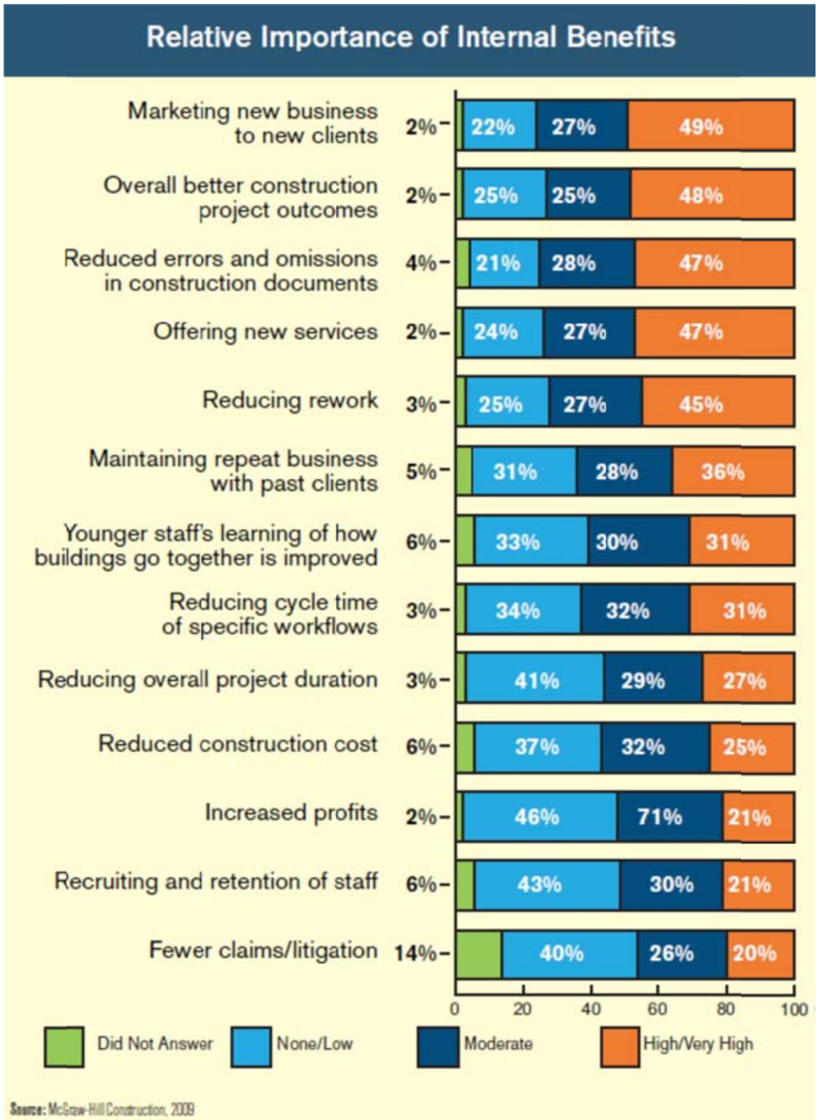


Figure 18: Relative importance of internal benefits for implementing BIM (from McGraw-Hill 2009)

The McGraw-Hill studies demonstrate the full range of benefits that can be achieved with BIM. The next section describes specific BIM projects and the impact of BIM for these projects.

2.7 BIBLIOGRAPHY

AIA California Council (2007), "Integrated Project Delivery – A Working Definition".

BIM Industry Working Group, Department for Business, Innovation and Skills (BIS), United Kingdom (2011). *A report for the Government Construction Client Group Building Information Modelling (BIM) Working Party Strategy Paper.* Available online at: (https://connect.innovateuk.org/c/document_library/get_file?uuid=6842e020-20df-4449-8817-08ce2ba9ef7c&groupId=68909).

Computer Integrated Construction Research Program (CIC). (2010). *BIM Project Execution Planning Guide – Version 2.0*, The Pennsylvania State University, University Park, PA, USA. Available online at: http://bim.psu.edu/Project/resources/default.aspx.

Cooperative Research Centre (CRC) for Construction Innovation. *(2009). National Guidelines for Digital Modeling*, Brisbane, Australia

General Services Administration (GSA). (2011). *3D-4D Building Information Modeling*. Available online at: http://www.gsa.gov/portal/content/105075

Cabinet Office, United Kingdom (2011). *Government Construction Strategy Report*. Available online at: http://www.cabinetoffice.gov.uk/sites/default/files/resources/Government-Construction-Strategy.pdf)

McGraw Hill Construction (2008). *Building Information: Transforming design Construction to Achieve Greater Industry Productivity,* Smart Market Report.

McGraw Hill Construction (2009). *The Business Value of BIM: Getting Building Information Modeling to the Bottom Line*, Smart Market Report.

Websites referenced:

- www.canbim.com
- www.ibc-bim.ca

3 CASE STUDIES

We developed a framework to evaluate all the BIM projects consistently. The framework considers each BIM project in terms of the three dimensions: **T**echnology, **O**rganization, and the **P**rocess. Staub-French and Khanzode (2007) highlighted these issues when documenting lessons learned on two BIM projects. This framework is also relatively consistent with how others have characterized a BIM implementation. For example, at Stanford University's Center for Integrated Facility Engineering (CIFE), they consider projects from a 'P-O-P' perspective - Product (this would align with our Technology perspective), Organization, and Process (Kunz and Fischer 2011). And at DPR Construction, they talk about the Model (this would align with our Technology perspective), Team (this would align with our 'Organizational' perspective), and Process (DPR website).

For each dimension, we further characterized the kinds of issues that would be addressed as outlined in Table 5. We recognize that there may be other kinds of information to include and that there is some ambiguity in terms of how a particular issue might be characterized. However, our aim was to try and ensure consistency across all the case studies as much as possible.

Table 5: The TOPP framework developed to analyze each of the BIM projects studied.

Technology	• Owner requirements • Uses of models • Scope of modeling • Level of BIM (e.g., DPR 4 levels of BIM) • Technologies used • Information infrastructure
Organization	• Participants involved • Timing of participant involvement • Business practices and structure (within firm and between firms) • BIM expertise • Contractual relationships • Legal considerations
Process/**P**rotocol	• Execution planning • Workflows • Hand-offs • Information exchange

In the following sections, we document seven case studies of BIM projects using this framework.

3.1 SUTTER MEDICAL CENTER (UNITED STATES)

This project was selected as an International BIM project because it exemplifies many of the 'best practices' that have been achieved to date, all in one project:

- 11-party IPD agreement
- Target value design
- Integrated supply chain
- Lean practices
- Production level modeling
- Model-based estimating
- Significant benefits, including faster design, faster cost feedback, improved productivity, increased pre-fabrication, less rework, etc.

3.1.1 PREFACE

This case study is written based on numerous publications that are publicly available. The intent has been to collect all relevant information in one document organized in a structure compatible with other such BIM case studies written. The content of this case study is predominately sourced from the following publications:

- "Sutter Medical Center Castro Valley: The Real Risks and Rewards of IPD" (Christian et al. 2011)
- "BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, and Contractors" (Eastman et al. 2011)
- "An Unprecedented 11 Partners Propel Integrated Project Delivery at Sutter's New California Hospital" (Post 2011)
- "Sutter Medical Center Castro Valley: IPD Process Innovation with Building Information Modeling" (Ghafari Associates, accessed on Oct. 2011)
- "Sutter Medical Center Castro Valley: Case Study of an IPD Project" (Khemlani 2009)
- "Model Based Estimating to Inform Target Value Design" (Tiwari et al. 2009)
- "Sutter Medical Center Castro Valley, USA" (Tekla website, accessed on Oct. 2011)
- "Transcending the BIM Hype: How to Make Sense and Dollars from Building Information Modeling" (Lamb et al. 2009)
- "Collaborating with a Permitting Agency to Deliver a Healthcare Project: Case Study of the Sutter Medical Center Castro Valley (SMCCV)" (Alarcon 2011)

The above publications are excellent sources of information about the project and are recommended for further reading on this case study. Refer to the Bibliography section for more information about these publications and other references. *Note that any text shown in italics in this case study is copied directly from one of these sources.*

3.1.2 PROJECT DESCRIPTION

This case study is about a state-of-the-art hospital owned by Sutter Health that is currently nearing completion at Castro Valley, California. The Sutter Medical Center Castro Valley (SMCCV) is a modern

130-bed capacity hospital that is being build adjacent to and will operate in replacement of the current Eden Medical Center in Castro Valley, California (Figure 19. The vision of Sutter Health is to create an extraordinary landmark medical center that integrates advanced technology, quality medical care and outstanding physicians and employees to provide the best care for their patients and community. The $320 million project is fully funded by Sutter Health and is financed without any taxpayer support or public funds. The SMCCV is a 230,000-sq-ft seven-story tall building consisting of cast-in-place friction piers, a three-story reinforced concrete shear-wall podium supporting a four-story steel-braced frame. In addition to the hospital, the project includes building additional parking on Eden Medical Center campus and demolition of the old hospital once SMCCV is operational. (Sutter Medical Center Castro Valley website) (Post 2011)

Figure 19: Model Images of SMCCV (top row: SMCCV website, bottom row: Ghafari Associates 2011)

The project was faced with a number of challenges from the outset (Christian et al. 2011):

- **Site:** the new hospital is being constructed on a sloped grade with limited space available for construction activities. In addition, the current Eden Medical Center had to stay operational with minimal disturbance throughout the entire process.
- **Schedule:** strict deadlines for design, permitting, and construction were set by the legislation governing the seismic safety standards for hospitals in California. In order to meet these fix deadlines, the project team had to design the hospital at least 30% faster.
- **Budget:** an aggressive target cost of $320 million was set for this project. Under no circumstances was the project cost to exceed the target value.
- **OSHPD:** the Office of Statewide Health Planning and Development (OSHPD) mandate extensive regulatory oversight on hospital projects in California. OSHPD typically takes 24 months for review upon completion of design. To accelerate the permitting process, the project had to be one of the first to use OSHPD's Phased Review Process.

Overall, the primary goal of Sutter Health was to design and deliver a facility of the highest quality, at least 30% faster, and for no more than the target cost of $320 million (Christian et al. 2011).

CONTEXT

Khemlani (2009) provides a concise and informative project background:

"Sutter Health is one of the nation's leading not-for-profit networks of community-based health care providers, with over 60 facilities in Northern California including hospitals, cancer centers, long-term care centers, research institutes, and home health and hospice centers.

The need for a new hospital arose from California's hospital seismic safety law, SB1953, passed in 1994, that requires every hospital in the state to meet specific criteria that would keep these structures standing and provide uninterrupted care if they were struck by a major earthquake. The deadline for complying with SB1953 is by 2013. Under the stringent earthquake safety requirements, the original hospital building built in 1954 would not be eligible to be licensed as an acute care hospital after January 1, 2013.

The new seismic safety law has mandated seismic improvements for many of other Sutter facilities as well, requiring the organization to execute several large projects within a specific time frame. This motivated Sutter to find ways to reduce the time delays and budget over-runs typically associated with large projects, as well as the extended litigation that often results. It was looking at ways by which the design and construction delivery model could be transformed, and IPD fortuitously emerged as a viable alternative to the traditional delivery model just as the SMCCV project was being initiated. Moreover, the SMCCV project had several additional challenges that made it a good candidate for IPD: it had hard deadlines for both design and construction, an accelerated schedule that was 30% faster than a conventional schedule, and an aggressive cost target that could not be exceeded. None of these could be met with the conventional design-bid-build process, as that is iterative and takes too long, and any attempt to fast track the process usually results in higher risk of rework or cost increases. The IPD approach was therefore adopted for this project, in conjunction with the principles of lean construction and the implementation of technologies such as BIM."

This case study will start off by describing the organizational considerations on this project, since this was a distinctive aspect of the way BIM was implemented.

3.1.3 THE ORGANIZATION

Project Participants

An unprecedented eleven-partner Integrated Project Delivery (IPD) team was assembled by Sutter Health to deliver the SMCCV project. Table 6 identifies these eleven partners with their associated function in the project.

Table 6 Eleven Members of SMCCV IPD Team (Eastman et al. 2011)

FUNCTION	FIRM
Owner	Sutter Health*
Architect	Devenney Group Ltd.*
General contractor	DPR Construction*
Mechanical & plumbing design	Capital Engineering Consultants Inc.*

Electrical design	The Engineering Enterprise (TEE)
Structural design	TMAD / Taylor and Gaines (TTG)
Fire protection – design-build	Transbay Fire Protection
Mechanical design assist and contractor	Superior Air Handling Co. (SAHCO)
Process and technology managers	Ghafari Associates
Plumbing design assist and contractor	J.W. McClenahan*
Electrical design assist and contractor	Morrow-Meadows

* The Core Group constituted individuals from these partners in addition to a representative from Eden Medical Center

Similar to the idea of Board of Directors and CEO advising and deciding on the best path forward for a corporation, the IPD team created a Core Group from the principals of the partner firms to provide oversight and guide the project to success. The Core Group's purpose has been to manage strategies and behaviors and to make critical decisions affecting project time-line, cost and risk. The Core Group decides through consensus with Sutter Health ultimately making the final call. Table 7 identifies the members of the Core Group.

Table 7 Members of SMCCV IDP Core Group (Post 2011)

FIRM	POSITION
Sutter Health	Senior Project Manager
Eden Medical Center	Vice President of Ancillary and Support Services
Devenney Group Ltd.	COO / Principal
DPR Construction	Project Executive
Capital Engineering Consultants Inc. also representing TTG and TEE	
J.W. McClenahan also representing Morrow-Meadows and Transbay	

In addition to the original eleven signatories to the IPD contract many other contractors, fabricators, and suppliers later became involved in the project through a traditional bid process. Figure 20 illustrates the SMCCV's IPD team structure.

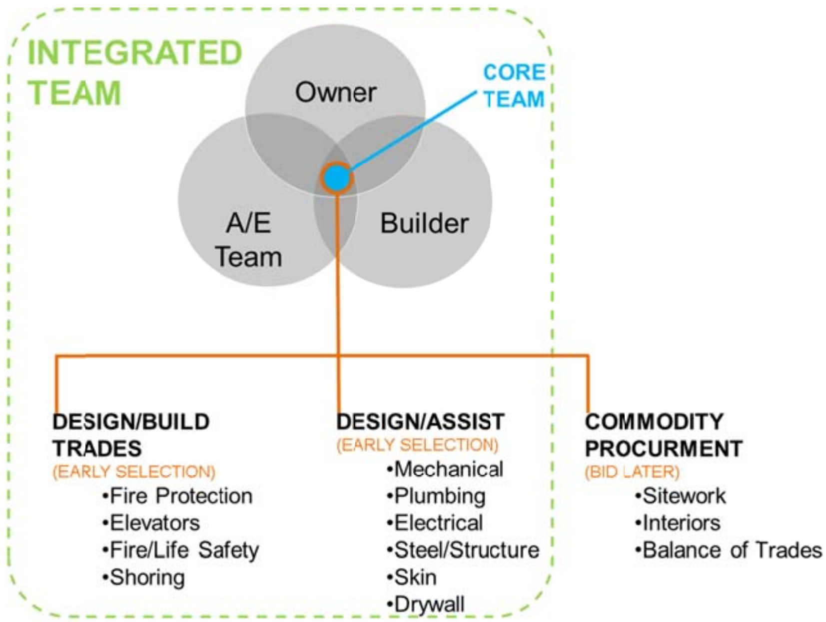


Figure 20: SMCCV Integrated Team Structure (Christian et al. 2011)

BIM Expertise

Sutter Health has done an excellent job in gathering the members of its SMCCV IDP team. The team members are well recognized for their ability to deliver efficient projects through employment of various techniques.

Sutter Health: an industry leader in promoting efficient project delivery methods. They are committed to utilizing lean practices coupled with Building Information Modeling (BIM) applications. They have successfully delivered a number of projects under an Integrated Form of Agreement (IFOA) contract. IFOA is Sutter Health's version of Integrated Project Delivery (IPD).

Devenney Group Ltd. Architects: "*a leading healthcare architectural firm with nearly 50 years of experience. As a firm that is 100% dedicated to healthcare design, they are innovative leaders in the use of Revit and Building Information Modeling, LEED, Lean Design Principles, and Integrated Project Delivery Methodologies."* (Devenney Group website, accessed on Oct. 2011)

DPR Construction: leaders in Virtual Design and Construction (VDC), BIM, lean construction, and IPD. They have delivered numerous projects employing these techniques. They are also experienced in green-construction (i.e. LEED) and pre-construction methodologies.

Ghafari Associates*: "a leading full-service architecture and engineering organization with a 29-year history of customer focus, quality work and technological innovation. Ghafari distinguishes itself as an operations-focused design practice with experienced management leadership, expert technical resources, and an impressive portfolio of projects. Ghafari was founded on innovation, and is recognized as a pioneer in adopting the latest technologies in real project applications. That tradition continues today; Ghafari's expertise in 3D building information modeling (BIM), combined with integrated project delivery and lean business practices, is transforming the industry."* (Ghafari Associates website, accessed on Oct. 2011)

With their expertise and knowledge combined the SMCCV IDP team is perhaps one of the strongest teams assembled for an Integrated Project Delivery method, employing lean construction practices and BIM.

Contractual Relationships and Legal Considerations

An Integrated Form of Agreement (IFOA) was selected as the contract type for the project. IFOA is Sutter Health's version of Integrated Project Delivery (IPD) method. A working definition of IPD as per 2007 document from AIA California Council is:

"Integrated Project Delivery (IPD) is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction. Integrated Project Delivery principles can be applied to a variety of contractual arrangements and Integrated Project Delivery teams will usually include members well beyond the basic triad of owner, designer and contractor. At a minimum, though, an integrated project includes tight collaboration between the owner, architect/engineers, and builders ultimately responsible for construction of the project, from early design through project handover."

In an IFOA contract the project team members manage and share the risk collectively, hence, promoting collaboration and efficient means of completing a project. Profitability is determined at the end of the job and all contract signatories share a pool of both risk and reward based on a predetermined percentage. Hence, each dollar saved through efficient means of delivery benefits the entire 11 members of the IFOA contract. (Christian et al. 2011)

When the current senior project manager joined the project in 2007 the plan had been to deliver the project under a more traditional tri-party IFOA with the owner, architect, and general contractor as the signatories. He believed getting more signatories only strengthens the collaborative process and prevents return to traditional relationships between the architect and its sub-consultants and similarly between the general contractor and its sub-contractors. He promoted and succeeded in expanding the painshare/gainshare scheme beyond the typical owner-architect-contractor tri-party to 11 signatories. He had to explain to each party that they could only profit from the project if the entire project profited as a whole. The contract signatories had to understand that even if they lowered their cost, where that cost reduction caused a bigger cost increase in another part of the project, they could lose money. (Post 2011)

The painshare/gainshare plan is quite simple. The profit is calculated by subtracting the actual cost of the project from the budgeted cost. The profit is then split between the non-Owner signatories as shown in Table 8. (Christian et al. 2011)

Table 8 Split Share of SMCCV IFOA Profit (Christian et al. 2011)

FIRM	SPLIT OF IFOA PROFIT POOL
DPR Construction	47.717 %
J.W. McClenahan	9.648 %
Morrow-Meadows	6.320 %
Superior Air Handling Co.	6.651 %
Transbay Fire Protection	1.863 %
Devenney Group Ltd.	17.163 %

Capital Engineering Consultants Inc.	3.755 %
The Engineering Enterprise	2.351 %
TMAD / Taylor and Gaines	2.625 %
Ghafari Associates	1.908 %

Post (2011) provides some further insight regarding the profit distribution:

"Under the Castro Valley IFOA, each non-Sutter signatory gets paid its costs based on audits. Sutter pays out 50% of the profit pool at agreed-upon project milestones. Designers typically receive profit earlier than contractors. Sutter pays the other 50% at completion, assuming it has not overspent the contingency fund. In that event, profits cover overage. If necessary, partners are required to return profit already dispensed. Any money left in the contingency fund is split 50-50 between Sutter and its partners, according to their share of risk."

3.1.4 TECHNOLOGY

Scope of Modeling

The IFOA members were required to provide their designs in a 3D object-based format. Ghafari Associates was responsible for the planning, coordination, workflows and technologies required to maintain alignment between the parties. Table 9 lists each member's scope of modeling and software used.

Table 9 Scope of Modeling and Software Used on the SMCCV Project (Eastman et al. 2011)

FIRM	ROLE	MODEL SCOPE	MODEL SOFTWARE
SAHCO	Design Assist Mechanical Subcontractor	Fabrication-level models of HVAC and Pneumatic Tube systems	AutoCAD CAD Duct
J.W. McMlenahan	Design Assist Plumbing Trade Contractor	Fabrication-level models of plumbing systems	AutoCAD CAD MEP
Transbay Fire Protection	Desing-Build Fire Protection Subcontractor	Fabrication-level models of Fire Protection systems	AutoSPRINK
Morrow-Meadows	Design Assist Electrical Subcontractor	Fabrication-level model of Electrical and Cable tray	AutoCAD CAD MEP
Capital Engineering Consultants	Mechanical and Plumbing Engineers	Design model for Mechanical and Plumbing systems	CAD Duct Design Line Auto CAD
TEE	Electrical Engineers	Design model for Electrical	AutoCAD
DPR Construction	General Contractor	Models of drywall, misc. supports and steel; Developing quantities and cost estimates from model	Revit, AutoCAD Architecture, Timberline Estimating, Innovaya Visual Estimating, StrucSoft Metal Wood Framer, Autodesk Design Review
TTG	Structural Engineer	Analysis and design model for Structure	ETABS Revit

ISAT	Seismic Support Contractor	Seismic support models	AutoCAD
Sparling			AutoCAD
ISEC	Casework Contractor	Casework models	Revit
Devenney Group	Architect	Architectural design models	Revit
Multiple Parties	N/A	Clash detection and coordination	Autodesk Design Review, Autodesk Navisworks Manage
Harris Salinas / Greg Luth	Rebar Trade and Rebar Detailer	Fabrication-level Rebar models	Tekla Structures 14
Herrick Steel	Structural Steel Subcontractor	Fabrication-level Structural steel models	Tekla Structures
Strategic Project Solutions	Software Supplier for Scheduling and Supply Chain	Last Planner System as well as system to manage the Process mapping process	Strategic Project Solutions Production Manager (not a model creation system)
Ghafari Associates	Process Consultant	BIM Coordination and Process mapping	Bentley ProjectWise Collaboration System (not a model creation system)

Owner Requirements

Sutter Health explicitly stated the project goals from the outset including the requirements for BIM. See Table 10 for SMCCV Project Goals from Christian et. al., 2011.

Table 10 SMCCV Project Goals (Christian et. al., 2011)

Introduction
A project is not considered successful by the owner unless it meets the owner's goals. Often these goals are unstated, not clear, vary with time, or vary with the individual. On this project this will not be the case. The goals will be explicitly stated in this document.

GOAL 1: Structural Design Completion
The first incremental package will be submitted to OSHPD for review no later than December 31, 2008.

GOAL 2: Project Cost
Total cost of the project shall not exceed $320,000,000.

GOAL 3: Project Completion
The replacement hospital shall open, fully complete and ready for business, no later than January 1, 2013.

GOAL 4: Healthcare Delivery Innovation

- Cellular concept of healthcare design to be utilized
- Control center concept to be utilized
- Electronic health record system implemented

GOAL 5: Environmental Stewardship
Meet any one of the following:

- The standards for certification on the SILVER level per LEED for Healthcare (draft version)
- The standards for certification on the SILVER level per LEED NC v2.2

- Achieve CERTIFIED level per LEED for Healthcare (final)
- Achieve CERTIFIED level per LEED NC v3.0

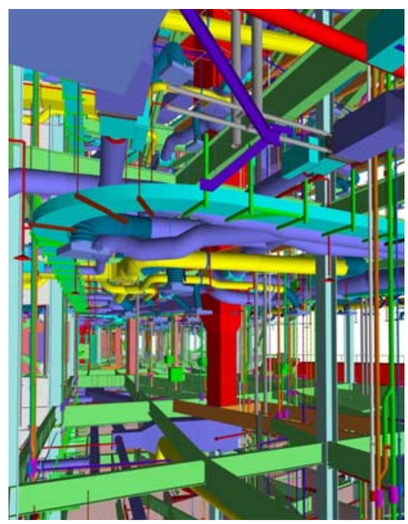
GOAL 6: Design & Construction Delivery Transformation

The building will significantly transform the delivery model for the design and construction of complex healthcare facilities:

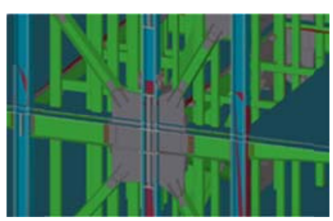
- Higher percentage of total budget under IFOA
- New incentive structure (gainshare/painshare)
- New method of defining project goals
- New methodology for the design process
- New methodology for planning and tracking commitments
- New methodology of active engagement with the state regulatory agency
- Far more extensive usage of BIM and virtual design and construction
- Use of target value design
- Sophisticated commissioning & operations and maintenance handover
- Energy modeling

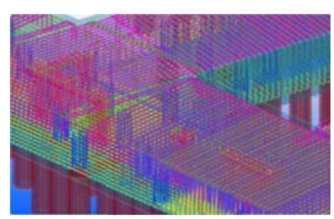
Level of BIM

The SMCCV project achieved a Level 4 model throughout most systems and components. The following are included in the model (see Figure 21):



- *Building interior*
- *Building exterior, curtain wall and pre-cast*
- *Stairs and elevators*
- *Structural steel and concrete*
- *Slabs and slab openings*
- *All mechanical and plumbing systems*
- *All electrical systems including conduit*
- *Fire protection*
- *IT and low voltage systems*
- *Nurse call systems*
- *Furniture*
- *Fixed medical equipment*
- *Rebar detailing*
- *Foundations*
- *All underground utilities*
- *Civil site*
- *All seismic restraints*
- *Drywall Framing*





The contract did not mandate the level of detail that should exist in the model. As the project was progressing, the team members constantly evaluated benefits versus effort required for adding further details to the model. If the anticipated benefits of increasing design certainty by adding further details to the model outweighed the cost of modeling, the design details were added. (Ghafari Associates, accessed on Oct. 2011)

Lamb et al. (2009) of DPR Construction provides an interesting example:

"When you have a patient lift, it has a track of three or four feet each that supports it. If you don't know exactly how many lifts or supports you need, you begin to guess. In a project that has very limited interstitial space, such as Sutter Medical Center Castro Valley, they had to incorporate the exact modeling for the supports, patient lifts and radiology (see Figure 22*)."*

Figure 22: Rendered Image of a Patient Room (SMCCV website, accessed on Oct. 2011)

By using the model, the shear wall and slab openings for risers, piping and ductwork were coordinated and included in the structural drawings that was submitted to OSHPD. The underground components were also modeled reasonably in detail to minimize potential conflicts. (see Figure 23). (Post 2011)

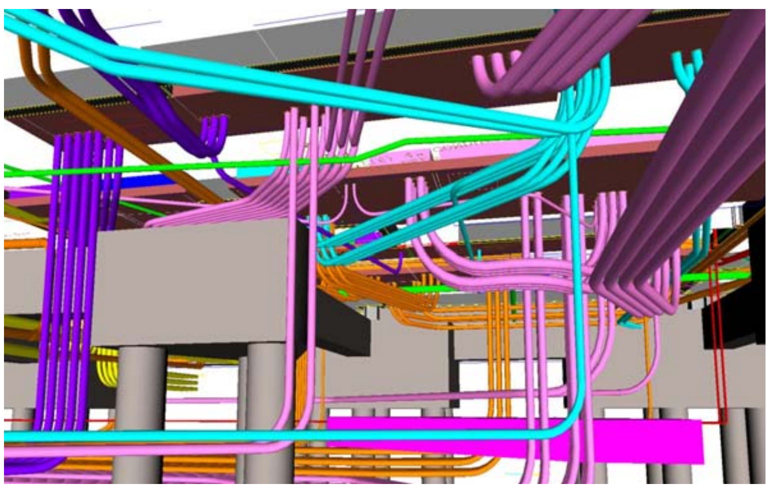


Figure 23: Underground Model (Ghafari Associates, accessed on Oct. 2011)

BIM Uses

Clash/Conflict Detection

NavisWorks was used to combine the models from the various parties into one multi-discipline model. The team was then able to review the entire design collectively and understand the interdependencies between disciplines. By using Navisworks multi-discipline design issues such as physical clashes were identified. Through collaboration the issues were either resolved on the spot or highlighted for future action dependent on the complexity of the issue and the availability of the parties. In a number of occasions, the team members were not sure what had changed since the last review process that had caused the conflict. In such occasions, a NavisWorks feature that color-codes the changes in each model from its previous version was used to identify the changed components. (See Figure 24) (Khemlani 2009)

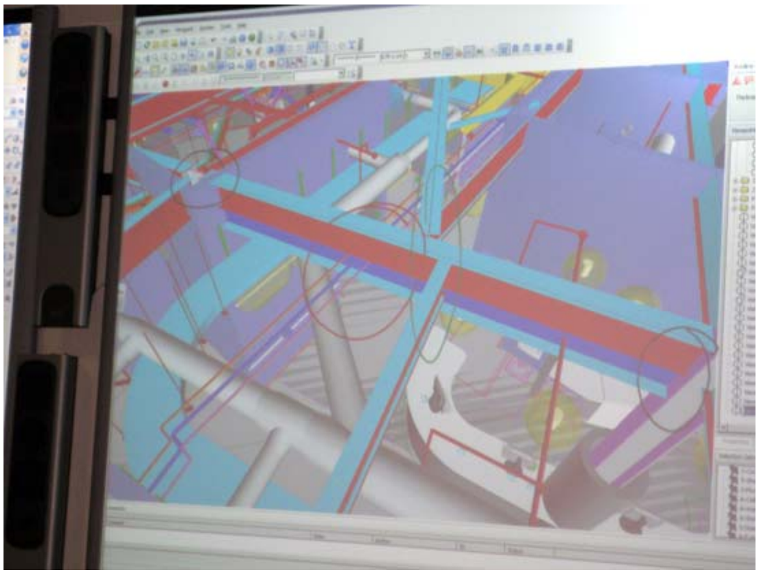


Figure 24: NavisWorks Capability to Highlight Design Changes since Last Review (Khemlani 2009)

Enhanced Constructability Reviews

Construction members of the general contractor and subcontractors review the multi-discipline model on an ongoing basis and have been able to identify and resolve hundreds of constructability issues without affecting site productivity. Through these constructability reviews, the team members have increased design certainty resulting in lowered construction risk at site. As a result, substantially lower field changes, request for information, and rework is achieved on the SMCCV project compared to similar projects with traditional delivery methods. For example, continuous constructability reviews were carried out on the interior walls and the team had to revise the wall detailing to ensure alignment and avoid installation conflicts with the MEP systems. (Christian et al. 2011)

Digital Information Exchange

It was decided from the outset to utilize as much 3D technologies as possible to eliminate risk and increase certainty in design. It was also very important to be able to seamlessly transfer the data/information from design to construction to eliminate duplication of work between project participants. The 3D model information was digitally exchanged from design to detailing to fabrication to construction on the SMCCV project. (Eastman et al. 2011)

Laser Scanning

Laser-scanning technologies are employed to uncover the discrepancies between the model and what is getting build on the field. Laser scanners are used to produce a 3D representation of the as-build building initially. The model is then superimposed on the scanned 3D representation to validate the as-build against the design layout as shown in Figure 25: Left: result from laser scanning. Right: Model superimposed on the laser scan to validate as-build accuracy (SMCCV website, accessed on Oct. 2011). By identifying the as-build discrepancies early on, the team was able to make minor adjustments to future components in advance of installation. The scanned data was also

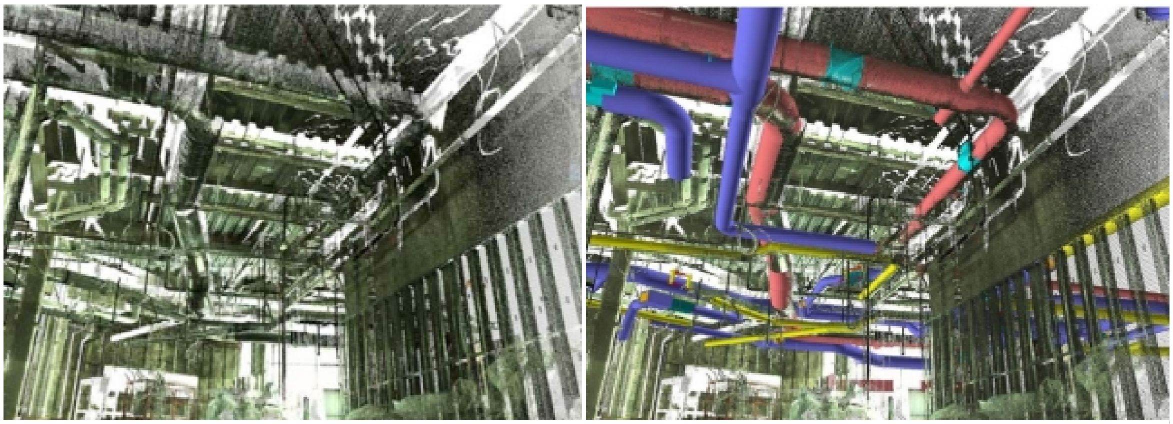


Figure 25: Left: result from laser scanning. Right: Model superimposed on the laser scan to validate as-build accuracy (SMCCV website, accessed on Oct. 2011)

Production of Reliable Paper Documents

The IFOA team strived to create a detailed multi-disciplinary, fully coordinated 3D model before production of paper documents. That way, the paper documents would benefit from high design certainly and require minimal rework. (Khemlani 2009)

Automated Code-Checking

As shown in Figure 26, Solibri Model Checker was used to perform automated code-checking for compliance with the building codes. Problems areas were identified early in the design which allowed the team to correct the design without major rework. It was recognized that even though this application is very useful and promising, there is still considerable amount of development required to make it practical and comprehensive. (Khemlani 2009)

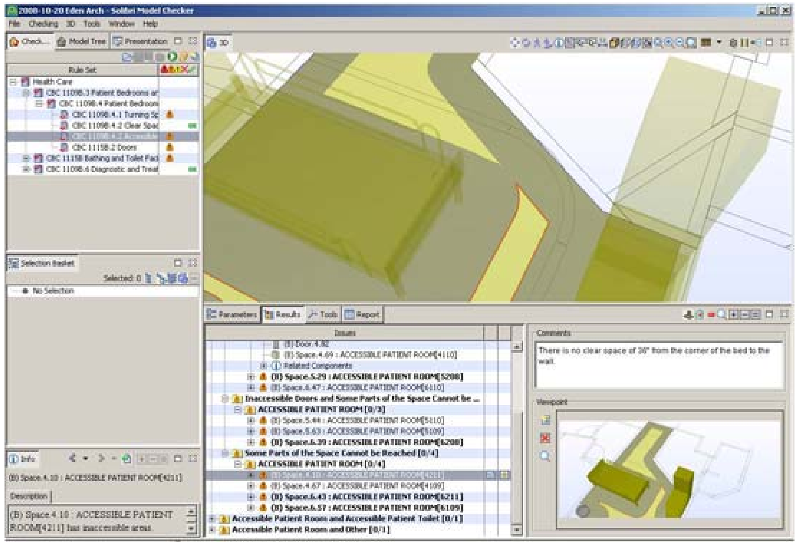


Figure 26: Checking the model for accessibility and other ADA code compliance using Solibri Model Checker (Khemlani 2009)

Automated Quantity Takeoffs

The team has been able to leverage on the reliability of the model to extract material quantities straight from the model frequently (see Figure 27). As the design evolves so does the accuracy of the automated quantity takeoffs, which keeps simplifying the estimating process. This information can be very useful for tracking quantity trends as the design evolves. (Khemlani 2009)

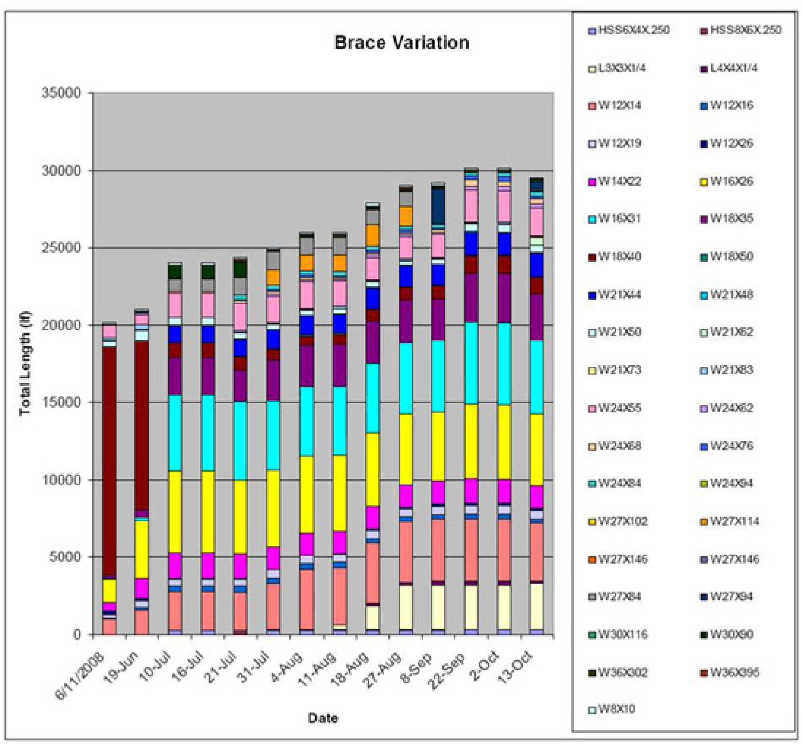


Figure 27: The quantity take-off and trending for structural bracing automatically derived from the model at different stages of the design (Khemlani 2009)

Model-based Cost Estimating

DPR Construction has developed significant expertise with model-based estimating with BIM and the SMCCV project is one of success stories. Although it took DPR several years to optimize this process and work through the issues, they are now reaping significant benefits reducing turnaround time on estimates from 8 weeks to as little as 2 weeks. The use of Target Value Design required the team to assess the cost of design frequently and model-based estimating proved instrumental for achieving that, although certain components could not be derived from the model. 3D model components had to be mapped to cost assemblies in the cost databases in order to generate automated cost estimates from the model. Figure 28 shows DPR's object parameters on the left side and the mapped cost assemblies created in Timberline on the right side. (Tiwari et al. 2009)

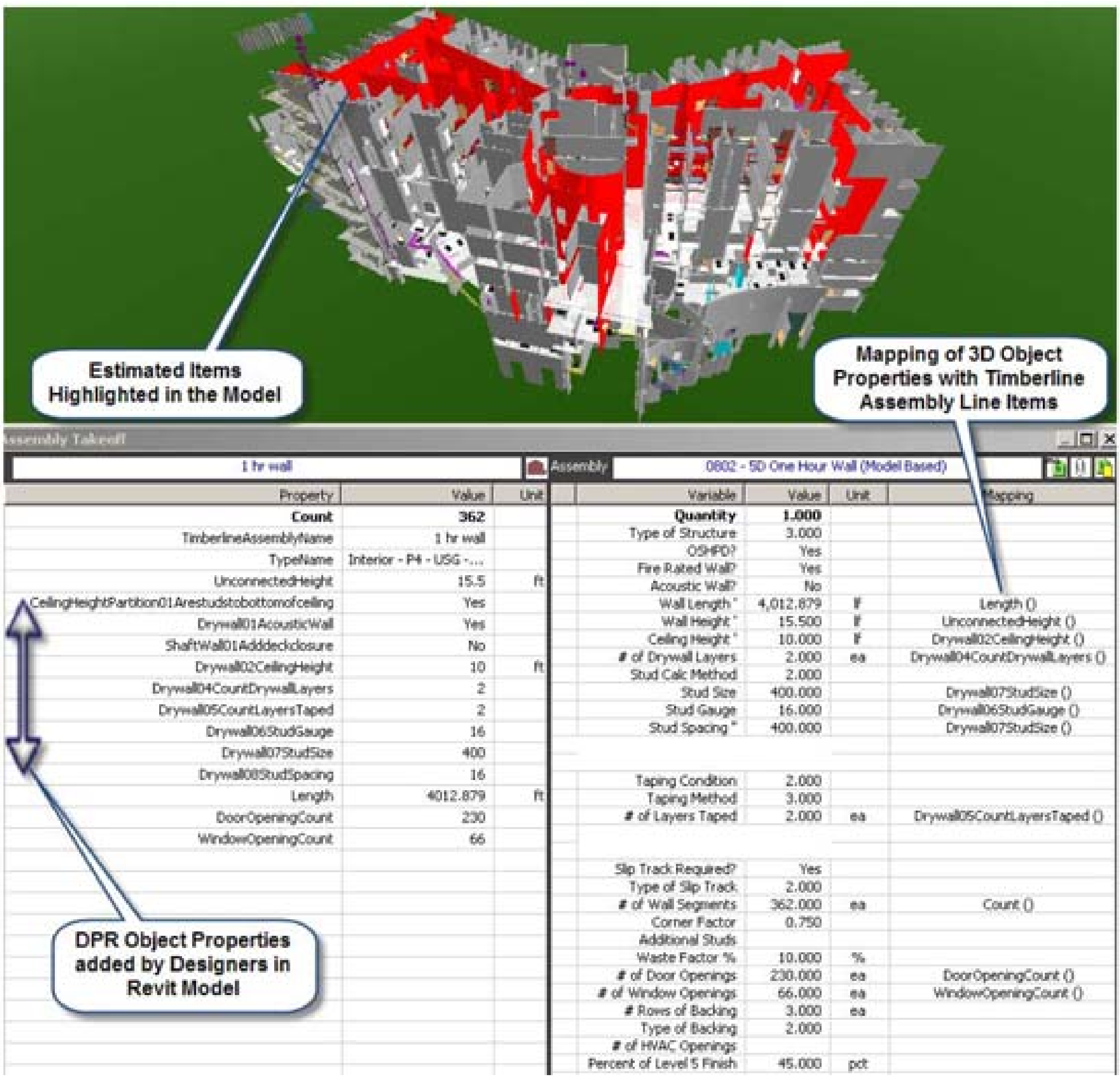


Figure 28: Mapping the 3D model to Cost Assembly in Timberline through Innovaya (Tiwari et al. 2009)

The team was able to produce a cost estimate every 2 weeks with considerably less effort. Further, by using model-based estimating the team was able to compare cost differences between design and construction alternatives, as show in Figure 29. (Tiwari et al. 2009)

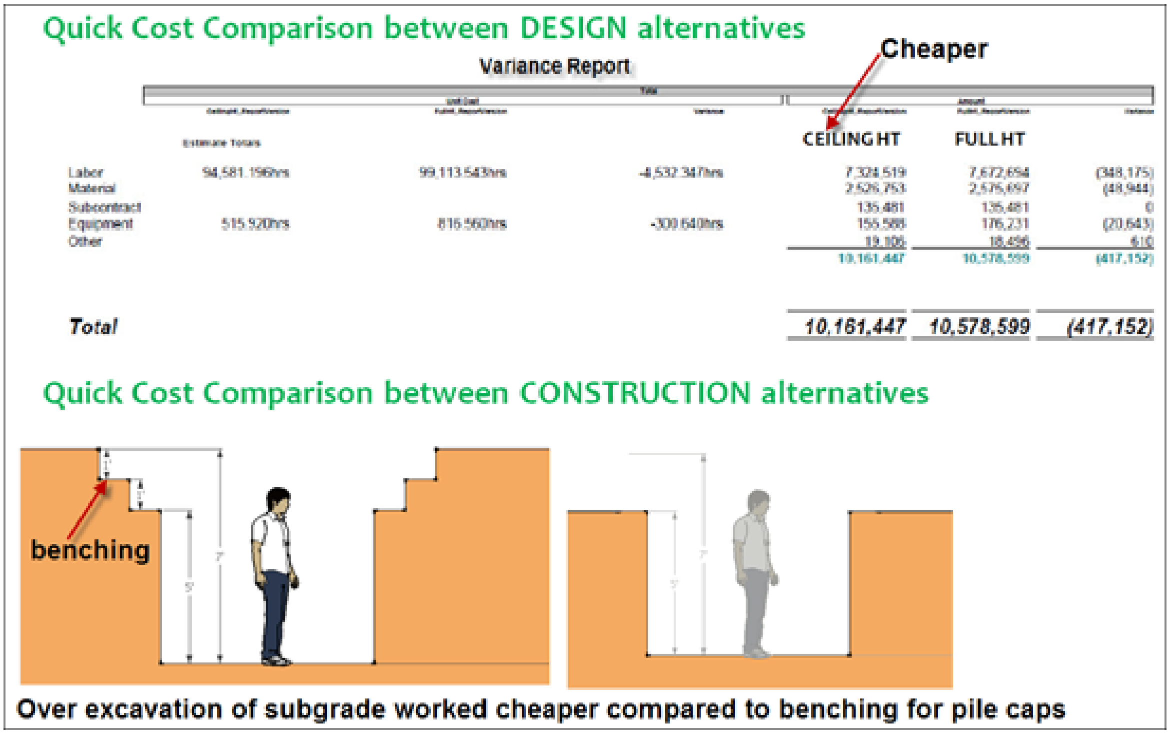


Figure 29: Cost comparison of design and construction alternatives (Tiwari et al. 2009)

Information Exchange

The SMCCV project members were located in multiple offices across the United States in various states. It quickly became apparent that in an IFOA delivery method where collaboration and information sharing is key, a method to allow the entire team members to have fast and real time access to project information was required. Portal solutions and cross office VPN solutions are not practical as considerable upload and download times are required that demotes collaboration and information sharing.

The team employed Bently ProjectWise for document control and model collaboration, which consists of eight gateway servers and two integration serves across the country (see Figure 30). ProjectWise allows each firm to keep and work on their files locally and automatically synchronizes the contents across all servers so every team member is able to have local access to all project information regardless of their location. (Ghafari Associates, accessed on Oct. 2011)

When a project team member needs to modify a document, that person is required to check-out the document prior to making the changes. In the meantime, other members are notified that the document is being worked on. Once the changes are complete, the document is checked back in and ProjecWise immediately updates all the servers with the modifications making them available to the remaining members. Further, ProjectWise transfers only the changes resulting in optimized synchronization time. (Ghafari Associates, accessed on Oct. 2011)

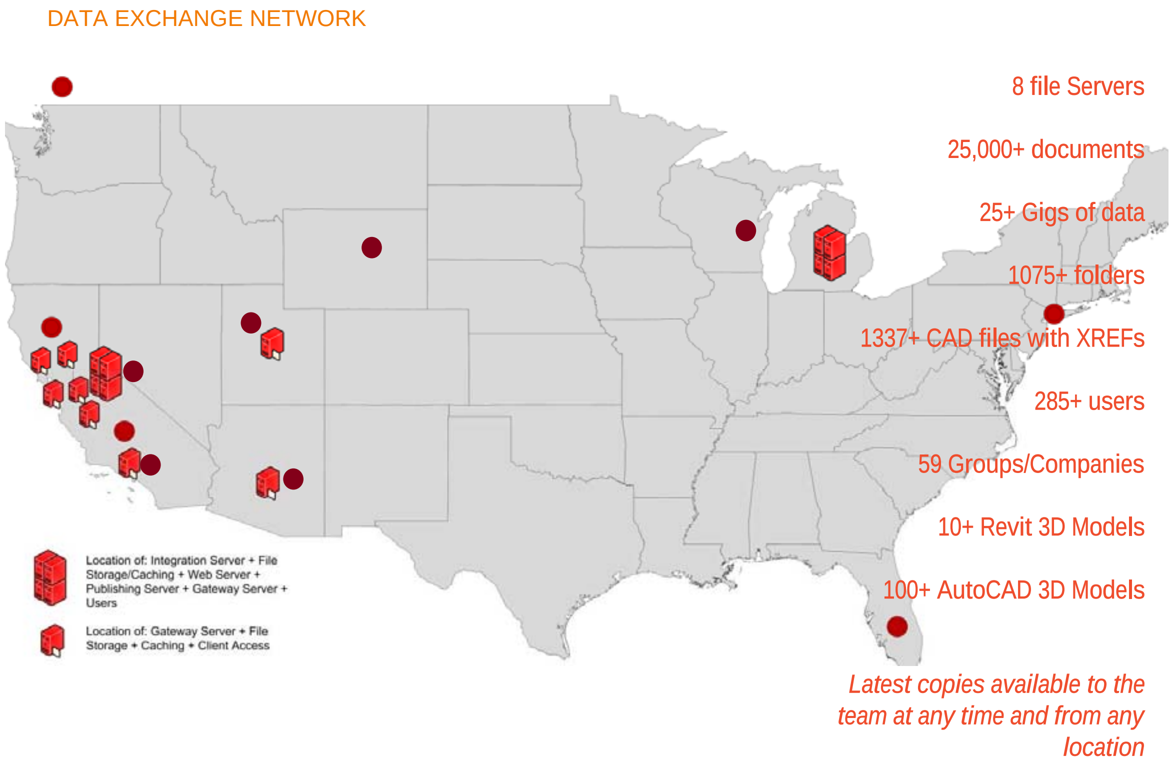


Figure 30: The Location of Model Servers (Ghafari Associates, accessed on Oct. 2011)

3.1.5 THE PROCESSES

Project Execution Planning

The project execution plan involved a number of key strategies as listed below: (Ghafari Associates, accessed on Oct. 2011)

1. ***"Project as laboratory:*** *to create opportunities to assess various evolving tools and technologies quickly and adopt what is appropriate to meet project goals. (Examples: Model based estimating, and automated code checking)*

2. ***Understand the process:*** *before starting design, the team will allocate adequate time to plan the design process. The IPD team used Value Stream Mapping, a lean tool, to map their workflow steps at appropriate levels of detail to have meaningful cross discipline discussions to identify value added steps and reduce rework loops.*

3. ***Manage by Commitments:*** *once flow of value is understood (via value stream mapping) members of the team make commitments to each other to complete the released activities and remove constraints to release downstream activities.*

4. ***Offsite fabrication and Preassembly:*** *designers work with the trade partners to make design decisions that lead to increased use of offsite fabrication and pre-assembly.*

5. ***Building Information Modeling:*** *the IPD team will use BIM to the extent possible to coordinate constantly, share information, and increase the reliability and certainty in the design so it can be directly used for fabrication and pre-assembly.*

6. ***Direct Digital Exchange:*** *information will be reused rather than recreated to the extent possible through model based estimating, detailing, coordination, automated fabrication, and scheduling.*

7. ***Real-time Access to Information:*** *all team members will be able to access project information at any time and regardless of where this information is created or stored."*

A notable action taken by the project team was to delay the start of design in order to provide more time to the Owner to finalize the clinical program. Delaying the start of design on a project, that has schedule as a major constraint, might seem counterintuitive. However by delaying the start of design the team achieved the following two key advantages: 1) an understanding of what exactly the owner wants (to a practical extent), and 2) a thorough understanding of the design process and workflow.

While waiting for the Owner to finalize the clinical program, the team work continuously on understanding the design process to shorten the overall duration. The team members worked diligently on Value Stream Mapping which provided them with a visual representation of the design interdependencies. Once the interdependencies were understood, value-adding and waste-reducing exercises were performed to make the design process as efficient as possible. Remarkably, the team was able to reduce the design process by 8 month. (Alarcon 2011)

Workflows

Alarcon et al. (2011) provide some insight on how the team managed the workflows and hand-offs:

"Recognizing that risks would manifest themselves in the course of design, the team created design workflows and did so in a highly visual and explicit way. Development of the design workflow engaged the entire team. They presented their work in an easy-to-digest format for the purpose of soliciting constructive debate about what it would actually take to complete design in a way that increases certainty and minimizes risk. This process helped the team buy into the process and practical conversation of "Is this really what is going to happen?," "Is that really what you are going to do?," "Is that enough time to do it?," "Is it really going to take that long?," as well as "Why are you doing that?," "Why do you need that?, etc. Christian's (Sutter's PM) instinct is that without that, the team would not have been successful."

The above process is referred to as Value Stream Mapping where all steps of a workflow are shown and the purpose is to find value and to reduce risk/waste from the perspective of the customer (see Figure 31). Attention is given to understand the prerequisites for commencement of each task and subsequent tasks that are dependent on the completion of each task at hand. Interdependencies for completing the design is well understood this way, and commitments are made between parties to allow release of downstream tasks. As the design evolves so does the plan. The team reviews the plan on a regular basis and as more information becomes available, tasks get added, modified, or removed from the process.

Figure 31: Examples of Value Stream Mapping at different stages of the design process (Khemlani 2009)

The goal was to design and acquire design approval faster and with more certainty. Value Steam Mapping compressed the design to an efficient process. OSHPD's Phased Plan Review (PPR) process was used to achieve similar compression in the approval process. The SMCCV project is one of the first that used PPR for accelerating the permitting process. (Ghafari Associates, accessed on Oct. 2011)

Alarcon et al. (2011) provide further insight on the Phased Plan Review process:

"A traditional design plan includes schematic design, design development, design detailing, and production of construction documents and final deliverables. However, this tends to create cycles of rework and miscommunication that make the overall duration longer.

In contrast, the Phased Plan Review (PPR) process does not follow the same logic. The PPR requires a deeper and more thorough understanding of interdependencies in order to allow 100% complete documentation with minimal rework. Each step in the design process must be analyzed, in order to understand what is being produced and how it is affecting what other specialists are producing. This detail makes it possible to sequence decision making in a way that directly supports the PPR. The *breakdown of interdisciplinary work and decisions in the process were analyzed in detail with all the decision makers. This provided insight in all the hidden dependencies and the team could identify and plan for them in advance in order to assure that all aspects involving each decision would be accounted for in time.*

The design planning process started with identifying what design decisions—if changed later—would generate large amounts of design rework. This led to a non- traditional sequencing of design decisions, which were rolled up into a series of major design-deliverable milestones, each major design-deliverable having a detailed list of what the specific sub-deliverables would be. This allowed for an in-depth discussion on what inputs would be necessary at each point and what outputs were expected from each activity for each flow of work for each detailed sub-deliverable.

This process was supported using Building Information Modeling (BIM) technology. 3D models served as powerful visual aids to the team while discussing inputs and outputs, and evaluating where each trade partner could get involved. It is important to note that no actual trade drawings were produced yet at that time. The model enabled to 'walk through' decisions about locations of shafts, major routings through the hospital, etc., before going into the specific design details for any discipline. This primary coordination effort allowed to transition into construction with a certainty for approval and minimal rework."

Information Exchange Processes

The IFOA delivery method requires extensive collaboration and information exchange among project participants. The Big Room concept and managing by commitment approach were key information exchange processes on the SMCCV project.

The Big Room Concept

The project team members were distributed in various locations mostly across the United States. With roughly over 240 project participants, the idea of relocating the entire team into one location for the project duration was impractical and costly. An effective method was hence needed to be able to gather the entire team periodically for information sharing.

The entire team gathers in the Big Room (see Figure 32) once every two weeks for 3 days. These sessions are intended to give the project team the chance to collectively review the design, assess the project schedule and cost, and optimize the workflow through Value Stream Mapping. Further, the MEP team meets in the Big Room on a weekly basis and goes through the detailed models for a closer coordination of the design. Those who cannot attend the meeting in person are able to connect remotely using the GoToMeeting collaboration application. (Ghafari Associates, accessed on Oct. 2011) (Khemlani 2009)

Figure 32: The Big Room allowing the entire team to collocate (Ghafari Associates, accessed on Oct. 2011)

A successful Big Room would benefit from the following key elements: (Ghafari Associates, accessed on Oct. 2011)

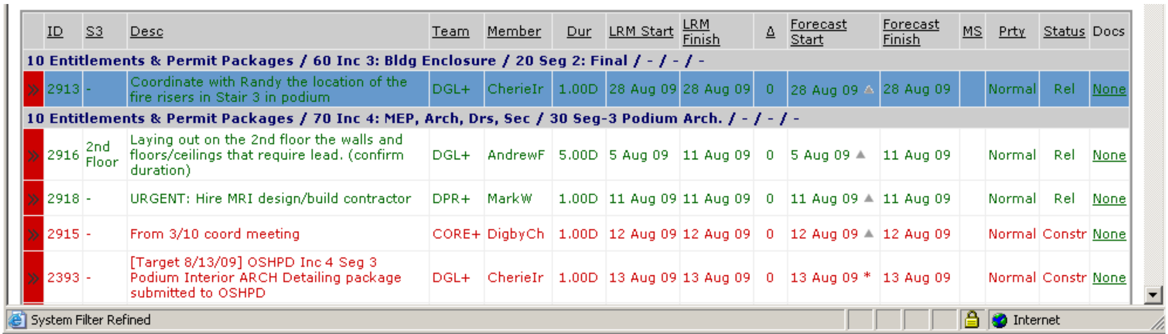
- *"Large configurable meeting space to allow 30+ peoples to work comfortably.*
- *A mix of hardwired and wireless networking solution (wireless did not work well for a large team).*
- *Space for planning the process (big wall) with enough room for 30+ people to stand and work)*
- *Space for planning the design (wall sized marker board) that can be used for both planning and sketching design ideas.*
- *Smartboard(s) – two or more to project the 3D model, plans, schedule, and be able to share them remotely with other team members.*
- *Planning tables so small teams can focus on refining their plans.*
- *Small team meeting rooms."*

Managing by Commitments

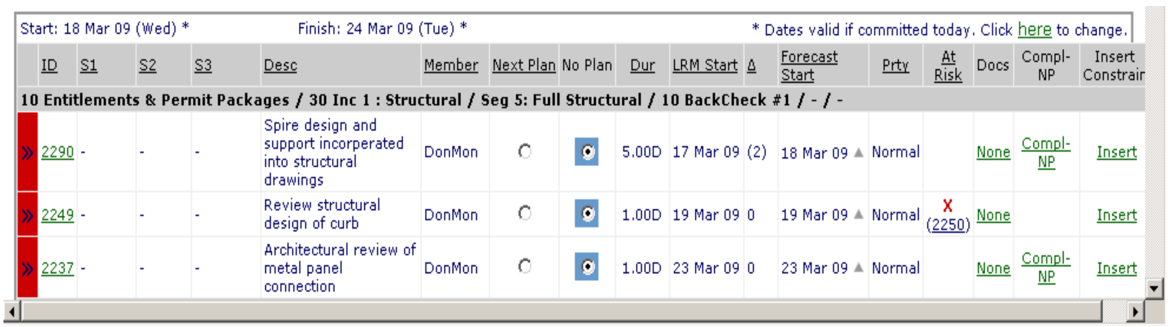
Unlike traditional practice where schedule is tracked based on high-level milestones, this project tracks performance at the task level based on the plan from Value Stream Mapping. A series of tasks in turn lead to a milestone and incase the forecast date of a milestone is affected, the team needs to review the Value Stream Mapping to achieve the original plan.

During the planning meetings in the Big Room, team members publicly commit to complete a set of specific tasks based on project priority before the next meeting. If completion of other tasks has constrained them in their progress, they discuss the issue in front of the team and collectively agree on a path forward to release the constraint. The team members then work on tasks with no constraints and strive to complete as many as possible within the period between the two meetings. This way, the design progresses with more certainly towards completion. At the next meeting, team members again publicly announce the status of their committed tasks to the project team. In case a committed task is not complete, a cause must be provided to the team explaining what impeded the progress.

After evaluating a number of commitment management software, the team selected SPS Production Manager to record, track, and update the project's commitments. See Figure 33 for a sample report from SPS Production Manager. (Ghafari Associates, accessed on Oct. 2011)



ID	S3	Desc	Team	Member	Dur	LRM Start	LRM Finish	Δ	Forecast Start	Forecast Finish	MS	Prty	Status	Docs
10 Entitlements & Permit Packages / 60 Inc 3: Bldg Enclosure / 20 Seg 2: Final / - / - / -														
2913	-	Coordinate with Randy the location of the fire risers in Stair 3 in podium	DGL+	CherieIr	1.00D	28 Aug 09	28 Aug 09	0	28 Aug 09	28 Aug 09		Normal	Rel	None
10 Entitlements & Permit Packages / 70 Inc 4: MEP, Arch, Drs, Sec / 30 Seg-3 Podium Arch. / - / - / -														
2916	2nd Floor	Laying out on the 2nd floor the walls and floors/ceilings that require lead. (confirm duration)	DGL+	AndrewF	5.00D	5 Aug 09	11 Aug 09	0	5 Aug 09	11 Aug 09		Normal	Rel	None
2918	-	URGENT: Hire MRI design/build contractor	DPR+	MarkW	1.00D	11 Aug 09	11 Aug 09	0	11 Aug 09	11 Aug 09		Normal	Rel	None
2915	-	From 3/10 coord meeting	CORE+	DigbyCh	1.00D	12 Aug 09	12 Aug 09	0	12 Aug 09	12 Aug 09		Normal	Constr	None
2393	-	[Target 8/13/09] OSHPD Inc 4 Seg 3 Podium Interior ARCH Detailing package submitted to OSHPD	DGL+	CherieIr	1.00D	13 Aug 09	13 Aug 09	0	13 Aug 09 *	13 Aug 09		Normal	Constr	None



Start: 18 Mar 09 (Wed) * Finish: 24 Mar 09 (Tue) * * Dates valid if committed today. Click here to change.

ID	S1	S2	S3	Desc	Member	Next Plan	No Plan	Dur	LRM Start	Δ	Forecast Start	Prty	At Risk	Docs	Compl-NP	Insert Constrair
10 Entitlements & Permit Packages / 30 Inc 1 : Structural / Seg 5: Full Structural / 10 BackCheck #1 / - / -																
2290	-	-	-	Spire design and support incorperated into structural drawings	DonMon			5.00D	17 Mar 09	(2)	18 Mar 09	Normal		None	Compl-NP	Insert
2249	-	-	-	Review structural design of curb	DonMon			1.00D	19 Mar 09	0	19 Mar 09	Normal	X (2250)	None		Insert
2237	-	-	-	Architectural review of metal panel connection	DonMon			1.00D	23 Mar 09	0	23 Mar 09	Normal		None	Compl-NP	Insert

Figure 33: SPS Production Manager for Commitment Management (Ghafari Associates, accessed on Oct. 2011)

Information Exchange – Interoperability

Direct Digital Exchange is one of SMCCV's key execution strategies. The intent is to reuse the information rather than recreate to limit duplication of work. However this is more challenging than one would imagine as each firm uses their preferred software and content are seldom easily transferable between various software.

The project team members were well aware of such interoperability issues from previous project experiences. They worked hard early in the project to understand the preferred modeling software and set the groundwork early to minimize future interoperability issues. For example, the mechanical, electrical and plumbing subcontractors were planning to use CAD Duct and CAD MEP, which would not have worked seamlessly with the consulting engineers' software of choice. Consequently, the consulting engineers switched to a software that was more interoperable with the subcontractors' software. (Lamb et al. 2009)

Ghafari Associates (2011), Tekla (2011), and Tiwari et al. (2009) describe, as provided below, three further examples of interoperability on the SMCCV project and explain how they were tackled.

Mechanical/Plumbing (source: Ghafari Associates website, accessed on Oct. 2011)

"The Mechanical/Plumbing team set an aggressive goal from themselves to design, detail, estimate, coordinate, and fabricate their systems directly in the 3D model with as little use of 2D drawings as possible.

The design team and the trade partners used the same software from TSI to design and detail the M/P components. This software has two modules one for use during design called MAP Design Line and the other typically used by the detailers called MAP CAD Duct for sheet metal & CAD Pipe for plumbing detailing and fabrication. This created an opportunity for using a complete digital and model based workflow from design to fabrication. Unfortunately there was no successful implementations to learn from as most teams that had tried to use this workflow in the past failed and abandoned this for a more traditional workflow.

Determined to make this work, key members of the design team and the detailing team collocated for almost an entire week at the offices of TSI, the software vendor, in Austin, TX working with their technical team to align the setups, software libraries, and configuration options so that the design models can be directly imported by the detailers, worked on, and then converted back to simplified design models. The goal was to use the best features of the design modules to do early routing and calculations, then have the detailers immediately apply fabrication logic to the route then have the design team incorporate that input onto the final drawings without having to recreate models or drawings.

This template is now serving as template and being implemented for other parts of the model and the design including shared responsibility for completing the design and detailing of the drywall and exterior elements between the architectural design team and the trade partners.

The next challenge for the M/P team is to implement automated quantity takeoffs and automated estimating to the extent possible. There are software limitations that the team is working to resolve with TSI as well as established estimated practices that are difficult to change."

Structural Steel (source: Tekla website, accessed on Oct. 2011)

"For rebar coordination, MEP wall sleeves were imported from the MEP modeling software into Tekla, and 50-60 2D DWG files were imported to create the exterior skin fabrication model. Tekla's ability to import 2D profiles from curtain wall manufacturers was used to create, for example, detailed mullion clips and door frames in 3D. The model created from these 2D drawings was compared with an IFC model of the architect's Revit model using Tekla. CADuct, AutoCAD MEP, and Revit software were all used to interface or exchange data with Tekla in this project.

On top of the main contract for the structural steel, general contractor DPR asked Herrick Corporation to model all the elements in the building skin system that connected to the structural steel, to assist in coordinating the various trades.

The company worked with Candraft, a steel detailing company based in Vancouver, Canada, to develop a Tekla toolkit to be used both within Herrick and by their subcontractors. The aim was to produce a single, standardized model that was information-rich and in a format that was accessible to all members of the project team. The toolkit includes standard reports, drawing templates, API interfaces for RFI creation and management, visualization tools, etc. It has since been used successfully on other projects and has become an integral part of Herrick's approach to many jobs.

Much of the toolkit was developed using Tekla Open APITM tools. To enable the project team to rely entirely on electronic approval, Herrick and Candraft created a 3D model-only approval interface for use by the Engineer of Record, TMAD. At various times during construction, the project team imported TMAD's Revit structure, Candraft's Tekla model, and models from various sub-trades. Drawings were only extracted from the fabrication model after it was approved."

Model-based Estimating (Tiwari et al. 2009)

"For the SMCCV project, the first step was a sanity check to identify components that were modeled incorrectly for estimating purposes (either the quantities were inaccurate or the elements were not broken down they way they are constructed). Next, the list of identified components was provided to the architects and structural engineers, who then incorporated those changes incrementally in the model over the span of two months. The list also included some parameters that needed to be added to the objects to automate the mapping process with the cost assemblies due to the limitations of the modeling software (Revit). For example, ceiling height information was added as a shared parameter to a wall, because it was needed to quantify the wall surface area that was required for finish taping.

On the SMCCV project, implementation of model-based cost estimating has been successful at different levels for different trades. The extent of usage of 3D modeling for cost estimating and quantification for different trades at SMCCV is described below and illustrated in Figure 34:

- ***Architectural and Structural:*** *Modeled in Revit and successfully estimated using Innovaya.*
- ***Fire Protection:*** *No compatible model-based estimating tool available in the market to integrate with AutoSprink, which is the software used for modeling.*
- ***Electrical:*** *Even though the model is created in AutoCAD MEP, Innovaya cannot be used for estimating because the cost database is not in Timberline or MC2. In this case, cost quantities are being driven out of the model.*
- ***Structural Steel:*** *Tocoman is being explored as an option for linking the Tekla model to the Timberline cost database.*
- ***Mechanical and Plumbing**: CADEst is the preferred model-based estimating tool for CADDuct/CADPipe, since they are developed by the same company. However, the Mechanical/Plumbing subcontractors have not yet replaced their existing estimating software (QuickPen, Accubid) with CADEst. (Some of the reasons are mentioned in the next section.) As a result, cost quantities from the model are being done manually."*

Trades	3D Model Tool	Current Model based Cost Estimating Tool	Model based Cost Estimating Tool *(Exploring)*
Architectural	Revit Architecture	Innovaya/Timberline	
Structural	Revit Structure/Tekla	Innovaya/Timberline	Tocoman (for Tekla)
Mechanical	CAD-Duct	None	CAD Est
Electrical	AutoCAD MEP	None	Innovaya
Plumbing	CAD-Pipe	None	CADEst
Fire Protection	AutoSprink	None	None

Figure 34: The software being used for 3D modeling and model-based cost estimating (Tiwari et al. 2009)

3.1.6 EVALUATION

Benefits

It is challenging to quantify the benefits of a project delivery method. This is because every project is a unique undertaking characterized by its scope, participants, location and other factors. It is difficult then to predict what the outcome would have been given a different project delivery method.

Nonetheless, a project could be compared to similar type and size projects for drawing some quantitative conclusions.

The following summarizes some of the schedule benefits to the project:

- With progress at seventy percent completion, the project is forecasted to be on budget and six weeks ahead of the original schedule. (Post 2011)
- Sutter finalized the Clinical Space Program and the LEED Goals in April 2008. The First Patient Day milestone has since improved by six weeks from January 1, 2013 to November 15, 2012. (Christian et al. 2011)
- The design was completed in 15.5 months and the construction commenced on schedule. (Lamb et al. 2009)
- The design period for the structural systems was reduced from an expected 15 months to 8 months. The design was also delivered with better quality as significantly more information from other disciplines was inputted. (Khemlani 2009)
- The OSHPD structural review process took considerably less time when compared with similar projects. It only took 11.5 months between the start of the structural review and construction commencement. Further all deadlines of the project review plan were achieved. (Alarcon 2011)
- The OSHPD normally takes about 24 months for review from the time of design completion for such facility; the Phased Review Process unique to SMCCV allowed construction to commence almost 12 months earlier than conventional practice. (Christian et al. 2011)

The original design and review process for the SMCCV project is shown in Figure 35.

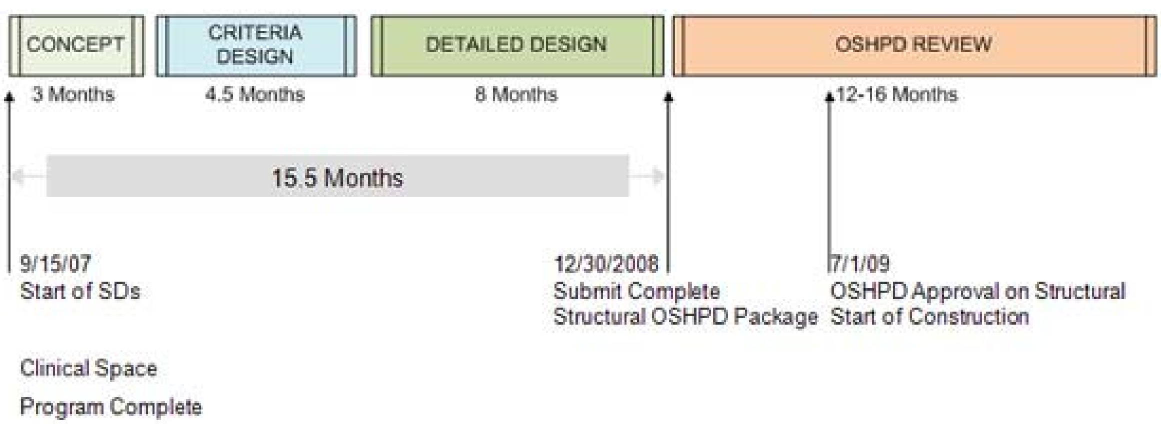


Figure 35: The design and OSHPD review schedule originally planned for the SMCCV project (Khemlani 2009)

The following summarizes some of the cost benefits to the project:

- As the design progressed not only the estimated cost of the project did not increase, but also it was reduced by more than $20 million to achieve the Target Cost value of $320 million. Figure 36 illustrates how the cost was reduced over the design life. (Lamb et al. 2009)

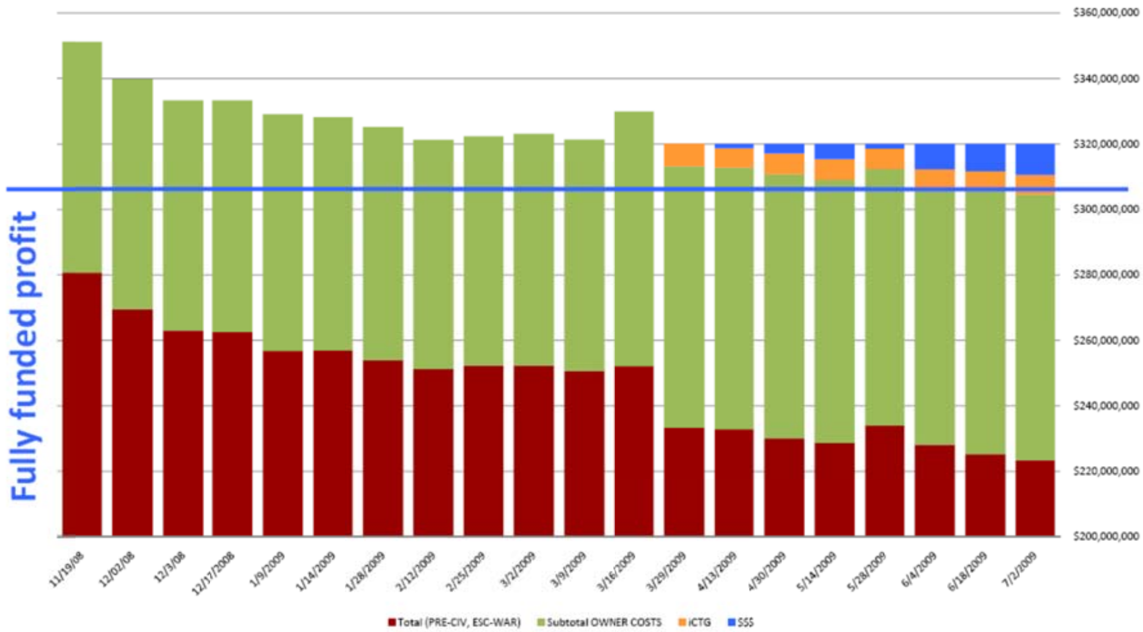


Figure 36: Project cost decreased as design progressed to achieve the Target Cost (Ghafari Associates, accessed on Oct. 2011)

- $2.2 million of the $5.8 million contingency fund is still available with most of the project bought and construction nearing turnover. (Post 2011)
- The steel package was completed $1.5 million under budget. This was accomplished by the fabricator's involvement in the BIM process that resulted in better connection details and conflict resolution ahead of time. (Post 2011)
- The start of the detailed design phase was delayed until there was more certainty in the input parameters such as the Clinical Space Program. The shortened design process saved $1.2 million in design labor. (Post 2011)
- Model Based Estimating enabled the project team to generate an updated project cost once every two weeks. Significant time and cost savings were realized as it only took two days to generate an updated project cost. This process was approximately 80 percent more efficient than traditional estimating effort due to automatic quantity takeoffs and automated mapping between the model objects and cost assemblies. (Tiwari et al. 2009)

Further, construction productivity has increased anywhere between 6% to 28%, while rework has decreased between 50% to 95%. Table 11 and Table 12 respectively present productivity and rework gains per discipline. (Christian et al. 2011)

Table 11 Increase in Construction Productivity (Christian et al. 2011)

DISCIPLINE	BASELINE	PLANNED	ACTUAL	PROJECTED
Mechanical	100%	105%	116%	120%
Plumbing	100%	100%	104%	106%
Electrical	100%	114%	110%	114%
Framing	100%	122%	125%	128%

Table 12 Reduction in Rate of Rework (Christian et al. 2011)

DISCIPLINE	BASELINE	ACTUAL
Mechanical	7%	0.5%
Plumbing	10%	0.5%
Electrical	10%	5.0%
Framing	5%	0.5%

The following are further benefits achieved on the SMCCV project:

- 10% increase in construction productivity during embed layouts. (Tekla website, accessed on Oct. 2011)
- An average variation of only 0.5% (-1.3% to +2.7%) in the floor areas of the ten major clinical functions since construction start. (Christian et al. 2011)
- An installed product that closely matches the model (see Figure 37 and Figure 38): (Christian et al. 2011)
    - mechanical 99%
    - plumbing 99%
    - electrical 71%
    - framing 79%

Figure 37: Photo-match of 3D Model to Construction Progress - Feb. 2010 (Ghafari Associates, accessed on Oct. 2011)

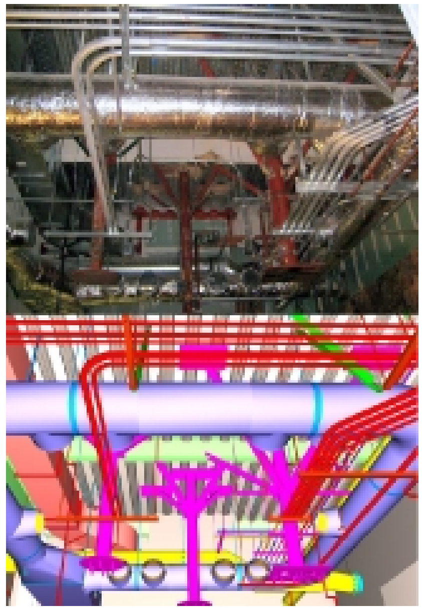


Figure 38: Comparison between a Model Shot and As-Build (SMCCV website, accessed on Oct. 2011)

- Approximately 90% less Request For Information (RFI) and owner-initiated change orders. At one time during the construction there were 333 RFIs and 26 change orders when the norm is 3,000 and 400 respectively for a similar conventionally built project. (Post 2011)

Challenges

It is by no means easy to setup and manage an IFOA or IPD project. The conventional practice promotes each participant to analyze the project in isolation and only for its own benefits. This is reinventing the wheel in the sense that most traditional mindsets have to be changed and change does not come easy. It requires sophisticated and forward-thinking companies to be willing to truly join forces for mutual goals of benefitting the project. The processes of IFOA and IPD are heavily front-loaded with setting up systems, planning, and aligning goals only to realize the benefits down the road, later in the project. The following highlights typical challenges that one might face in implementing a project such as SMCCV:

- Costly and lengthy negotiation process for finalizing a mutually agreeable contract.
- It is often counter-intuitive for participants to understand and accept a cost increase in their portion of work in aims of benefiting the entire project.
- Frequent multi-discipline design reviews instead of reviews at key design milestones. (Ghafari Associates, accessed on Oct. 2011)
- Lack of interoperability between many of the used software (i.e. design and estimating software) (Ghafari Associates, accessed on Oct. 2011)
- Common project directory that is live and accessible by all project participants.
- Software and hardware limitations. For example, the architectural team had to split their model twice as the software would run out of memory due to model complexity. (Ghafari Associates, accessed on Oct. 2011)
- Setting up model-based estimating is a lengthy process. It took over three months of effort from architects, engineers, estimators, and BIM engineers to automate the process on the SMCCV project. (Tiwari et al. 2009)

Tiwari et al. (2009) elaborate on the challenges of model-based estimating as follows:

> *The challenges of model-based estimating go beyond finding appropriate software solutions. To transition from manual estimating processes to a model-based estimating process takes substantial effort, time and cost. In our experience, the easier part is the purchase of new programs and transferring the estimating database from one source to another. The more difficult part is the cultural shift and training required. Estimators must be thoroughly trained in the software and run test cases to make sure that the information coming out of the model is accurate and can be trusted. At first, the model-based estimating process may also take more time than their traditional way of estimating. However, after time and greater proficiency using the software, the new method should take less time than the older method, achieving results like the SMCCV project.*

Tiwari et al. (2009) further explain where model-based estimating falls short of producing an accurate estimate:

- *The element is not in the 3D model (e.g., temporary shoring).*
- *The element is part of the cost assembly related to a modeled component that cannot be determined by examining physical attributes. For example, the quantities of construction joints cannot be calculated from any property of slab on grade (i.e., perimeter, area, etc.). Its quantification depends on how the slab on grade is broken down into different pours.*
- *The model is not intelligent enough to give a desired quantity. For example, the length of a concrete wall against slab on grade will provide the length of the expansion joint, but currently this information cannot be quantified from the model, because the model does not know there is a wall adjacent to the slab on grade.*
- *Model-based estimating does not work when the cost is a function of time and not the 3D element. For example, construction trailers, temporary power, equipment, etc., are dependent on the duration of multiple construction activities and the project as a whole.*

Lessons Learned

The SMCCV is an unprecedented eleven-partner IPD process. Naturally there are many lessons to be learned from this project. These lessons would cover such topics as contract initiation, legal considerations, level of BIM, uses of model, information infrastructure, software interoperability, and project execution strategy. Even though the project is not completed yet, a number of these lessons have already surfaced, as listed below.

- Strive to become partners with organizations you know and have trust in. (Post 2011)
- Be prepared for lengthy contract negotiations. (Post 2011)
- Be prepared for a culture change and expect to share information otherwise considered private. (Post 2011)
- It is beneficial to have an experienced consulting firm with sole responsibilities of managing the process, ensuring efficient information exchange (including access and interoperability), and advising on proper lean and BIM practices. (Khemlani 2009)
- It is vital to be able to provide solutions or make decisions in a timely fashion. With many stakeholders involved making quick decisions might become challenging. It is therefore recommended to create a decision-making process to involve only the participants with the particular expertise. (Lamb et al. 2009)
- Communicate very early on how the process will work, what performance measures will be used, what will be the expectations, what will be the expected challenges and what will define success as a project. (Lamb et al. 2009)

- Plan and re-plan (again and again) at every step of the project. (Christian et al. 2011)
- Better communication is paramount. The importance of face-to-face meetings cannot be over emphasized. Even though today's advanced technologies allow for real-time meeting applications and video conferencing, they cannot be compared with the efficiencies gained through personal and real interactions. (Khemlani 2009)
- The project would benefit from presence of more tradespeople during the design process. (Post 2011)
- The designers should be encouraged to share incomplete solutions. That way, earlier feedback is acquired from the IPD team which in turn reduces the amount of rework. (Ghafari Associates, accessed on Oct. 2011)
- No design change should be considered as minor. A design change that seems minor to one discipline might create a ripple effect that impacts the project significantly. Instead of the traditional design-then-check methodology a more proactive design approach should be employed where even minor changes are communicated to the team and the best cross discipline solution is selected for moving forward. (Ghafari Associates, accessed on Oct. 2011)
- It is far more costly to resolve conflicts in field than to model and recognize the conflicts early on. Careful consideration must then be given to the level of detail in the model. It might well worth the effort to model the next level of detail if it would prevent a number of field conflicts. (Post 2011)

The SMCCV project has taken model-based estimating to an extent not previously achieved in any other project. Tiwari et al. (2009) provide a number of lessons learned relating to model-based estimating as listed below.

- ***Senior Company Management buy-in of model-based cost estimating:*** *If the senior company management sees the value in the model-based cost estimating process and endorses it, it is much easier to implement within the company. This is one of the major reasons why some of the trades are still generating traditional estimates as there is still resistance to move away from traditional estimating practices.*
- ***Contractual language of the project to support collaborative work environment:*** *Compared to non-IPD projects, it has been easier to work with designers and get requests of model modifications entertained because of the IFOA contractual setting. The IFOA leverages a collaborative work environment by providing incentives, such as a common pool of profit.*
- ***Not all cost estimates can be model-based:*** *Some of the items in the estimate cannot be quantified or formulated from the existing 3D elements in the model. Items like construction joints in slabs are means and method items, which need to be manually quantified. Also, there are time-based cost elements (e.g., man lifts, temporary power, trailers, etc.), which are estimated by how long they are on the jobsite and cannot be easily quantified from the 3D model.*
- ***Transitioning traditional estimates to model-based estimates:*** *A visual record in the form of marked up drawings of what was a part of the hand takeoff is important to have, so that quantities can be compared easily with the model quantities.*
- ***A new software tool does not always perform the way you expect it to:*** *Implementation of new technology is not always successful the first time. A lot of collaboration with the software developer is required to make it work to give you the desired result.*
- ***Always check the quantities from the model at least once:*** *Some of the elements might have been modeled using a tool that does not give you the right quantities. In case of SMCCV project, there were irregular shared pile caps whose quantities were not read correctly. Taking another example, Revit gives you the flexibility of modeling certain elements in different ways but quantification does not work with all of them. For example, openings can*

be modeled using an "edit profile" tool or "opening tool" or an "opening family" or a "void extrusion." The only way openings get quantified is if they are modeled using opening tool or by using the opening family.

- ***Model-based cost estimating is not a click of a button process****: As you may have grasped by now, there is a lot of pre-requisite work in preparing the cost assemblies, preparing the model, training the estimators, etc. All of these steps are required to make this process work successfully.*
- ***Start the process early by the end of conceptual design phase:*** *The earlier the teams start this process in the preconstruction phase, the more in sync the model will be for cost estimating, and the more time design will have in the design development phase to react to the regular cost updates to attain Target Value Design.*

Finally, Christian et al. (2011) provide the following lesson learned:

> *Perhaps the greatest lesson learned that is transferable to future projects is this: integrated project delivery, Lean practices, and BIM are all most effective when intertwined into a single process and when they are implemented together as an entire package. Bringing together modelers, builders, architects, engineers and trades people as true partners, who share in the profit and loss of a project's outcome, has the most potential for success; it offers the promise not only of maximizing the profitability of an individual company, but of changing the entire industry by creating better projects that are ultimately more efficient and more cost effective.*

Sutter Health will apply the lessons learned from Castro Valley on their next project already underway. The 250,000 square feet Patient Care Pavilion for the Alta Bates Summit Medical Center, Alta Bates, California, is expected for Phase 1 completion by 2014. This project has twelve partners, five of which are from the SMCCV project including DPR Construction and Devenney Group Ltd. (Post 2011).

3.1.7 BIBLIOGRAPHY

"About Sutter Medical Center Castro Valley." *Sutter Health Eden Medical Center*. Sutter Health, n.d. Web. 26 Oct 2011. <http://suttermedicalcentercastrovalley.org/>.

"Devenney Group Profile." Devenney Group, n.d. Web. 26 Oct 2011. <http://www.devenneygroup .com/>.

"Ghafari Firm." Ghafari Associates, n.d. Web. 26 Oct 2011. <http://www.ghafari.com/content.cfm /firm>.

"Integrated Project Delivery - A Working Definition." AIA California Council. 2007. Print.

"Sutter Medical Center Castro Valley, USA." Tekla, 2011. Web. 17 Oct 2011. <http://www.tekla.com/us/solutions/references/Pages/sutter-medical-center-USA.aspx>.

Alarcon, Isabel, Christian, Digby and Tommelein, Iris D.. "Collaborating with a Permitting Agency to Deliver a Healthcare Project: Case Study of the Sutter Medical Center Castro Valley (SMCCV)." *19th Annual Conference of the International Group for Lean Construction IGLC 19*. Lima, Peru, 2011. 13-15. Web. 22 Oct. 2011. <http://p2sl.berkeley.edu/2011-06-

23/Alarcon&Christian&Tommelein 2011-IGLC Case study of the Sutter Medical Center Castro Valley SMCCV .pdf>.

Christian, Digby, George Hurley, James Mobley, and Zach Sargent. "Sutter Medical Center Castro Valley: The Real Risks and Rewards of IPD." *ASHE 48th Annual Conference and Technical Exhibition* . 2011. Print. <http://www.hfmadv.org/uploads/2011 ASHE Seattle Annual Conference/The Real Risks of IPD.pdf>.

DPR Construction, 2010. "The Four Levels of BIM: Taking Virtual Design and Construction to a Higher Level." Web. 24 Oct 2011. <http://dpr-review.com/fall-winter-2010/story/the-four-levels-of-bim>.

Eastman, Chuck, Paul Teicholz, Rafael Sacks, and Kathleen Liston. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, and Contractors*. 2nd ed. Hoboken, New Jersey, USA: John Wiley & Sons, Inc., 2011. 431-80. Print.

Emdanat, Samir. "Sutter Medical Center Castro Valley: IPD Process Innovation with Building Information Modeling." Ghafari Associates, n.d. Web. 16 Oct 2011. <http://www.placevision.net/AIA_TAP/SutterMedCNTRValley.pdf>.

Ghafari Associates, “Sutter Medical Center Castro Valley: IPD Process Innovation with Building Information Modeling” (Ghafari Associates, accessed on Oct. 2011)

Khemlani, Lachmi. "Sutter Medical Center Castro Valley: Case Study of an IPD Project." 06 Mar 2009. 1-11. *AECbytes.* Web. 22 Oct 2011.

Lamb, Eric, Dean Reed, and Atul Khanzode. "Transcending the BIM Hype: How to Make Sense and Dollars from Building Information Modeling." 22 Sep 2009. 1-8. *AECbytes*. Web. 22 Oct 2011.

Post, Nadine M. "An Unprecedented 11 Partners Propel Integrated Project Delivery at Sutter's New California Hospital." 19 Sep 2011. 1-4. *Engineering News-Record*. Web. 19 Oct 2011.

Tiwari, Saurabh, Josh Odelson, Alan Watt, and Atul Khanzode. "Model Based Estimating to Inform Target Value Design." 12 Aug 2009. 1-12. *AECbytes*. Web. 15 Oct 2011.

3.2 UNIVERSITY OF COLORADO-DENVER, RESEARCH 2 (R2) (UNITED STATES)

This project was selected as an International BIM project to highlight for several reasons:

- It is one of the few projects that have tried to measure the benefits of BIM when compared to a very similar project recently built using a traditional delivery approach.
- It demonstrates the uses of BIM through all the project phases, starting with design, through field construction, and into operations.
- It provides excellent applications of BIM for construction uses and demonstrates the impact on field productivity.
- Significant benefits, including improved productivity, increased Pre-fabrication, less rework, increased coordination, reduction in RFI's/CO's, completed ahead of schedule and under budget.

3.2.1 PROJECT DESCRIPTION

University of Colorado-Denver Health Science Center Research 2 (RC2) (Figure 39) is an 11 story, 540,000 square foot biomedical research facility located in Aurora, Colorado on the UCDHSC Anschutz Medical Campus. Guaranteed Maximum Price (GMP) construction cost was $201 million (US dollars). Planned project duration was 32 months but the project was completed two months ahead of schedule.

Figure 39: RC 2 Project during construction (left) and snapshots from the construction model (right) (Image from Cunz, 2010)

The RC2 project was built using an integrated Virtual Design and Construction (VDC) process. VDC is a collaborative process incorporating both design and construction input through the use of Building Information Models (BIM), CPM schedules and cost estimates to create a virtual building prototype prior to construction (Mortenson, 2009). The construction of the RC2 project by Mortenson Construction follows the completion of the similar RC1 project by another company employing a non-integrated VDC approach. The RC2 project is an interesting case study, because it allows for comparative analysis of integrated VDC (RC2) with non-integrated VDC (RC1). One such study by an independent research student from the University of Colorado shows the substantial reduction in the number of RFIs and change orders on RC2 when compared to RC1. The study also shows a significant reduction in mechanical sub-trade schedule duration and required labour on RC2 (Mortenson, 2009).

The list below summarizes the project participants and their contribution to the BIM (Mortenson, 2011):

- **Fentress Bradburn Architects Inc.** – 3D Design Model
- **Martin & Martin Structural Engineers** – 3D Structural Design Model
- **Mortenson Construction** - CM At Risk and the General Contractor
    - Architectural 3D Construction Model
    - 4D Visualization Schedule
    - Concrete Placement Documents
    - 3D MEP Clash Detection
- **Sturgeon Electric Company** – 3D Electrical Construction Model
- **Western States Fire Protection** – 3D Fire Protection Piping Model
- **U.S. Engineering** – 3D Mechanical Duct and Piping Construction Model
- **Cives Steel Company** – 3D Steel Fabrication Model

3.2.2 TECHNOLOGY

Technology Used

The project team used a number of software that best met the needs of the different project participants. The software used by each discipline is presented in Figure 40.

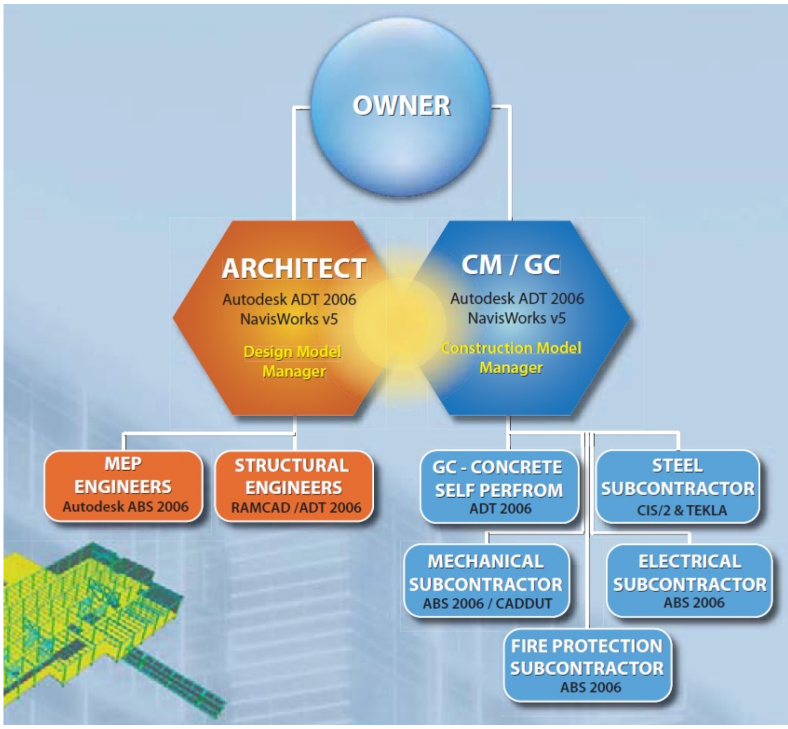


Figure 40: The software used by the project team (Mortenson, 2009)

Below is a list of software packages used by each project team member (Mortenson, 2009):

Autodesk ADT 2006 was used by the architect (Design Model Manager) and GM/GC (Construction Model Manager). Mortenson Construction (GC) self performed the concrete work for the project and used ADT 2006 for creating concrete placement documents.

Autodesk ABS 2006 was used by the MEP engineers, the electrical subcontractor and the fire protection subcontractor.

RAMCAD/ ADT 2006 were used by the structural engineers.

CIS/2 & Tekla were used by the steel subcontractor.

ABS 2006/ CADDUCT were used by the mechanical subcontractor.

Navisworks JetStream allowed the model manager to combine models from all disciplines and find collisions between various systems, which might otherwise have gone unnoticed using traditional coordination methods (Mortenson, 2009). Mortenson used **NavisWorks Timeliner** for 4D visualization of schedule and **NavisWorks Clash Detective and Publisher** for 3D design MEP clash detection.

ReadClash was used for better visualization of data produced by JetStream. By using ReadClash, the conflicts that were found using Navisworks JetStream were easily located within AutoCad environment, which was the native software used by the project designers (Mortenson, 2009).

Software vendors are coming up with new and improved versions almost every year. The GC compares the technology used during the project to the current state-of-the-art (Mortenson, 2009, p.5): *"Because this commitment [implementation of a collaboration based process] was made in 2003, some of the BIM tools utilized by the team were truly pushing the capabilities of the available technology and are less sophisticated than tools we use today."*

Further, Mortenson deployed their in-house collaboration solution for information sharing and exchange.

Scope of Modeling

This section explains the scope of the BIM effort, focusing on what was modeled in the RC2 project.

Design model: the architect managed the consultants in the creation of the BIM and acted as the design model manager. The architect's model provided 3D design information for the exterior skin and the interior architecture. The consultants' models provided 3D design information for their respective disciplines. The design models provided the design intent that was then transferred to the construction team (Mortenson, 2009).

Construction model: the architect performed early 3D coordination using Navisworks JetStream followed by the GC (Mortenson Construction) who performed the 3D coordination process of MEP and Fire Protection systems by compiling a composite 3D model of the various MEP systems prior to fabrication and installation. The GC also added important structural and architectural elements to the model to increase its accuracy and usability for construction coordination. The Project Scheduler from Mortenson used Navisworks Timeliner to simulate the construction process (i.e. to create a 4D-model) (Mortenson, 2009). Further, the ReadClash and Navisworks JetStream applications allowed each subcontractor to use their native AutoCad plug-in software to generate accurate, coordinated 3D MEP models, which were then passed to CNC machinery for fabrication.

Incorporation of Facility Management's (FM) requirements: engagement of the owner's facility management team throughout the 3D MEP coordination process helped to ensure all MEP/FP systems would easily be accessible for future maintenance purposes (Mortenson, 2009).

Level of BIM

When evaluated according to DPR's four levels of BIM, the RC2 project could be considered as a level four BIM for the key disciplines involved during construction. A level four BIM project, as described by DPR: *integrates substantially more stakeholders into the process from the early design stage to provide input and review, test the constructability, and determine the best materials and methods for design and construction, in accordance with the project's budget, schedule and quality. Level 4 BIM results in the creation of a model that incorporates such fine details as seismic and gravity hangers, metal framing systems, and detailed models of components like rebar. These models can be used to produce permit documents and shop drawings, pull material quantities, produce accurate model‐based estimates, perform cross‐trade prefabrication, and produce actual installation drawings.*

Uses of Models

The 3D models in the RC2 project were used for design, construction and for facilities management purposes. The main uses of the 3D models in RC2 project are provided below.

Early Project Cost and Schedule Analyses

Mortenson (GC) used the architect's model for early project cost and schedule analysis shortly after their involvement in the project.

Model Based Coordination

Model based coordination was used to avoid clashes between building systems. Design models from the consultants were converted to construction models. While the architect was the design model manager, Mortenson became the construction model manager and led and managed the 3D MEP coordination efforts on RC2.

Constructability studies

Constructability studies were facilitated by using the 3D models and the 4D construction simulations (Figure 41). The 4D simulations were also used in the pre-planning coordination meetings to avoid field conflicts between subcontractors scheduled to work in adjacent areas. Early engagement of GC and 3D and 4D studies helped to resolve constructability issues well in advance of the actual construction activities.

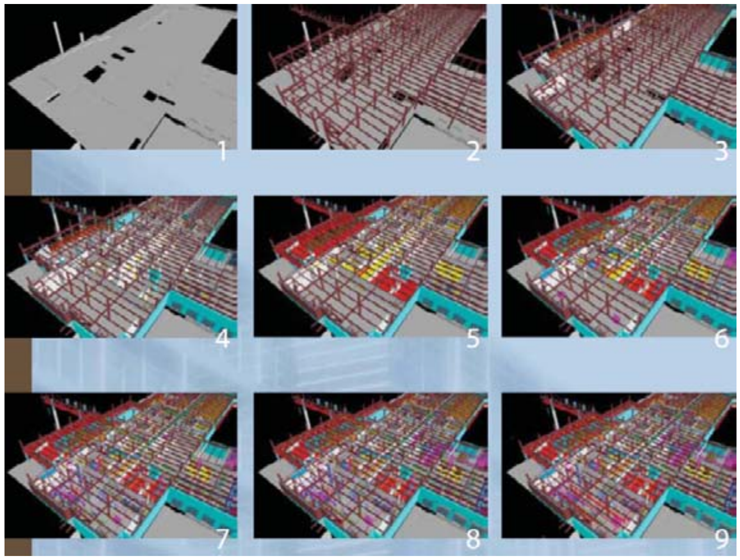


Figure 41: Early engagement of GC helped to resolve constructability issues well in advance of the actual construction activities. (Mortenson, 2009)

Model Based Fabrication

Models created for 3D coordination of MEP and Fire Protection systems were used to facilitate fabrication (Figure 42). Mortenson, by utilizing AutoCAD Architecture and Navisworks, was able to streamline the handoffs between design and fabrication. (Autodesk, 2009).

Figure 42: A coordinated composite 3D model of the various MEP systems resulted in high degree of fabrication accuracy and simplified error free installation (Mortenson, 2009).

Shop Drawings

Steel design and fabrication were coordinated by using the designers' and fabricator's models. The structural steel analysis model from the engineer was exported and used by the steel detailer/fabricator. The fabricator added details to the engineer's model. The 3D steel fabrication model was then integrated with the models from other disciplines for coordination purposes. The fabrication model was used to develop structural steel shop drawings (Figure 43). The structural steel was fabricated off-site and delivered as per the project steel erection schedule (Mortenson, 2009). Mortenson's VDC Subcontractor Exhibit was utilized which requires construction models as part of the shop drawing process for the concrete, steel structure, drywall, and MEP trades.

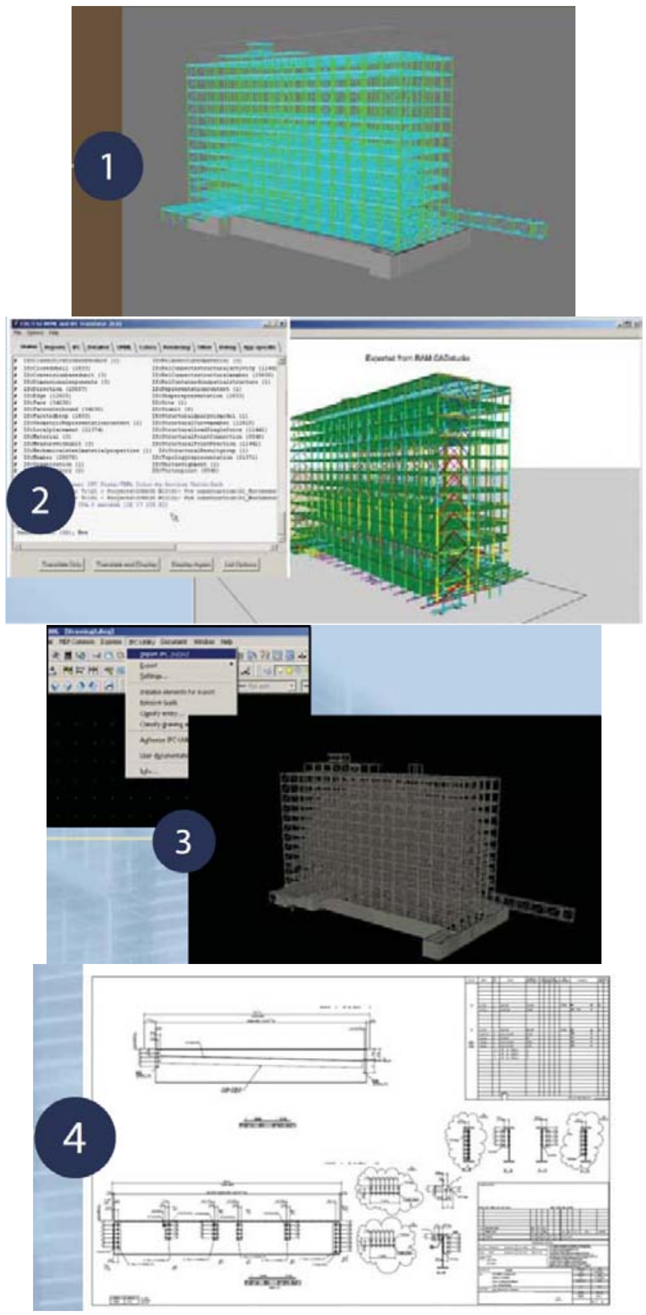


Figure 43: Creation of steel shop drawings: 1) structural steel analysis model, 2-3) steel detailer/fabricator model, 4) structural steel shop drawings (Mortenson, 2009)

Assembly instructions

Concrete work was self-performed by the general contractor and assembly drawings were generated from the models. The process began with a base 3D building model (Figure 44.1 and Figure 44.2), and subsequent layers of information, such as embeds and MEP sleeves, were added (Figure 44.3). The construction team reviewed the quality of the data with all related disciplines. The composite 3D model (Figure 44.4) was distilled and translated into installation drawings (Figure 44.5) for use by the concrete crew. The information provided was an accurate, single-source set of instructions that eliminated the risk of using incomplete or uncoordinated drawings (Mortenson, 2009).

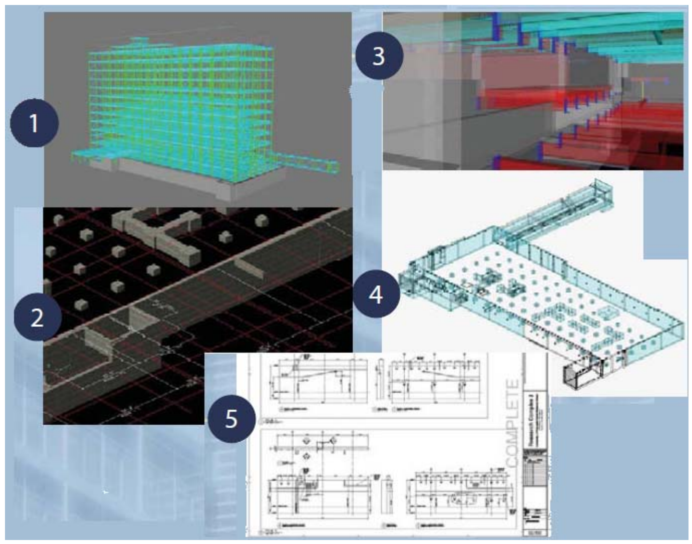


Figure 44: Creation of assembly instructions for concrete construction (Mortenson, 2009, images modified)

4D Simulation

4D simulations of the construction process were created by linking the CPM schedule to the BIM (Figure 45). The team was then able to easily visualize the schedule that provided opportunity to optimize the construction plan. The CM used a multi layered approach to scheduling, which involved studying different installation scenarios, communicating the results to the subcontractors and tracking material procurement and delivery, which was enabled by 4D simulation.

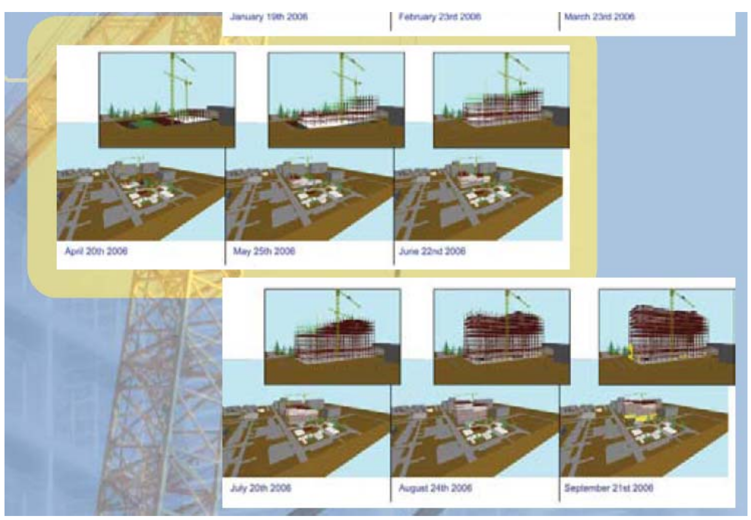


Figure 45: 4D visualization enabled instantaneous feedback on the schedule (Mortenson, 2009)

RFI Submission

RFI submissions were done with 2D/3D media attachments derived from BIM, providing quick and exact explanations of the issues (Mortenson, 2009).

Facility Management

The owner's facility management team received construction model CAD files representing 90% of the as built conditions to use for management of the facility (Figure 46). A Navisworks model with hyperlinks to an Excel equipment list was also provided to the facility management team (Mortenson, 2009).

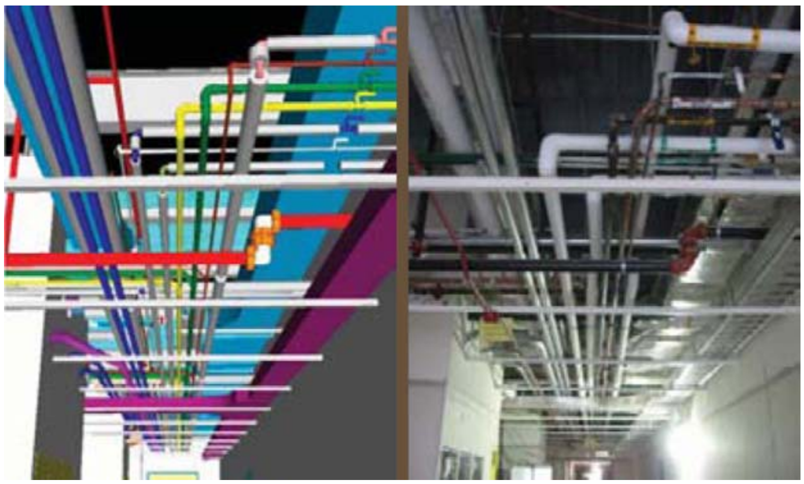


Figure 46: MEP Coordination and field verification by Mortenson resulted in an as-built facility that is very close to as-planned. (Mortenson 2009)

3.2.3 THE PROCESSES

The VDC process and BIM increased the effectiveness of the RC2 project team's collaboration and communication. The Owner defined the collaborative process as "*a process that demands self-less execution* (Mortenson, 2009, p. 3)."

Project Execution Planning

The planning process was incremental and evolved according to the level of detail required by the project team. For example, collision detection was initially done on smaller sections of the project, then on larger zones and floors, and finally on the entire project (Mortenson, 2009). Complex areas that required extensive analyses and coordination were modeled in greater detail. As the Architect explains: "*the most complex portion of the project was the interstitial mechanical level above a subterranean vivarium. The contractor expended the design model to include every trade and every service element. Meetings between the design and construction team often included members of the client's facilities group to assure access and maintenance issues* (Figure 47) *were suitably addressed* (Mortenson, 2009, p. 4)." 4D scheduling helped the contractor to plan the execution of the construction processes by providing the opportunity to study the installation scenarios, communicating the results to the subcontractors and tracking material procurement and delivery.

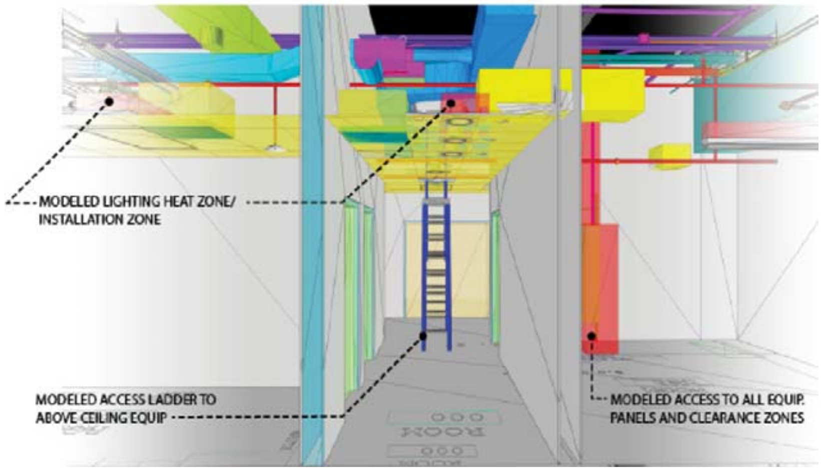


Figure 47: Owner facility management team integration in design for coordinating access/maintenance requirements (Voss and Rumpf, 2010).

Workflows

The RC2 project team needed to establish well-structured protocols and workflows for the successful implementation of the VDC process. Data interoperability, seamless exchange of information, clear division of tasks and responsibilities among project team members were some of the high priority tasks. In order to provide a seamless exchange of information between project participants, the project team produced specific strategies and execution plans. Early on the project, the team agreed on specific criteria for developing the different models to ensure interoperability in the future.

Multiple coordination sessions were held between the design members and the construction subcontractors, each time using the 3D model as the primary tool for understanding and resolving conflicts (Mortenson, 2009, p. 4).

Transferring the Model

The bid documents were issued in 2D but the 3D design model accompanied each bid package. The contractor and the primary subcontractors made the model their own and used the design team's updated models to update their own (Mortenson, 2009, p. 4).

The design team delivered the "design BIM" to the contractor at the end of the design phase and the contractor became the steward of the new "construction BIM". Sets of 2D drawings or "assembly instructions" for various phases and disciplines of construction were ultimately derived from the construction BIM (Mortenson, 2009).

Information Exchange Process and Protocols

In order to provide a seamless information transfer between project participants, the project team produced specific strategies and execution plans: "*…the team quickly agreed on a 'language' that the electronic design files would speak. Common layering strategies, coordinated base points, and an* *open model sharing philosophy were determined to be critical for proper collision detection and reporting* (Mortenson, 2009, p. 5)"

Since integrated VDC was not included in the R2 contract and this approach was new to the project team, the team had to address model ownership issues for liability reasons. Mortenson verified the accuracy of the designers' model for constructability issues and then took ownership of the model when construction documents were complete (Young, Jones, Bernstein, & Gudgel, 2009, p. 10). Cunz, Vice President of Mortenson, explains the model ownership as follows: "*model ownership was consistent with traditional 'paper' practices in that the design team owned the design model and the construction team and trade contractors owned the means and methods model similar to shop drawings.*"

3.2.4 EVALUATION

The following sections provide some benefits, challenges and lessons learned from implementing BIM on the R2 project.

Benefits

Early detection of problems: the architectural firm realized many benefits in the RC2 project. The Architect expressed the experience as follows: "*previously unforeseen problems occurred in the model and on the viewing screen rather than in physical conflicts. The overall project construction schedule was substantially foreshortened because of minimized conflicts, shared data, and the ability to study sequence issues in the model. And a true sense of collaboration was developed between all participants – design team members, contractor and subs, client and ultimate users, and the facilities personnel who operate and maintain the project* (Mortenson, 2009, p. 3)."

Successful project execution: the successful use of BIM as a planning tool allowed the construction team to increase productivity and enhance communication among the project team (Mortenson, 2009). The 3D process "*guaranteed the plan to be accurate and the work uninterrupted, allowing the field to have very predictable safety, quality and schedule*", recalls the GC superintendent (Mortenson, 2009, p. 11).

Reduction in RFI response time: the submission with 2D/3D media attachments derived from BIM resulted in reduction in RFI response time. It also eliminated trial-and-error in the field. Further, this resulted in increased pride in the work by the subcontractors, who were included in the resolution process of the RFIs (Mortenson, 2009). The resulting reduction in RFI and change order administration costs offset the cost of BIM/VDC.

Better schedule management: The 4D simulation was a key component in visually communicating the aggressive CPM schedule. By leveraging on VDC, particularly 4D simulation, the construction team completed the RC2 project two months early and six months faster than the similar RC1 project.

Increased subcontractor efficiency: the subcontractors increased their efficiency as a result of the VDC implementation. The electrical subcontractor had the least amount of rework they have ever observed on the field. Further, the mechanical subcontractor estimated a 50 percent reduction in both labour and schedule (Mortenson, 2009, p. 12).

Coordination with FM personnel: the initial coordination work of the MEP/FP systems with the owner's facilities team resulted in the complete elimination of field changes related to improving or increasing access for maintenance purposes (Mortenson, 2009, p. 13).

Fewer RFIs: a study was performed by The University of Colorado that analyzed and compared the R1 (traditional method) and R2 (BIM) projects. Ricardo Khan, LEED AP Integrated Construction Manager for Mortenson Construction compares the two projects according to the findings of this study (Autodesk, 2009, p. 2): "*there were 780 fewer RFIs on R2, leading to a $585,000 savings just on the cost of administering RFIs. This savings calculation does not account for the actual cost aversion if the issues were addressed during construction. The project was also completed six months faster than R1*." Because Mortenson often self-performs concrete work, the company was particularly interested in comparing the structural aspects of the two projects. Khan reports that, "*compared to R1, there were 74 percent fewer RFIs during the foundation phase and 47 percent fewer during steel erection. As a self-performing contractor, we see that as a great bottom-line benefit of BIM. That's just one of the reasons we've used BIM and VDC on more than 100 projects with a total construction value of more than $6 billion.*"

Lessons learned

The case study underlines the importance of collaboration, early involvement and dedication of key project participants in using VDC technologies in the design and construction. Lessons learned from the RC2 project as documented by Cunz (2010) are as follows:

- *Early team discussions were key in developing the culture–attitude drives results.*
- *The last 100 feet is where the efficiency is realized. The VDC is a front-end-loaded process in terms of planning but there is improved efficiency during installation and construction.*
- *Craft workers have issues with the fully planned and prefabrication process – feeling of losing the "craft".*
- *Without more owner engagement and requirement definition it's difficult to realize more model use in O&M.*
- *Planning is equal to improved efficiency. BIM is just one of the tools to achieve the goals.*

Cunz provides further insight about the challenges and lessons learned on the R2 project: "*the challenge and difficulty was in actually doing everything we did as early adopters. Then, and in some ways still today, much of what we were asking the team to do was not common-place and was more work to plan and execute. We drove more pre-planning, addressed issues earlier, and forced people out of their typical process. The result was all the positive benefits - a better building, faster, lower cost, and higher quality. What we have done on subsequent projects: we have now used VDC on 170 projects valued at over $11B U.S. Since this project, we have continued to push to execute VDC Execution plans in as early as possible to allow more integration of the systems coordination during design with designer assist subcontractors involved - we know that we could have built even faster with these techniques. While the model data flowed effectively on the project, we did not have the contracts aligned with the process we utilized. We have now developed design "right of reliance"* *contract language to avoid some of the redundant model development hand-off "checking" against 2D."*

It is necessary for the Owners to start mandating BIM/VDC in order for the industry to adapt to these technologies and processes. It is also necessary for the industry practitioners to be willing to get out of their comfort zones and change their traditional ways of doing work, in order to benefit from these new technologies and processes. Some important considerations and suggested next steps identified from the experience gained in RC2 project have been identified by Cunz (2010, p. 6) as follows:

- *Sophisticated owner BIM/VDC requirements*
- *Change in mindset: Think about operational requirements and implement a backward approach at project start*
- *Far more user interface/ collaboration*
- *BIM enabled review agencies*
- *Facilities management embedded into BIM as a standard delivery*

3.2.5 BIBLIOGRAPHY

Autodesk. (2009). *Adding up the benefits.* Retrieved 10 17, 2011, from Autodesk Web site: http://images.autodesk.com/adsk/files/navisworks10_custstory_mortenson_final.pdf

Cunz, D. (2010). A Mortenson VDC Case Study: Research 2 [PowerPoint presentation]. Presentation at BIM Forum in 2010, M.A. Mortenson Company.

Mortenson. (2009). *University of Colorado-Denver Health Science Center Research Complex II [Power Point slides].* Retrieved 10 17, 2011, from M.A. Mortenson Company Web site: http://www.mortenson.com/resources/images/11320.pdf

Mortenson. (2011). *University of Colorado Health Science Center Research Complex II.* Retrieved 10 17, 2011, from M.A. Mortenson Company Web site: http://mortenson.com/Resources/Images/13744.pdf

Voss, D., & Rumpf, P. (2010). Virtual Design and Construction: Tools that Pay Off [PowerPoint presentation]. Conference presentation to DataCenter Dynamics (Examining the Evolution of Data Centers and IT Infrestructure), September 30,2010 at Hilton, Chicago. Mortenson Construction.

Young, N., Jones, S., Bernstein, H. M., & Gudgel, J. (2009). *The Business Value of BIM: Getting Bilding Information to the Bottom Line.* In SmartMarket Report. New York: NY: McGraw Hill Construction.

3.3 CATHAY PACIFIC CARGO TERMINAL – HONG KONG AIRPORT (HONK KONG)

This project was chosen as a 'best practice' case study for the following reasons:

- InteliBuild is providing construction coordination services to the project team through managing the 3D and 4D BIM.
- InteliBuild's expertise combines deep knowledge about the construction processes and technology with the most advanced 3D and 4D BIM technologies, thus providing unique expertise for construction management and multidisciplinary coordination.
- Construction risk is diminished through virtual construction simulation before and during construction.

3.3.1 PROJECT DESCRIPTION

The Cathay Pacific Cargo Terminal at the Hong Kong International Airport is an eight storey building with total area of 246,000 ft^2(Figure 48), and will be the world's largest air cargo terminal building. The facility will process 2.6 million tons of cargo each year and is equipped with a complex materials handling system (MHS), considered to be the most advanced in the world at this moment. The terminal will deliver shorter cargo delivery times, reduced cut-off times for export cargo, a shorter trans-shipment connection window and shorter truck queue times. Its construction is evaluated at $HK5.5 billion, which is approximately $700 million CA. Construction started in 2010 and is scheduled for completion in 2013, though InteliBuild completed their scope of work in 2011.

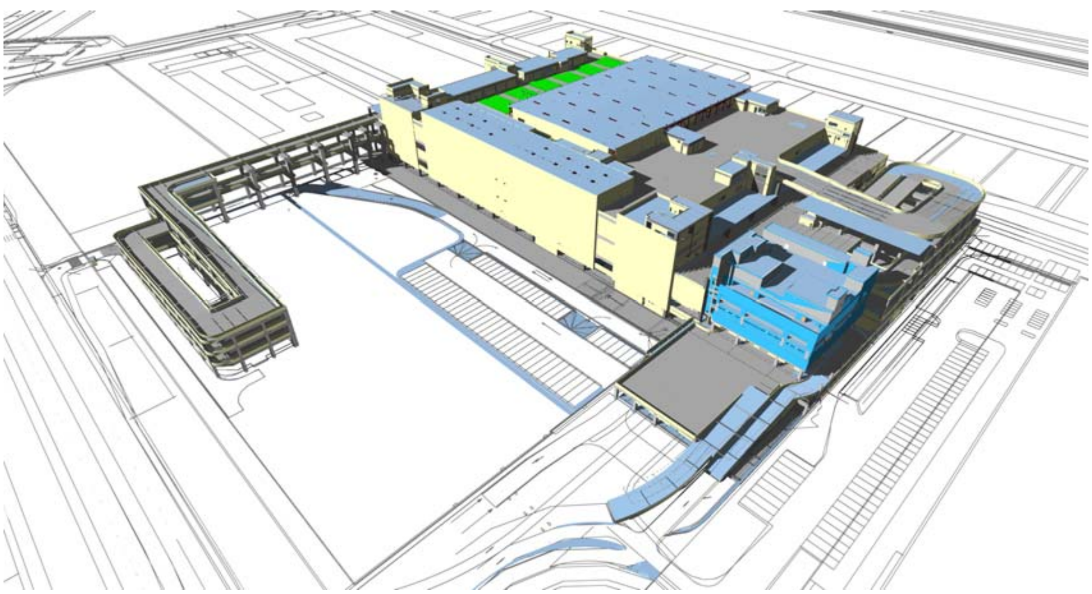


Figure 48: Cathay Pacific Cargo Terminal - Hong Kong

Project Participants

The main participants involved in this project include:

- **Client**: Cathay Pacific Airways

- **Operator**: Cathay Pacific Services Ltd.
- **BIM Consultant:** Intelibuild
- **Architect**: Aedas
- **Engineer**: Meinhardt for the design phase and Arup for modifications of the prefabricated concrete during the construction phase
- **Project Management**: Meinhardt and Aedas
- **General Contractor**: Gammon Hip Hing
- **Cargo handling system (MHS) designer and fabricator**: Siemens

This case study focuses on the unique role of Intelibuild as the BIM Consultant. InteliBuild is a business unit of Canam Group, a Canadian-owned company headquartered in Montreal. Intelibuild provides a broad range virtual design and construction consulting services, which may include 2D to 3D model conversion, architectural renderings and animation, BIM coordination, clash detection, energy efficiency and environmental (LEED) analysis, 4D (3D + time) modeling, 5D (4D + cost), and 6D (5D + facility management) (Intelibuild website: accessed Nov. 2011). InteliBuild has offices in Hong Kong and in Montreal, and additional modelling resources are located in Kolkata, India, Brasov, and Romania. A team from Romania participated on this project. Their BIM Managers also train architects, structural and building services engineers on how to use the BIM process to improve design integration and drawing production.

Background

Situated at the Hong-Kong International Airport, the cargo terminal has two warehouse floors to handle cargo. There are three cargo-handling zones: non-perishable containers, perishable cargo, and transit cargo. The administrative part of the building accommodates offices for a number of governmental departments: Agriculture, Fisheries and Conservation Department, Food and Environmental Hygiene Department, and Customs. The close proximity of these government agencies allows the cargo terminal to work efficiently. The Terminal was designed with a strong commitment to environmental considerations. Offices will utilize natural light to save energy, and the facility will use an advanced waste management system, and the cladding system will regulate the temperature inside the building.

InteliBuild became involved in the project during the design phase as the design coordinator and BIM Manager, which was triggered by project coordination difficulties. Together with the architect and the engineer, they agreed on the specifications and standards for modelling. Employees of InteliBuild became part of the architecut's and the strucutral engineer's teams. At this stage, the models were being created based on the 2D drawings.

The construction contract was given to a joint venture of two general contractors: 1) Gammon, and 2) Hip Hing. As the client was satisfied with InterliBuild's performance, collaboration with InteliBuild was specified in the tender documents for the procurement of the contractors. InteliBuild had the sole responsibility for creation of the structural model. As there were considerable changes in the design of the structure (i.e. from in-place cast concrete to prefabricated concrete), the model had to be recreated entirely from scratch. This in turn required coordination with the other design disciplines. The contractor was responsible for the architectural model but lacked the necessary resources. InteliBuild was then asked to assist with the architectural model as well. A specialist from

InteliBuild was given the task to remodel the components that had changed since the design phase. The MEP models for the construction phase were continued by each respective subcontractor on the basis of the MEP design drawings. These revisions included updating the models and verifying them against the construction method of each subtrade in a way that ensures constructability.

InteliBuild was responsible for analysing the model including clash detection and visual identification of problem areas. Coordination sessions were regularly organized with all the key team members present for model 'walkthroughs'. When a problem was detected, it was immediately discussed, a decision was made and the model was sent for modification. It should be noted that seasoned design and construction personel are required for these sessions to identify the important conflicts. During these sessions, InteliBuild employees would not judge or comment on the quality of the design, but would rather ask questions to ensure constructibility and maintainability. For example, different types of analysis were performed to ensure that the operation trucks would have enough space for manuevering, or the contrainers could be moved around freely and easily. The critical component in the Cargo Terminal is the cargo-handling system and the building is subordinated to it. InteliBuild worked with the contractor to raise issues but the contractor had full responsibility for any decisions.

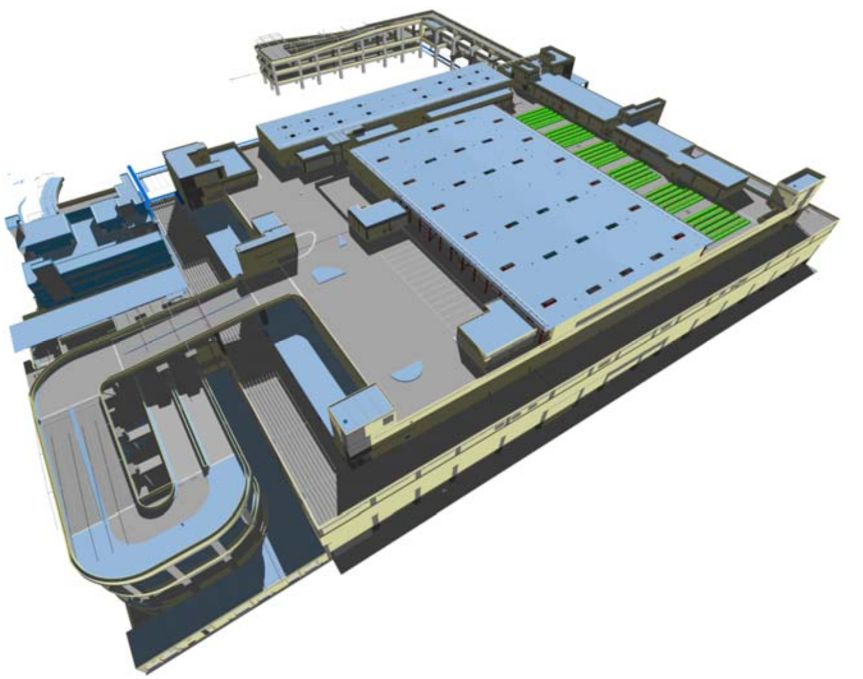


Figure 49: Cathay Pacific Cargo Terminal - Building Information Model

3.3.2 TECHNOLOGY

BIM-enabled technologies were extensively used for this project from design through construction. The following programs were used: AutoCAD 2D, AutoCAD 3D, Revit Architecture, Revit Structure, Revit MEP, Tekla Structures, Navisworks, and a number of other smaller programs.

Technology Used

At the beginning of the project, Revit MEP was not developed enough, so the MEP plans were produced from AutoCad MEP 3D models. The design of the cargo-handling system was done by Siemens in AutoCAD 3D. Structural and Architectural models were detailed in Revit. During construction, Tekla Structure was used because InteliBuild had developed an application for precast concrete tracking. At times, partial AutoCAD drawings (2D and 3D) were created for the internal and external architectural walls due to lack of resources to update the architectural model in Revit.

Navisworks was used during design for clash detection on the basis of the 3D design models. The respective updated models were analysed in Navisworks during construction as well. As 2D drawings were modified, the 3D models were updated to perform clash detection and visual analyses.

Scope of Modeling

One of the main goals of BIM on the Cathay Pacific project was successful multi-disciplinary coordination. The use of interference analysis was quite beneficial. The various stakeholders defined the level of detail required for proper interference analysis. If the model was intended for Facility Management, then considerably more detail would have been required. The BIM specifications prescribed each discipline's scope of modeling. The intent was to model all relevant scope to minimize conflicts in the field. For example, pipes with diameter smaller than 50mm were considered as minor elements and were not required to be a part of the MEP model.

A rather detailed model was required for the MEP and MHS (by Siemens) systems in order to facilitate the creation of shop-drawings. These models therefore needed to become much more detailed than the design models.

Level of BIM

The majority of the models were created to Level 300 according to the AIA classification, which means that they are: *suitable for the generation of traditional construction documents and shop drawings. Analyses and simulations can be performed for detailed elements and systems*. They also created more detailed *partial* models to verify specific points of interest during construction. Also, in order to avoid overloading the models, they tried to maintain the lowest level of detail required for each particular use. Based on DPR's four levels of BIM, the model created on this project would rank between Levels 2 and Level 3, with some partial models reaching Level 4.

Uses of Models

This section provides information about the various model uses on the Cathay Pacific Cargo Terminal project:

Design coordination

According to Ir. Ronan Collins, Managing Director of InteliBuild, the cargo terminal design started with the MHS equipment. The concrete structure was then wrapped around it followed by the architectural design, including the offices. The MEP – ducts, pipes and electrical systems – were finally added. The coordination and conflict resolution process resulted in a much higher quality design benefitting the construction process.

Clash detection

The models in Revit were subdivided per floor (Figure 50) for file size reduction to increase computer the speed of analysis. The Tekla model was not however subdivided as adequate working speeds were realized with the entire model as one. Sub-models per floor were exported from each software tool for coordination and clash detection purposes. The clash detection was performed regularly in order to limit the number of clashes at a time.

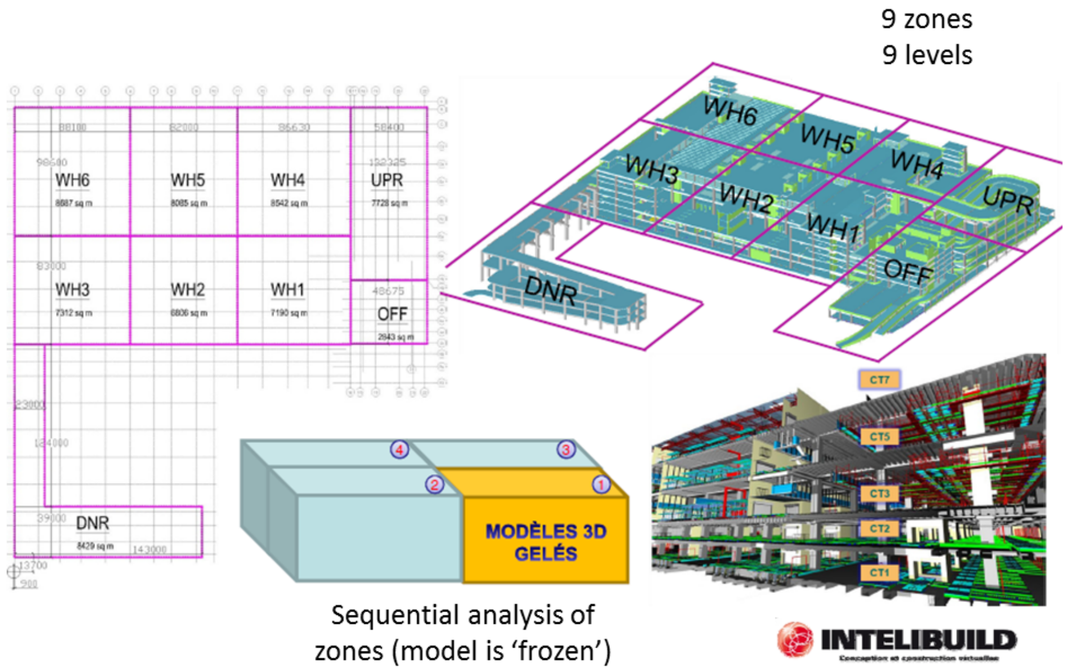


Figure 50: Subdivision of the building into zones

Operational Simulation of Truck Movement

It was important to ensure that trucks would be able to get to their desired location during operation. Elements with approximate sizing of trucks were included in the model to ensure adequate clearance exists on the truck routes. A special volume was modeled in order to represent the volumetric path (like a tunnel) of the trucks. It was then used for clash detection with the other elements. This was modeled in AutoCAD 3D and then analysed in Navisworks. Ir. Collins explains further: "*there's an envelope of space within the terminal, such as headroom of 4.7 metres for trucks. We model the spatial envelope, and made sure there are no pipes and ducts along the truck routes. Cargo containers are different shapes and sizes, and there are maximum envelopes in different areas – sometimes two inches clearance might be required, sometimes four inches. Using the model, the design team can determine whether clearances in the design meet the client's operating requirements.*"

As standard procedure, InteliBuild recommends establishment of a ‘clash tolerances matrix’ with the client on all BIM projects (Figure 51). These tolerances enhance the conflict analysis by capturing both hard and soft conflicts.

Clash Tolerances	STR Cols & Walls	STR Beams & Framing	STR Foundations	STR Slabs	ARC Walls	ARC Facades	ARC Components	Drainage	HVAC	Electrical	Fire Protection
ARC Internal Walls	01 10 H	02 10 H	N/A	N/A							
ARC Facades	03 10 H	04 10 H	N/A	N/A							
ARC Components	05 10 H	06 10 H	N/A	N/A							
Drainage	07 50 C	08 50 C	09 75 C	N/A	19 50 C	20 50 C	21 50 C				
HVAC	10 50 C	11 50 C	N/A	N/A	22 50 C	23 50 C	24 50 C	34 75 C			
Electrical	12 50 C	13 50 C	N/A	N/A	25 50 C	26 50 C	27 50 C	35 75 C	36 75 C		
Fire Protection	14 25 C	15 25 C	N/A	N/A	28 25 C	29 25 C	30 25 C	37 75 C	38 75 C	39 75 C	
Plumbing	16 50 C	17 50 C	18 75 C	N/A	31 50 C	32 50 C	33 50 C	40 75 C	41 75 C	42 75 C	43 75 C

C = Clearance Check

H = Hard Clash Check

Figure 51: A typical ‘clash tolerances matrix’.

Identifying Potential Coordination Problems

The BIM process is used to identify a host of potential coordination issues, such as where a pipe will hit a beam. These conflicts are communicated with the designers, who can revise the designs accordingly.

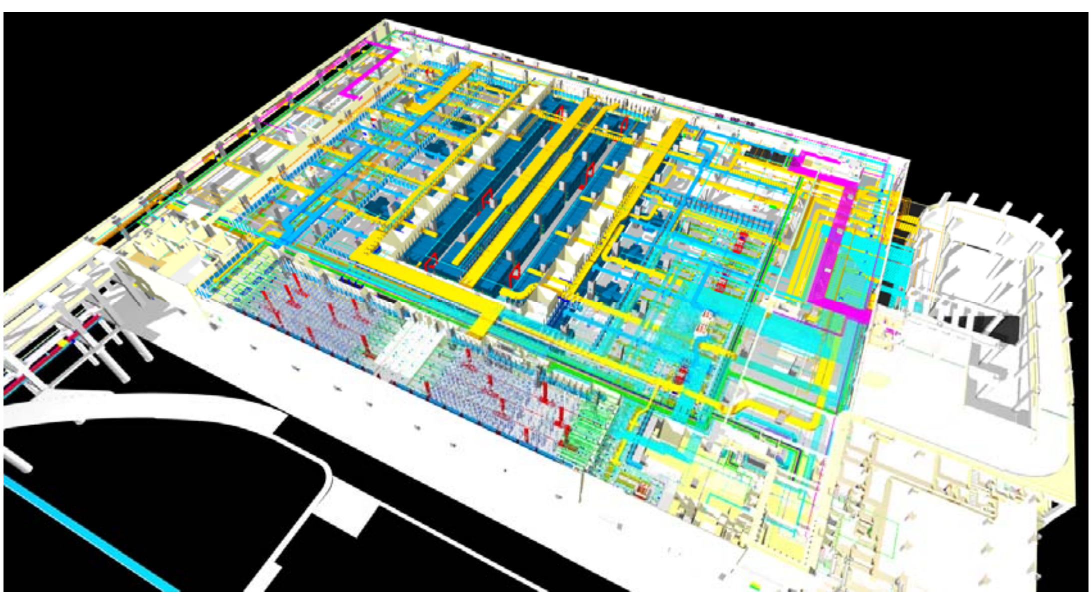


Figure 52: Combined BIM model for clash detection (floor view in NavisWorks).

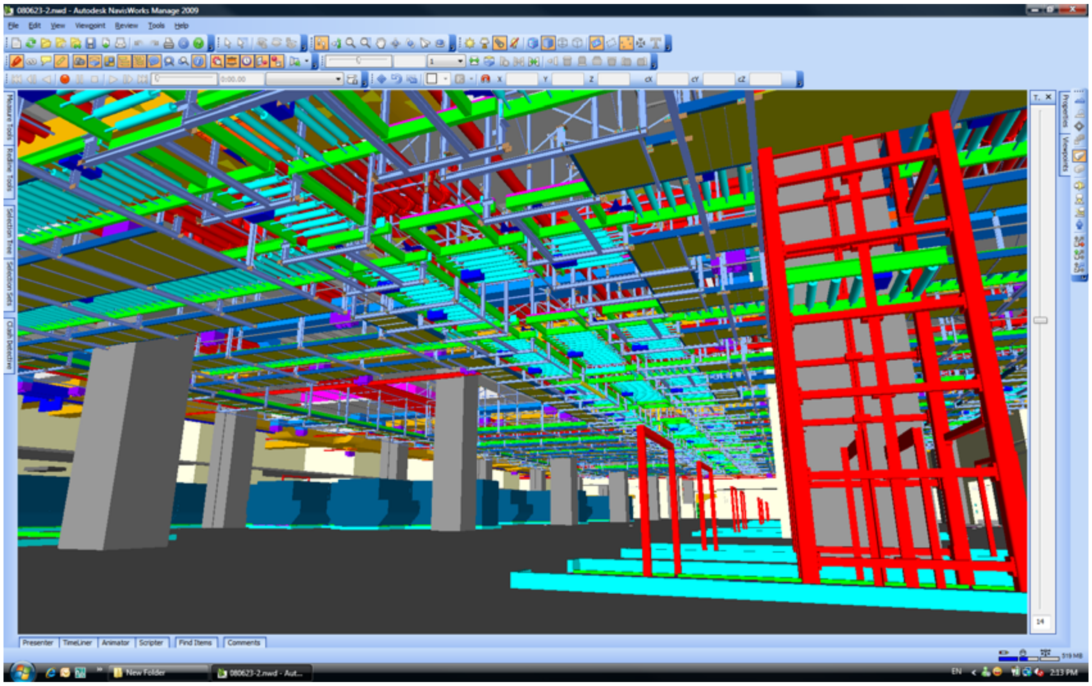


Figure 53 : Combined BIM model: warehouse (virtual walkthrough in NavisWorks).

Quantity Take-off

During the conceptual phase, the Revit and 3D CAD models (mainly Revit MEP and AutoCAD-3D) were used for quantity take-offs, facilitating the cost estimation process. During the construction phase, each sub-contractor, MEP, Siemens and the General Contractor extracted quantities from the model according to their needs.

Linked and coordinated drawings and models

Over 3,000 linked and coordinated drawings were created from the combined model. This was a major benefit of BIM on this project. Document creation and processing based on traditional practice would have been much more time consuming and costly.

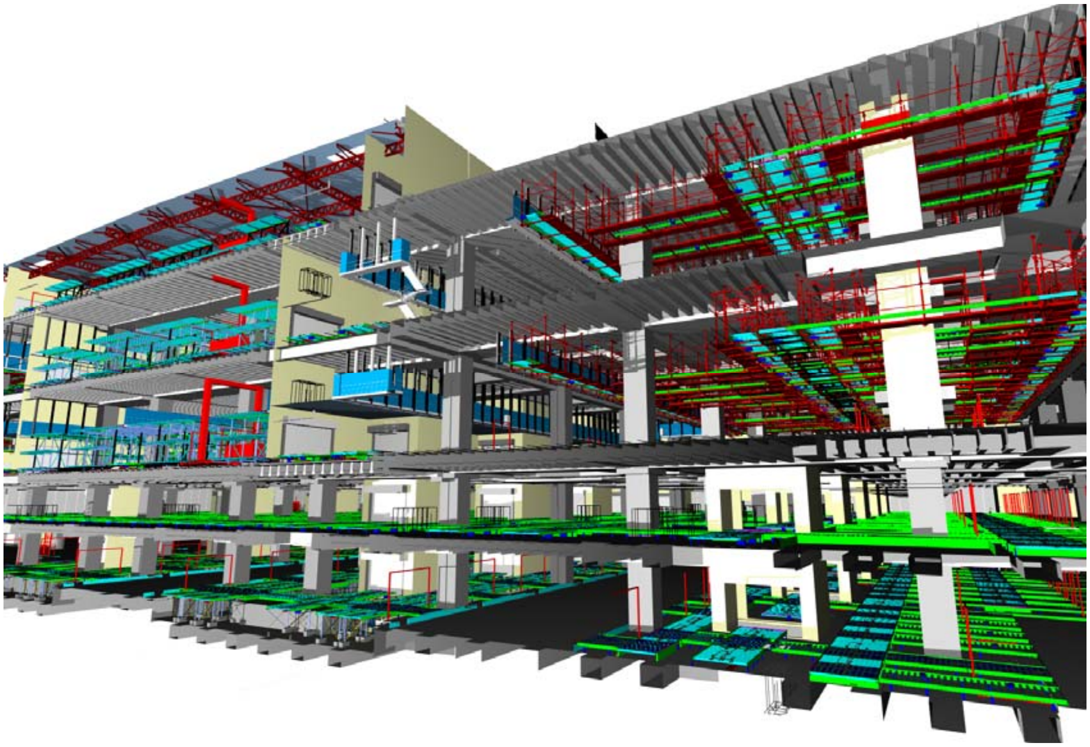


Figure 54: Combined model of several disciplines.

Information Exchange

Teams from three locations worked on the project: Hong Kong, Canada and Romania. During design and construction, most of the Intelibuild team was co-located at the construction site. The Tekla model was synchronized between the Hong Kong site office and the Romania InteliBuild office via a secure FTP site. The files were saved on a server provided by the client.

Even though the computers used were powerful, the models were quite heavy and needed to be split into zones for effective analyses. The models of the neighbouring zones were used as references (Figure 55). The structural model in Tekla did not need to be split as Tekla was able to handle bigger models.

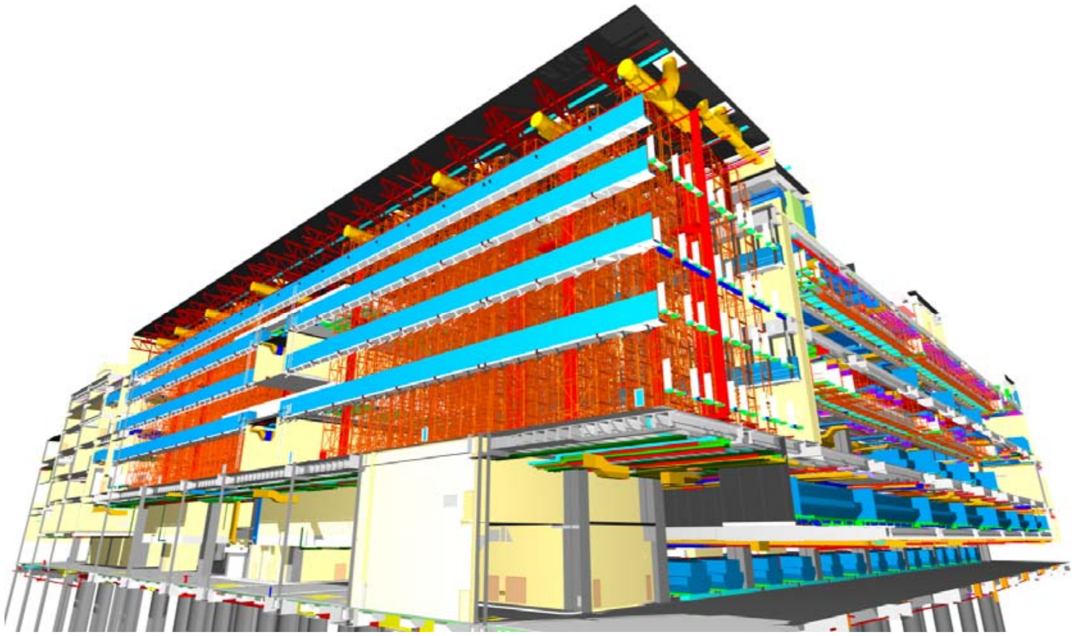


Figure 55: A combined model for a specific zone

3.3.3 ORGANIZATION

On the Cathay Pacific Cargo Terminal project, InteliBuild was providing services to the design and construction teams and was reporting directly to the owner.

Owner Requirements

Design coordination and construction verification through BIM were the main purpose for InteliBuild's participation in the project. The strategy of InteliBuild was to employ small, specialised teams to offices as directed by the client. The team initially worked on devising a methodology for the various file creation and the sharing protocol. The 'core' of the team, which constituted five people, were working full time on the BIM for the cargo terminal, coordinating with the client, project managers, architects, structural engineers and building services engineers from Meinhardt. Though not stipulated in the contracts, the client requested to acquire the model for future facilities management purposes.

Project Participants

InteliBuild was often providing teams of modellers consisting of 7 to 8 people. Overall more than 100 people (including Intellibuild staff) were working at the construction site during construction.

There was a manager for each scope of the project: architecture, structure and mechanical. The client had representatives responsible for each discipline and a team directing the construction workers on site (Figure 56).

Figure 56: A snapshot during the construction process.

BIM Maturity

InteliBuild has a high maturity level for the services it provides, especially design coordination and constructability verification. InteliBuild's maturity is estimated at level D (integrated) based on BIM Maturity Levels established by Succar 2010. Some of their processes are also optimized, reaching the highest maturity, level E (optimized).

Contractual Relationships

During the design phase, InteliBuild was reporting directly to the owner. During the construction phase, however, InteliBuild was reporting to the General Contractor, but still getting direction from the Owner.

When models or drawings were not delivered on time, InteliBuild would raise the issue highlighting the negative impact the delay would have on the timing of the analyses that needed to be performed. The issue would get reported to the client and they would decide on any measures that needed to be taken and direct on the best path forward.

3.3.4 PROCESSES

InteliBuild has considerable experience with BIM management and has created a template which serves as a basis for writing the specification of each project. It consists of the following chapters:

- BIM requirements: specifies the scope and content of the model for the different disciplines, as well as the purpose for modeling (e.g. clash detection, 4D simulation, etc.).

- Scope of services provided by InteliBuild, such as:
  - Generate the BIM models from the design consultant's 2D drawings;
  - Integrate the different models and provide 3D geometry such that the model is compatible with clash detection software (Navisworks);
  - Provide guidance to the project team on how to review the BIM models to resolve clashes.
- Description of the deliverables:
  - BIM models
  - Flythrough animations
  - Plans, sections and elevation drawings
  - Technical query reports
  - Monthly reports
- BIM specifications
- Construction information from contractor, which may include site context and other information;
- Hardware and software specifications, such as:
  - software platform (Revit) and version
  - hardware requirements (Figure 57)

Item	*Configuration*
Operating System	*MS Windows XP Professional x64 Edition / Windows 7*
CPU Type	*Intel Core 2 Duo 2.4 GHz or equivalent AMD processor*
Memory	*8 GB RAM (minimum)*
Video Display	*Dedicated video card with hardware support for open GL specification 1.3 or later, and support for MS DirectX 9 or later*
Hard Disk	*10 GB free disk space*
Pointing Device	*Two-button mouse with scroll wheel.*

Figure 57: Modeling hardware requirements

Project Execution Planning

Extensive discussions are held with the client early on the project to clearly understand the client's expectations and set BIM objectives in line with those expectations. Roles should be clearly set to understand the responsibilities of the BIM manager versus the Project manager. The role of a BIM Manager is typically explained as: '*to coordinate the models and to diminish the construction risks*.'

The designers and engineers plan to meet on a weekly basis to review the progress on design, perform clash detection, provide solutions, and communicate the results to the appropriate project participants.

BIM Specifications

InteliBuild was responsible for the BIM management. In collaboration with the other team members they established a modeling specification. Each item was discussed within the team and decisions were made collectively to ensure everybody's experience and concerns are voiced during the decision-making process. These decisions were assembled into the 'BIM Specification'. Topics such as the following were included in the BIM Specification: Revit BIM data structures, CAD file structures, file naming conventions, digital file exchange protocols, Revit BIM standards, quality control processes, and annotation specifications.

The specifications are organized in the following structure:

- 3D Model File Naming System – including:
    - discipline,
    - type (model or view),
    - building area and level.
- Modelling Guidelines (CAD reference point and axes)
- BIM Model Definition - for example:
    - produce the Revit model and maintain it up-to-date,
    - keep a 'Technical queries' document including all identified design conflicts, clashes, discrepancies in drawing details and design documentation, lack of information and co-ordination issues
- Building System Modelled and Level of Detail - determines the minimum level of detail for each discipline and contains:
    - a list of items to be modeled, for example:
        - exterior walls (including doors and windows)
        - curtain wall with mullions and window panes according to their true outer profile
    - a list of items excluded from each model, for example:
        - water proofing membranes, flashings, etc.
        - studs and individual layers of drywall
- File Folder Structure and Server Information – specifying the access to the files and the file structure
- Family Naming System
    - Rule: Family Type_Level_Component_Property
(2letters)_(3letters)_(3Letter)_(Size)
    - Family type correspondence to 2 letters:

WL	Wall
DR	Door
WD	Window

    - Examples: WL-B04-EXT-250mm (250mm Exterior wall on level B04)
CO-B04-2000x1000mm (2000x1000mm Column on level B04)
- RFI Naming - including naming format and file format

Teams and Software used during the Design Phase

At the beginning of the project, InteliBuild was not part of the team (Figure 58 - left). InteliBuild was only approached by the client when difficulties with coordination between disciplines was noticed (Figure 58 - right).

The role of InteliBuild was defined as follows:

- BIM process management
- Coordination between all the disciplines
- Definition of BIM specifications

- Participation in creation of the model

Aconex was used for communication between InteliBuild, the architects, the structural engineer and Siemens.

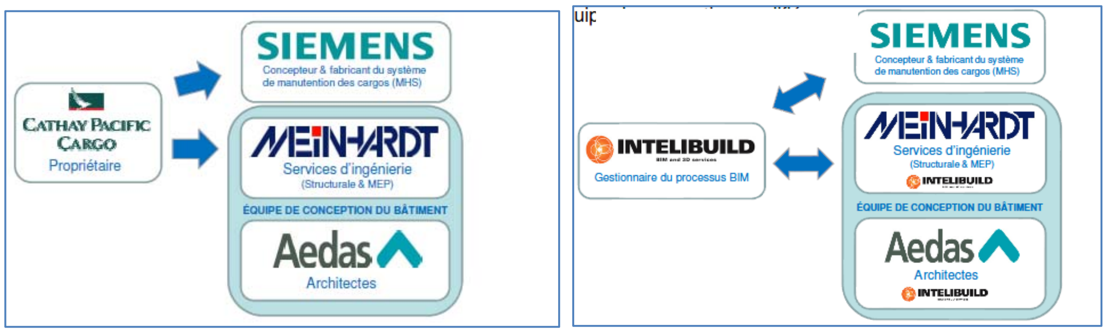


Figure 58: Initial design team (left) and modified design team (right) (Source: InteliBuild).

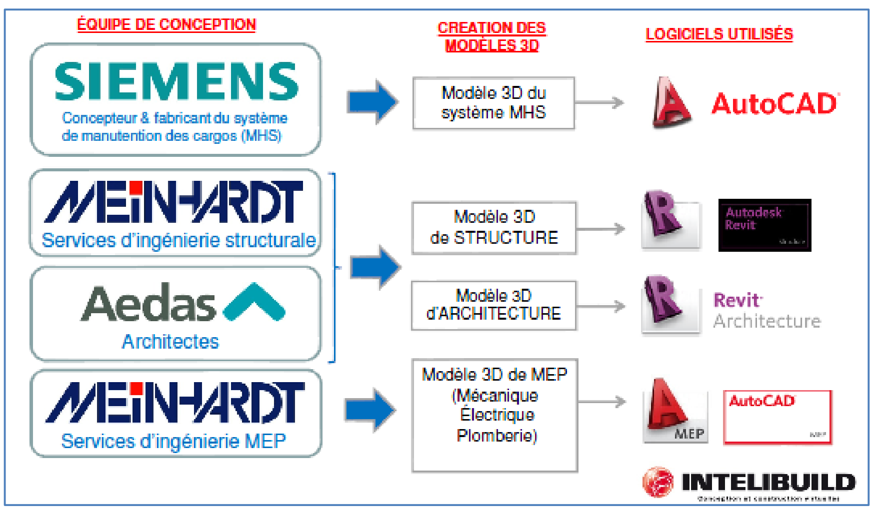


Figure 59: Teams participating in the project during the design phase, models produced by each of them and the software used (Source: InteliBuild).

Upon completion of the design, InteliBuild's contract was essentially complete. The team continued without assistance from InteliBuild. Many coordination problems however soon surfaced again:

- Modifications were not reflected in the 3D models
- The analyses were not systematically performed
- The modifications were only made in 2D drawings

Given this situation, the owner called for the services of InteliBuild once again, this time for the construction phase.

The major modifications to the building design was influenced by the general contractor. These design modifications include substitution of the main beams by cast-in place concrete (previously designed with precast concrete beams) and reduction in the amount of secondary precast beams, by using semi-precast slabs (a composition of precast planks and cast-in place concrete slab). This new design allowed for easier installation of the MEP systems and walkways that needed to be attached underneath each floor structure. A new team member, the engineering company Lambeth, was also brought into the project.

Teams and software used During the Construction Phase

Figure 60 shows the organisation between the project team during the construction phase.

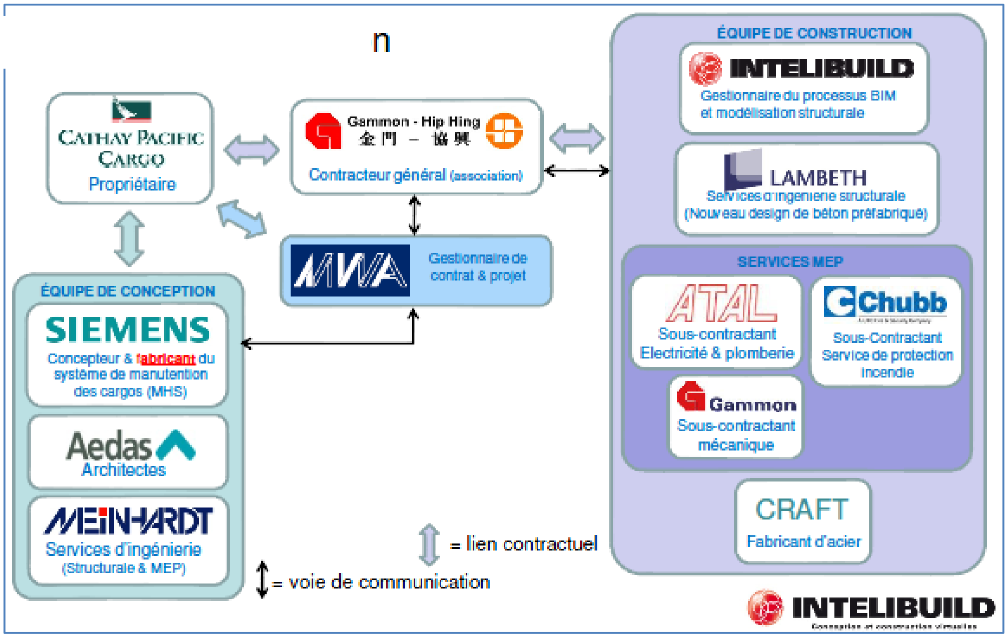


Figure 60: Project participants and their relations to one another during the construction phase (thick arrows represent contractual relations, while thin arrows represent communication channels). (Source: InteliBuild)

During the construction phase, the timing of the modeling was very important. For each stage of construction, a clash detection analysis had to be made well in advance in order to find the potential problems and to modify the design prior to errors reaching the construction site. During this phase, detailed elements that could have had impact on other disciplines were to be modeled to avoid potential clashes and conflicts (Figure 61).

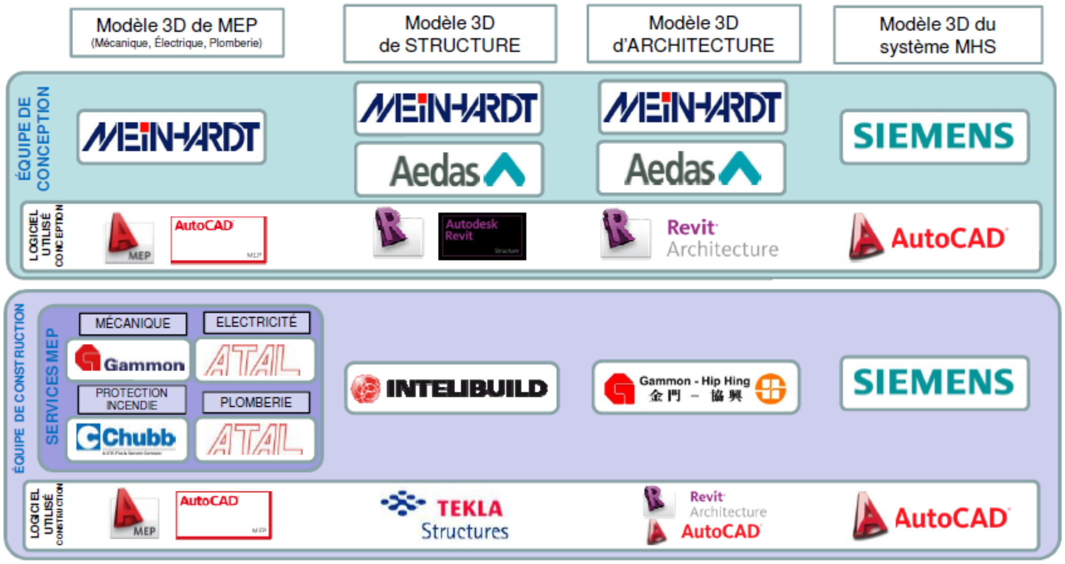


Figure 61: Software used by the project team during the conceptual design (above) and during the construction (below). (Source: InteliBuild)

InteliBuild had employees embedded in the different discipline teams to be able to react proactively and to modify each model continuously as modifications took place. This continuous collaboration was necessary for the quick progress of the project. InteliBuild was also working with the subcontractors during the construction phase. The relation was different with the architects as they had a separate contract with the client. A procedure for freezing and analyzing the model was established. The communication channels during this phase are represented in Figure 62.

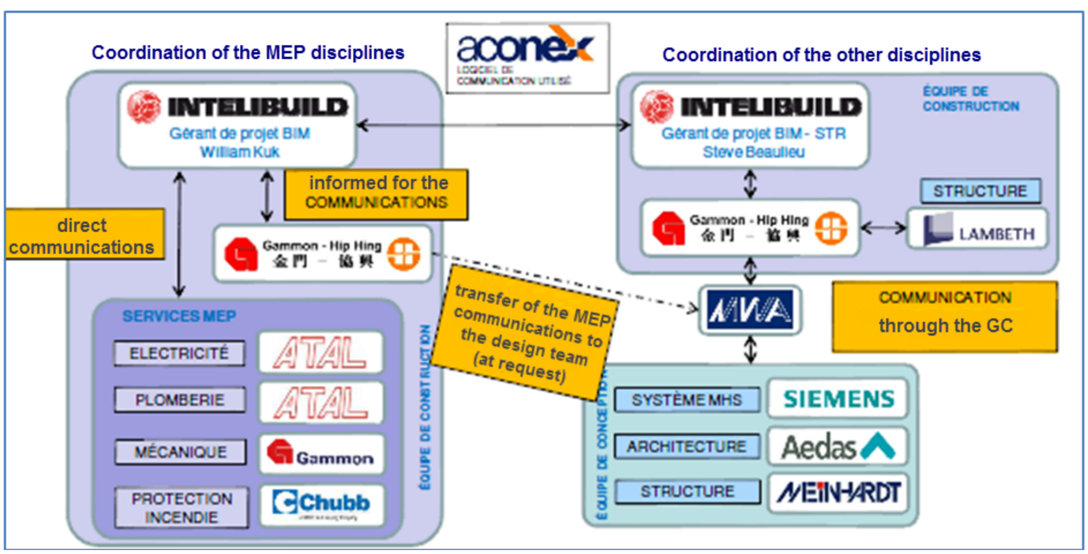


Figure 62: Coordination and communication channels during the construction phase and specifically when BIM analysis was performed.

Information Exchange Process and Protocols

The models were updated on a regular basis for coordination and analysis. Given the complexity of the project and the tight deadlines, a system of 'almost' real-time model sharing was put in place between the offices in Hong Kong, Romania and Canada.

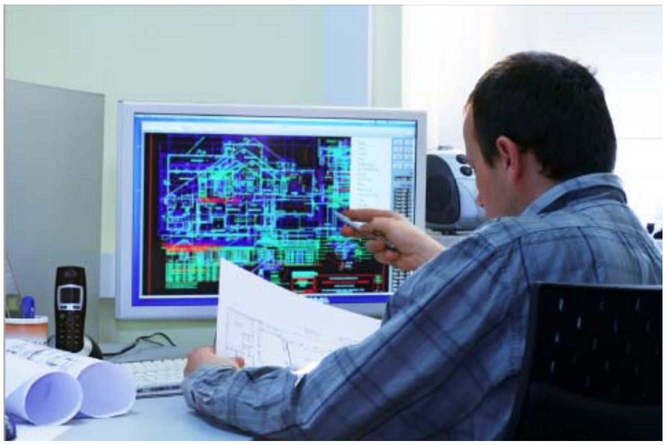


Figure 63: Verification process.

A synchronisation schedule and procedure was established in order to keep the models up-to-date without having multiple teams synchronizing at the same time (Figure 64).

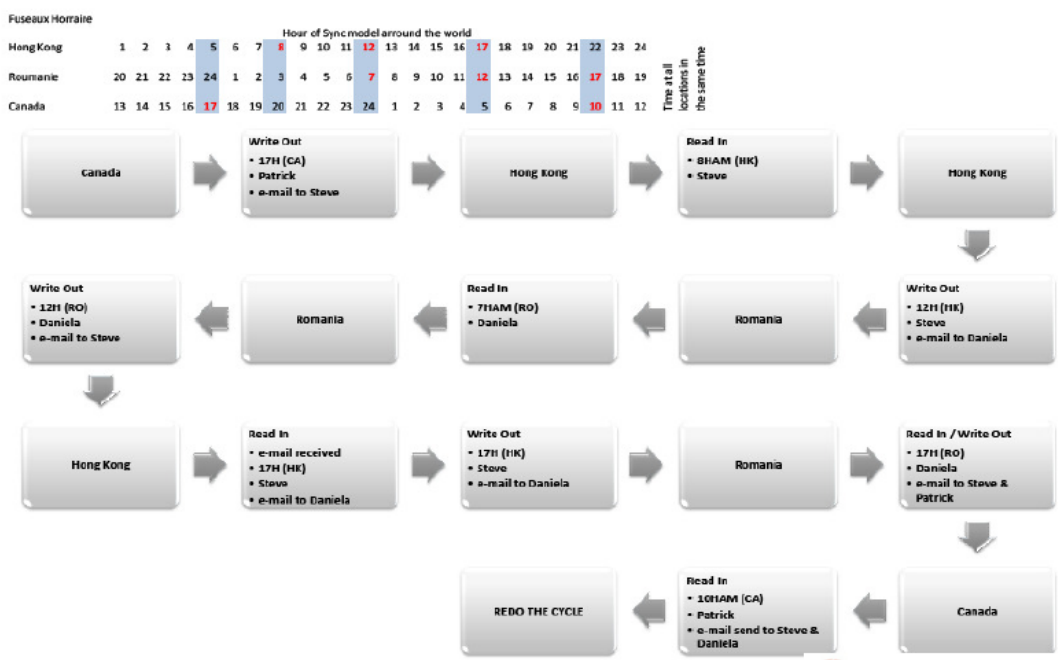


Figure 64: Model synchronisation scheme between the 3 offices: Hong-Kong, Romania and Canada.

Having a detailed execution plan for synchronization is important for preserving the integrity of the models and the stability of the IT infrastructure as the project progresses.

3.3.5 EVALUATION

InteliBuild considers the following as key aspects of this project that lead to its success:

- The client had clear objectives from the very beginning
- The project participants were motivated and engaged in the project
- The well-established methodology of work (specifications, workflows, etc.)
- The joint expertise in design, technology, management and construction
- The support by the IT team

Benefits

BIM provides an easy-to-understand 3D model: With 2D drawings, interpretation is required whereas with a 3D model, all can easily visualize the design and understand the conflicts much better, hence speeding the design process. By linking the 3D model to the construction schedule, the team produced a 4D model that helped the contractors throughout the construction process, including the MHS contractors.

A BIM model includes multiple layers of information: Content can be filtered in seconds to generate various views as required for different purposes for design and construction tasks.

Easy production of construction documents: Revit was used to produce 760 architectural drawings and 845 structural drawings. Additionally, Autodesk MEP was used to produce more than 1,600 building services drawings. These drawings were linked and coordinated. Overall, more than 3,000 linked and coordinated drawings were produced with considerably less effort.

Lower project cost: Although BIM implementation might seem as an extra cost on a project, the cost savings realized from its implementation far outweighs its initial cost. According to Ir. Collins: "*saving five percent of construction costs is feasible and well documented*".

Increased certainty in project schedule: BIM increases design certainty, which in turn improves construction schedule certainty. With BIM, the project benefits from increased probability of completing on schedule and on budget.

Lower disputes: the collaborative process of BIM promotes proper communication that minimizes unexpected surprises at the end of the project. Decisions are collectively made throughout the project leaving less incentive and room for disputes (i.e. arbitration and litigation).

Competitive edge: InteliBuild has been employed for a number of other projects by the owner, as well as, by both contractors (i.e. Gammon and Hip Hing).

Challenges

As the delivery mode was not IPD, sometimes the interests of the participants were not in sync which created some difficulties in the BIM process. Further, working abroad was a challenge due to language and cultural barriers. InteliBuild has since developed some strategies to deal with this.

Lessons Learned

On this project, the use of BIM and InteliBuild's involvement were mandated by the owner (Cathay Pacific). At the beginning of the process, the contractor was not convinced of the need for BIM. However as the project progressed, the added value provided by InteliBuild was realized and BIM was taken very seriously and considered crucial for the success of the project. Initially InteliBuild was only 'tolerated', while at the end, they were listened to and truly appreciated.

Initially there were not enough resources for BIM purposes. As model coordination was required, additional resources were provided to create a model containing only the necessary components. Later, the benefits of the BIM were clearly seen which promoted more model detail and regular model updates.

The following lessons learned were identified by InteliBuild:

- Get acquainted with the 'culture' of the place.
- When there is a language barrier, graphical communication (3D models) facilitates the communication.
- The construction expertise of InteliBuild was important; modeling expertise alone is not enough.

The following were also important lessons learned from this case study:

- Modeling should be detailed to the minimum level possible level for a given use.
- For clients that are going to hire BIM Consultants, it is a sound organizational principle to have the companies offering BIM services reporting to the client.
- Collaboration and effective communication is key in implementing a successful BIM Project. A BIM Standard is highly encouraged to ensure proper coordination and integration of the models.

3.3.6 ACKNOWLEDGEMENTS

Special thanks to Steve Beaulieu (BIM Project Coordinator), Jean Thibodeau (Senior VP), and Diane Leclerc (Director of Marketing and Business Development) for their contributions to this case study.

3.3.7 BIBLIOGRAPHY

Videos referenced:

1. http://www.youtube.com/watch?v=nU3q-GT-9IY
2. http://www.youtube.com/watch?v=mJ4aJntl-7M&feature=related

3.4 VANCOUVER CONVENTION CENTRE (BRITISH COLUMBIA)

This project was selected as a case study because it implemented the following 'best practices' in the design and construction of steel structures:

- Supply chain integration
- Level of modeling
- Information exchange and sharing
- Integrated design and analysis
- Model-based design coordination
- Procurement and fabrication
- Model-based review (no shop drawings)
- 4D Modeling

3.4.1 PROJECT DESCRIPTION

The Vancouver Convention Centre expansion is a 1.1 million-ft^2 (100,000-m^2) project that achieved LEED Platinum certification (Naturally:Wood, 2010). It rests on the shore of the Vancouver harbour beside the previous convention centre and facing the world-renowned Stanley Park. The project imposed such physical constraints that necessitated an innovative approach from the structural engineers. The building is supported on more than 1,000 piles and a concrete deck that together allow the steel structure to bridge roads and railway tracks (Naturally:Wood, 2010). Its main structure consists of 18,000 metric tons of structural steel and is considered to be one of the largest steel projects in BC history. One of the Centre's distinctive features is a six-acre living roof which is landscaped with more than 400,000 indigenous plants and grasses, providing natural habitat to birds, insects and small mammals (Chami, 2009). Figure 65 shows the facility: (1) during design, (2) during construction, and (3) after it was constructed.

Figure 65: The Convention Centre: (1) Rendered representation created by the Architect, (2) under construction, (3) photo of the finished building.

The final cost of the project was $883 million. The total design time for the project was approximately 2 years, the steel fabrication time was 1 year, and the construction time was 1.5 years for the marine mat and piles and 2 years for the superstructure. The project was completed in time for the Winter Olympics hosted in Vancouver in 2010. After hosting a successful Olympics where the structure was one of the focal points, the convention centre went on to win numerous design awards throughout Canada and the world.

There were numerous organizations involved with the delivery of this facility. The project was managed by a consortium called the Vancouver Convention Centre Expansion Project (VCCEP). In terms of designers, there were three Architects on the project. The first architecture firm, LMN Architects, had expertise in convention centre design and was involved at the design development stage. The second two architecture firms were Musson Cattell Mackey Partnership (MCMP) and DA Architects + Planners, which were local architecture firms that got involved at the detailed design stage. The structural engineer on the project was Glotman Simpson Consulting Engineers and the mechanical engineer was Stantec. The contractor on the project was PCL Construction and the fabricator and detailer were Canron Western Constructors and Dowco Consultants respectively.

The project was designed and built using a BIM workflow that was mandated by the owners and agreed upon by the architect, the structural engineer, the mechanical engineer, and the general contractor. The owner required BIM for a number of reasons:

- it was a fast-tracked Olympic project, meaning that it could not be delayed;
- it was a highly complex project, particularly the geometry, which made BIM very useful visualization, coordination, and identifying issues early;
- the use of structural steel as the material for the structure was another driver for BIM because the steel industry is particularly advanced in its use of BIM.

This case study focuses on the delivery of the steel structure.

3.4.2 TECHNOLOGY

Technology Used

The software used by each of the organizations included the following:

Architects: *LMN, MCMP and DA Architects*

- Create the Architectural BIM: Revit Architecture
- Produce 2D Drawings: AutoCAD

Structural Engineer: *Glotman Simpson Structural Engineers*

- Create the Structural BIM : Tekla Structures
- Produce 2D Drawings: AutoCAD
- Gravity System Design: RAM Steel (now Bentley - integrated with Tekla and AutoCAD).
- Seismic Design: SAP 2000 (integrated with Tekla).

Mechanical Engineer: *Stantec*

- Create the Mechanical BIM: Revit Systems

General Contractor: *PCL Construction*

- 4D Modeling: Navisworks Timeliner
- 3D MEP Clash Detection: Navisworks Clash Detective

Steel Detailer: *Dowco Consultants*

- 3D Steel Detailing: Tekla Structures

Steel Fabricator: *Canron Western Constructors*

- 3D Fabrication Model: Tekla Structures

Mechanical Subcontractor: *Fred Welsh*

- 3D as-built Mechanical Model: In-house 3D CAD.

Scope of Modeling

The scope of modeling on this project was directed by the ownership consortium VCCEP. The directive was for all the consultants and the contractor to perform 3D modeling and to leverage BIM throughout the design and construction planning process. This directive was more of an overall mandate to use BIM without the details being laid out of how it was going to be accomplished.

During the design phase, all the consultants were creating BIMs but on different software platforms, as noted in the previous section. Figure 65 shows the BIM models created by the (1) Architect, (2) Structural Engineer, (3) Mechanical Trade and (4) Contractor. The architect used Autodesk Revit to create a model with all the building components. The structural engineer used Tekla Structures to create the structural steel model. The structural model was then later passed off to Canron Western Constructors and Dowco Consultants where they used Tekla to further detail the model to create the steel detailing/fabrication model. Tekla was also used to output steel shop drawings that were reviewed in the form of a 'virtual' shop drawing approval process. The fabrication-level Tekla model was also used to output CNC files, which linked directly to the fabrication machines for cutting steel pieces such as shear plates and gusset plates.

The mechanical engineer used 3D AutoCAD to model their mechanical ductwork and piping systems. The mechanical engineer used the architect's model and the structural model as a reference for which to model the HVAC and the piping systems. The contractor used their 4D Navisworks model (Figure 66.4) for construction planning and collision detection. To further enhance coordination, the contractor sourced the mechanical trade, Fred Welsh, to create 3D BIMs (Figure 66.3) of the most complex mechanical areas. The contractor then imported these models into Navisworks in order to perform collision detection.

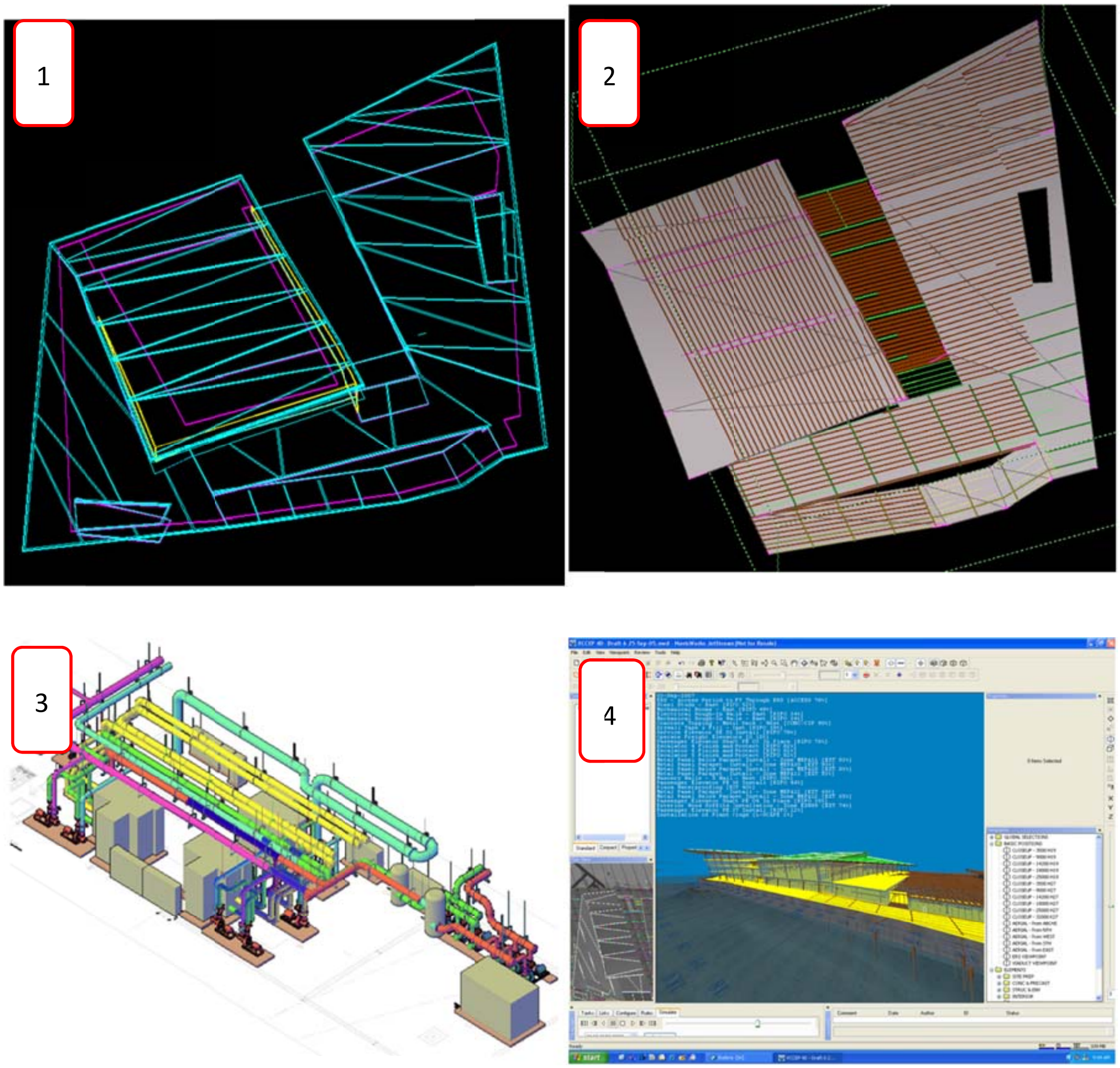


Figure 66: Multiple BIM models created by the (1) Architect, (2) Structural Engineer, (3) Mechanical Trade and (4) Contractor.

Level of BIM

When defined by DPR Construction's Four Levels of BIM, the Vancouver Convention Centre Expansion Project would be defined as a level 4 project for the structural system since it included all the details of the steel structure. For the other systems, Level 3 models were created for the architectural and mechanical system, which were utilized extensively for coordination and quantity takeoff but lacked the finer details of these systems.

Uses of Models

The structural model was used in a variety of ways on this project, including design integration, coordination, quantity take-off, 4D analysis of temporary bracing, issuing the 3D structural model, and virtually reviewing the steel shop drawings.

Structural Design Integration: Analysis and Modeling

The structural system of the Convention Centre is split into two sides separated by an expansion joint. For simplicity, each side can be analysed independent of the other. For the east side, the integration between the Tekla building model and the various analysis models was less efficient as the team spent considerable time troubleshooting throughout the process to figure out the best way to integrate the models. The west side models were integrated far more efficiently as the integration process was established based on the experience of the east side design process.

Three software tools were used to analyze the building: SAP 2000, RAM Steel and Excel. SAP 2000 was used for the seismic system, which makes up the shell of the building. The gravity-loaded system (non-seismic) was analyzed using RAM Steel. The gravity loaded system filled in between the shell of the seismic system. Excel was used to analyze the eccentric bracing system. This system is a unique part of the overall seismic system. Once each eccentric bracing system was analyzed, the sizes generated from excel were input into the SAP 2000 model to see how they worked with the rest of the seismic system.

East Side

On the east side, the SAP analysis model and the AutoCAD structural drawings were created independent of one another. The RAM analysis model was built from the AutoCAD drawings and the Tekla Structures model was built from the transfer of the SAP analysis model.

West Side

On the west side, a more efficient procedure was employed, which involved creating the Tekla Structures model first so that they could be utilized during design. The Tekla model was then transferred to SAP as a 3D stick model, and to AutoCAD as 2D drawing files (Figure 67). The AutoCAD files were then slightly modified to facilitate transferring to the RAM analysis model.

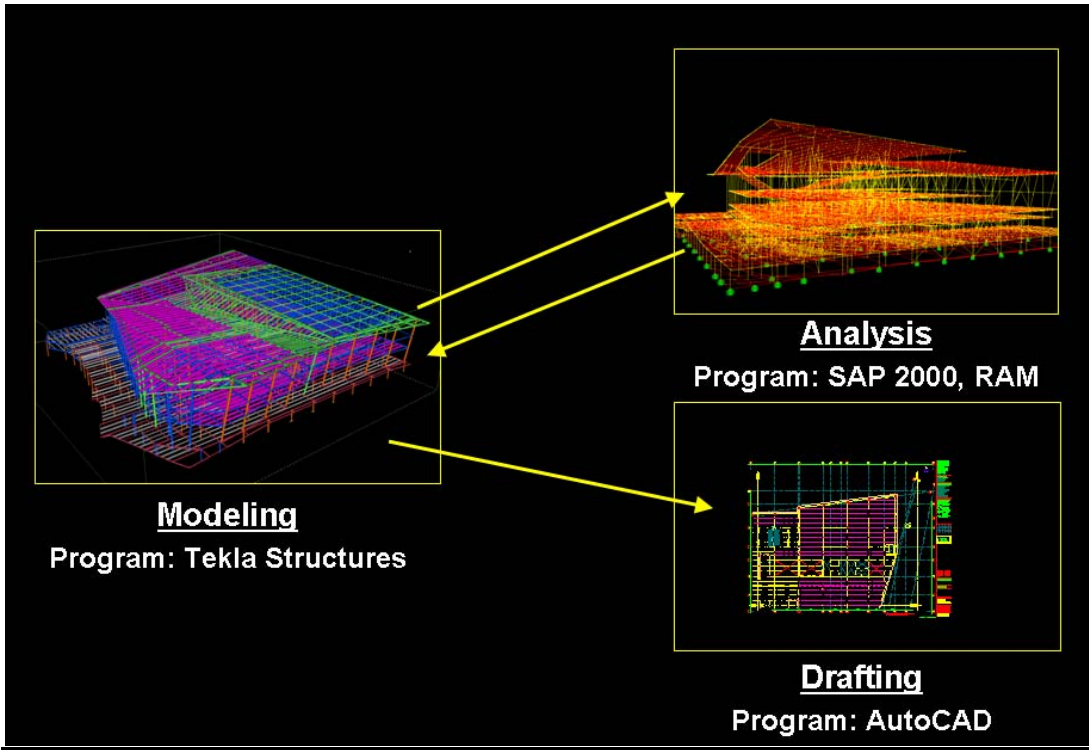


Figure 67: Flow diagram showing how the transfer of models took place on the west side

This change in the design approach resulted in considerable time-savings and increased accuracy. Approximately 3 weeks of modeling time on SAP 2000 was saved and the accuracy of the SAP model was improved as the Tekla model is an exact as-built model. A considerable amount of time was also saved in drafting as the plan and elevation drawings were exported from Tekla to AutoCAD for the addition of notes and forces. Some challenges however surfaced during the transfer of the models between the different software. These challenges involved setting up the Tekla model correctly to enable a smooth export to both the analysis software and AutoCAD. For the SAP transfer, the team had to make sure that the members were all modeled on-centre with their joints all intersecting because if they were offset, the structure would not be analysed correctly. For the AutoCAD transfer the team had to make sure that the pen types for the drawings were mapped correctly between Tekla and AutoCAD. Once these steps were taken, the process was fairly smooth.

Information Added to the Structural BIM

Each truss member has an axial and a shear force. These forces needed to be relayed to the fabricator in order for them to design connections at these joints. These forces are usually given on elevation drawings. Since the elevation drawings were being exported from the BIM, the structural modeler decided to add this information to each member in the model using two attributes to show the force at each end of the member (Figure 68). These forces would then be called up automatically on the elevation drawings (Figure 69).

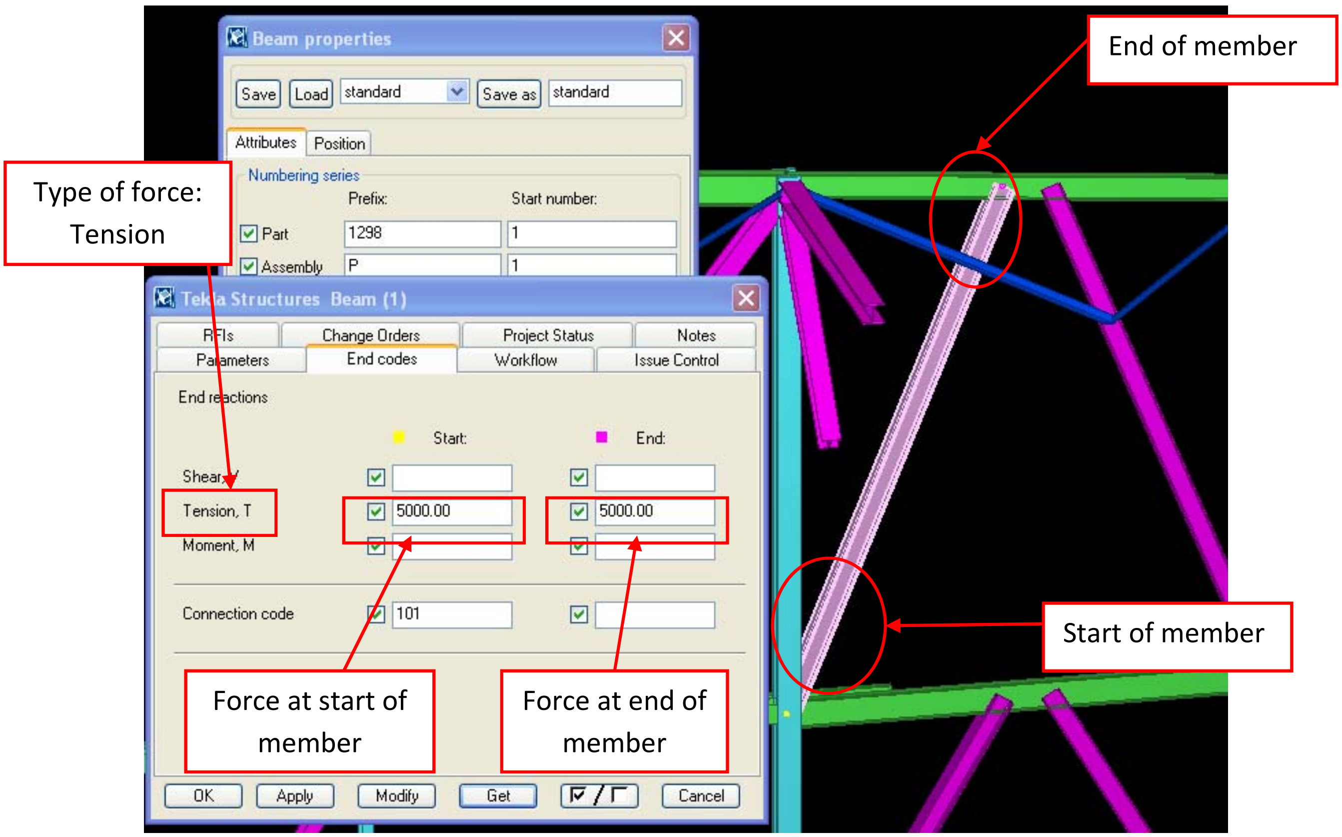


Figure 68: Forces added to certain members in the model in the 'Beam Properties' dialogue box.

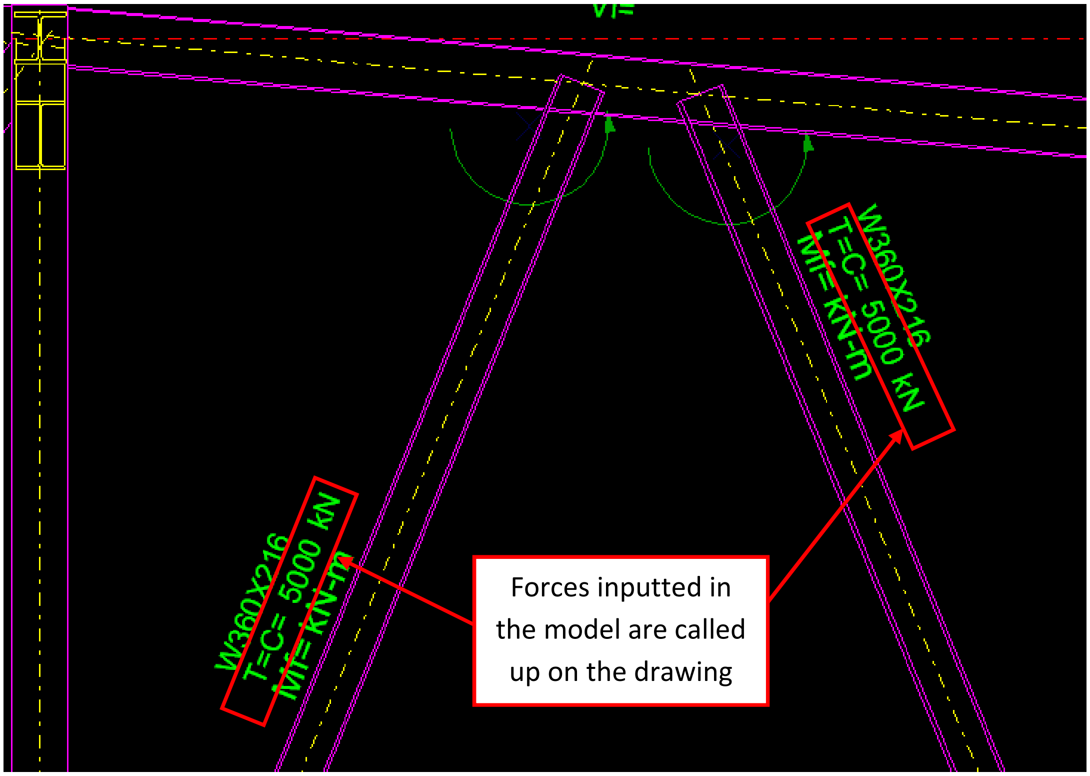


Figure 69: Elevation drawing showing how the forces were added automatically on each member.

Information was also added to the Tekla model for the purpose of filtering to help make it easier to add certain elements on the drawings and in the model, and to identify member types and percentage of model completion. In terms of the drawings, truss names were given to certain trusses (e.g. T-51) (Figure 70) that could be called up on truss elevation drawings (Figure 71) and on a truss plan (Figure 72) showing each truss' location. In terms of the model, data was input in the attributes of each member in Tekla showing where each member came from (e.g. some members came from the SAP analysis model and some members came from other analysis models) (Figure 73) These members could later be filtered easily to export to various analysis and design software. The last information that was added in terms of filters was colours. Colours were used for various purposes such as differentiating between member types like beams, columns, etc., or for showing completion of the model (Figure 74). To show completion, the team used yellow to represent up-to-date member size and geometry, and all other colours to represent members that still required updating.

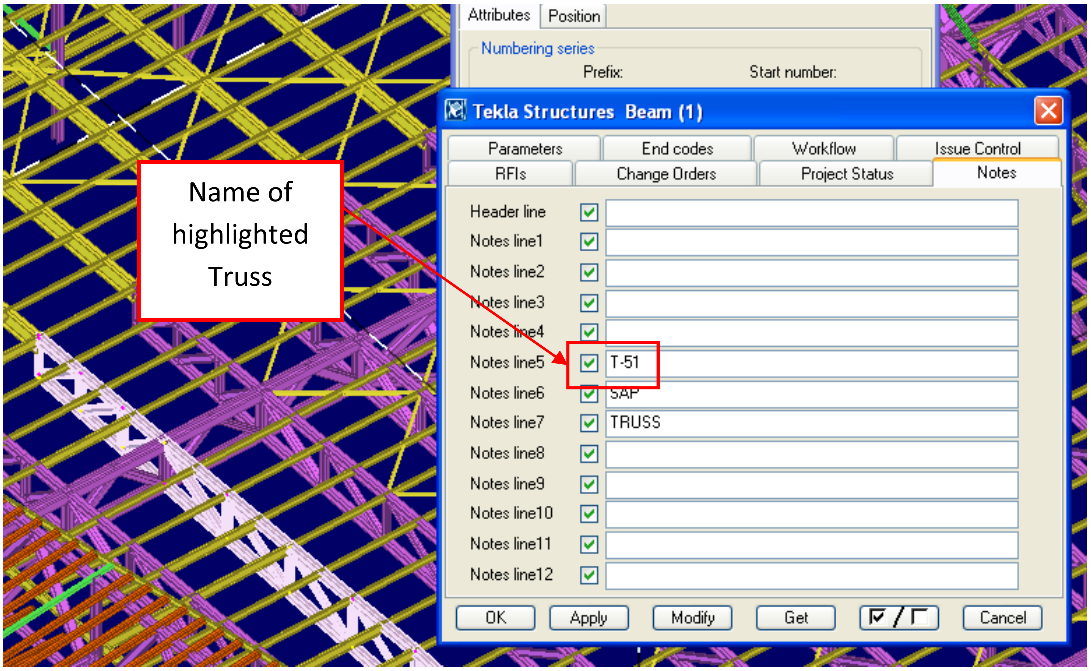


Figure 70: Names were given to trusses in the model that could then be called up automatically on a truss elevation and truss schedule.

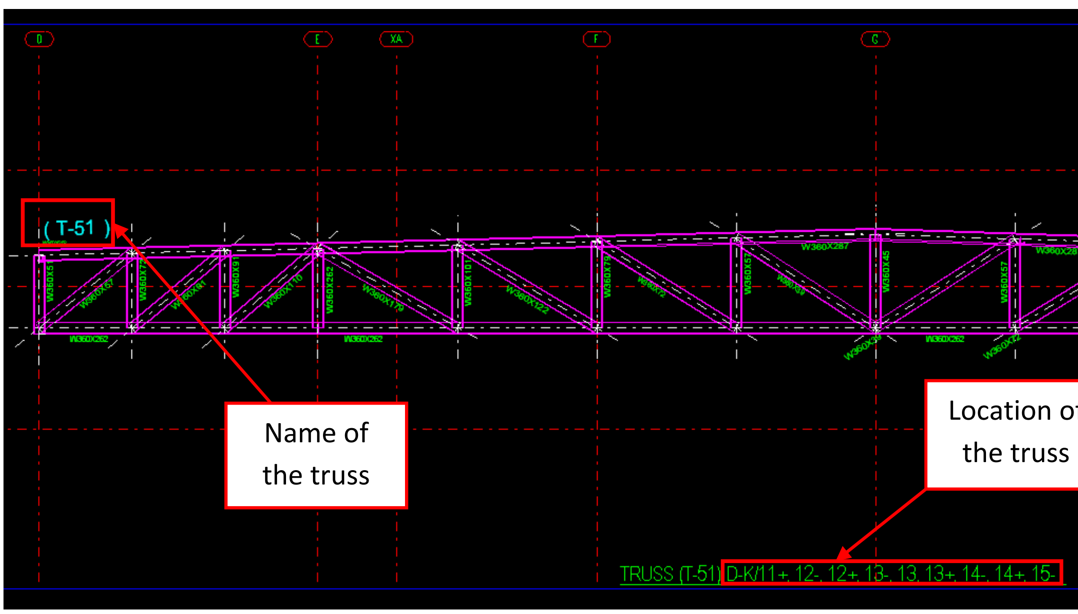


Figure 71: Example of a truss elevation showing the name of the truss and where it is located. The truss name and location appeared automatically on drawings using specific attributes added to the model.

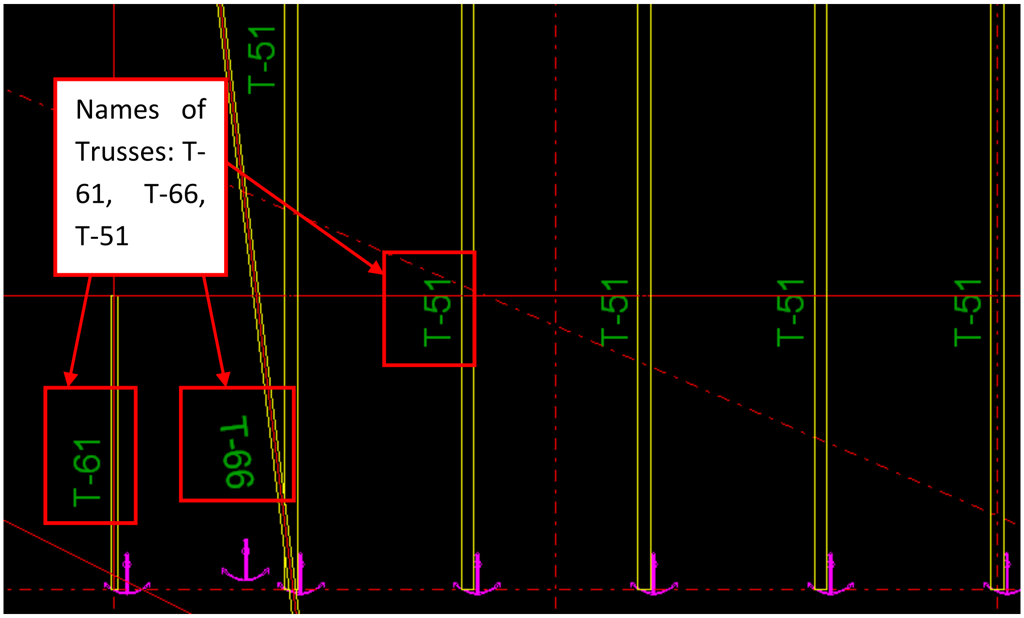


Figure 72: Example of a truss schedule which is a plan drawing showing the locations of steel trusses. The truss names are added automatically.

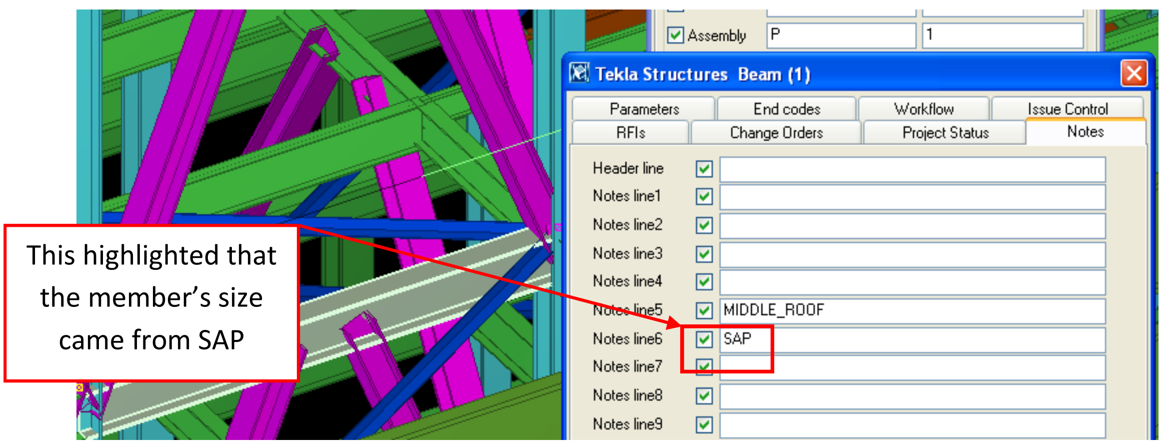


Figure 73: Properties added to members in order to differentiate the analysis program used. This attribute would help to filter members out for export to specific analysis programs. The member shown would be exported to a SAP analysis model for design.

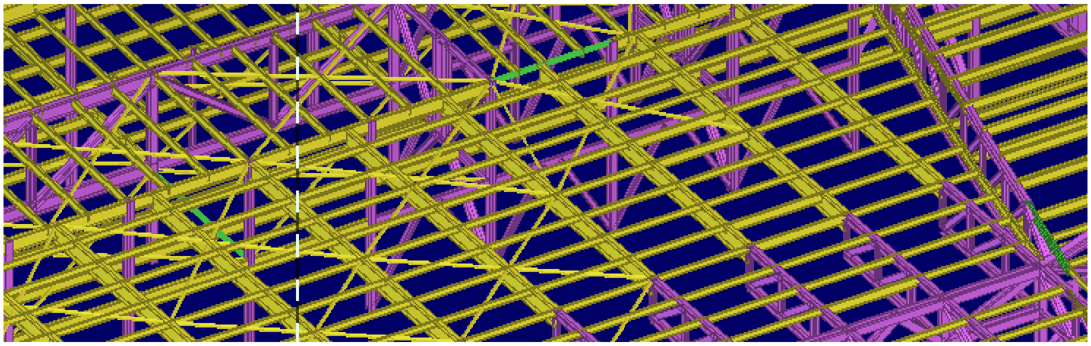


Figure 74: Members shown in yellow represent the members that have been updated to match current geometry and sizes. All other coloured members still require updating.

Coordination between Consultants

BIM enabled effective coordination between the architect, design consultants, and contractor on this project, which was critical for the timely delivery of this facility.

Structural and Architectural Coordination

There was open and efficient communication and coordination between the structural engineer and the architect. Figure 75 presents a snapshot of the architect's 3D model of the roof geometry. It was a large benefit to have open sharing of models between the two consultants as this is often not the case on other projects. The process of sharing the models involved the architect initially creating their model in Revit Architecture. Once created, they would export their model in a 3D drawing format (dwg) which could be then imported into the Tekla Structures model. The architect would also send a 2D drawing with key workpoints in order for the structural engineer to not only line up the model, but also double check the workpoints. Once the model was imported correctly, the structural engineer used it as a reference surface in order to model their structural frame. This process would go through multiple iterations as the design evolved. Throughout the process, the architect would also import an exported 3D drawing of the structure, which they would use to compare and integrate with their own design.

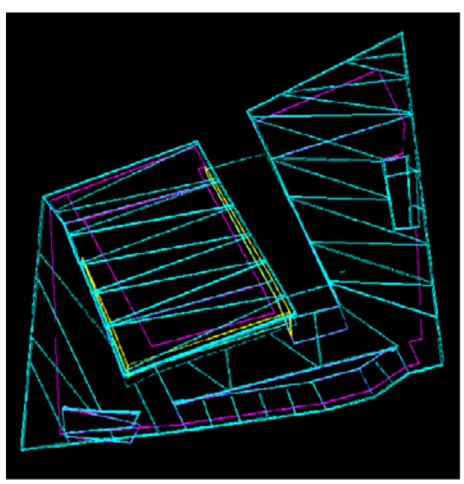


Figure 75: Architect's 3D plane model which the engineers aligned their members to.

Structural and Mechanical Coordination

The mechanical engineers used 2D and 3D software. The 3D software used did not have a good interface for importing large models, and as a result, they had to resort to using the 2D structural plans instead of taking advantage of the 3D structural model. However, they were able to take advantage of the 3D structural model by comparing their 3D mechanical layout with the structural model in Navisworks. The mechanical trade Fred Welsh continued with the 3D modeling of the mechanical on the project, creating more of an as-built model as shown in Figure 76.

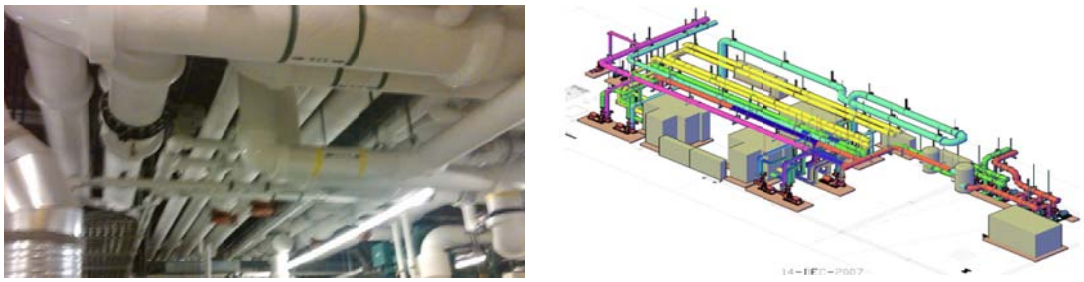


Figure 76: Central Plant photo (left) and model (right) created by the mechanical trade Fred Welsh.

Structural and General Contractor Coordination

The contractor was a large supporter of BIM technology on this job. Figure 77 shows a snapshot of the 4D model created using Navisworks Timeliner. The 4D model was created by linking the contractor's schedule with the consultants' 3D models that were imported into Navisworks Timeliner. The model was mainly used to plan the construction and erection of the concrete and steel and to communicate the construction plan and schedule to all the sub-contractors on the project. Further, the 4D model was used in a number of other ways including the planning of the installation of the green roof and identifying the temporary bracing requirements throughout the erection of the building. The general contractor also used Navisworks clash detective to identify conflicts between the architectural and structural models and the mechanical trade's model.

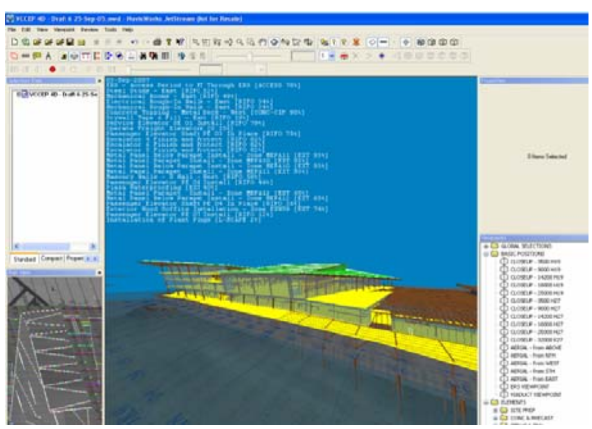


Figure 77: 4D model created in Navisworks.

Quantity take-off (structural only)

Performing quantity take-off is a time-consuming process that is particularly challenging on complex projects such as the convention centre. On this project the structural engineer was able to use the Tekla structural model to generate lists of sizes and weights of steel in any specific area of the model at any given time, which was beneficial for owner, the structural engineer, and the cost estimating consultant. A report could be generated at any time that would provide the breakdown of each member's individual weight and the combined weight of all the members in any selected group (Figure 78).

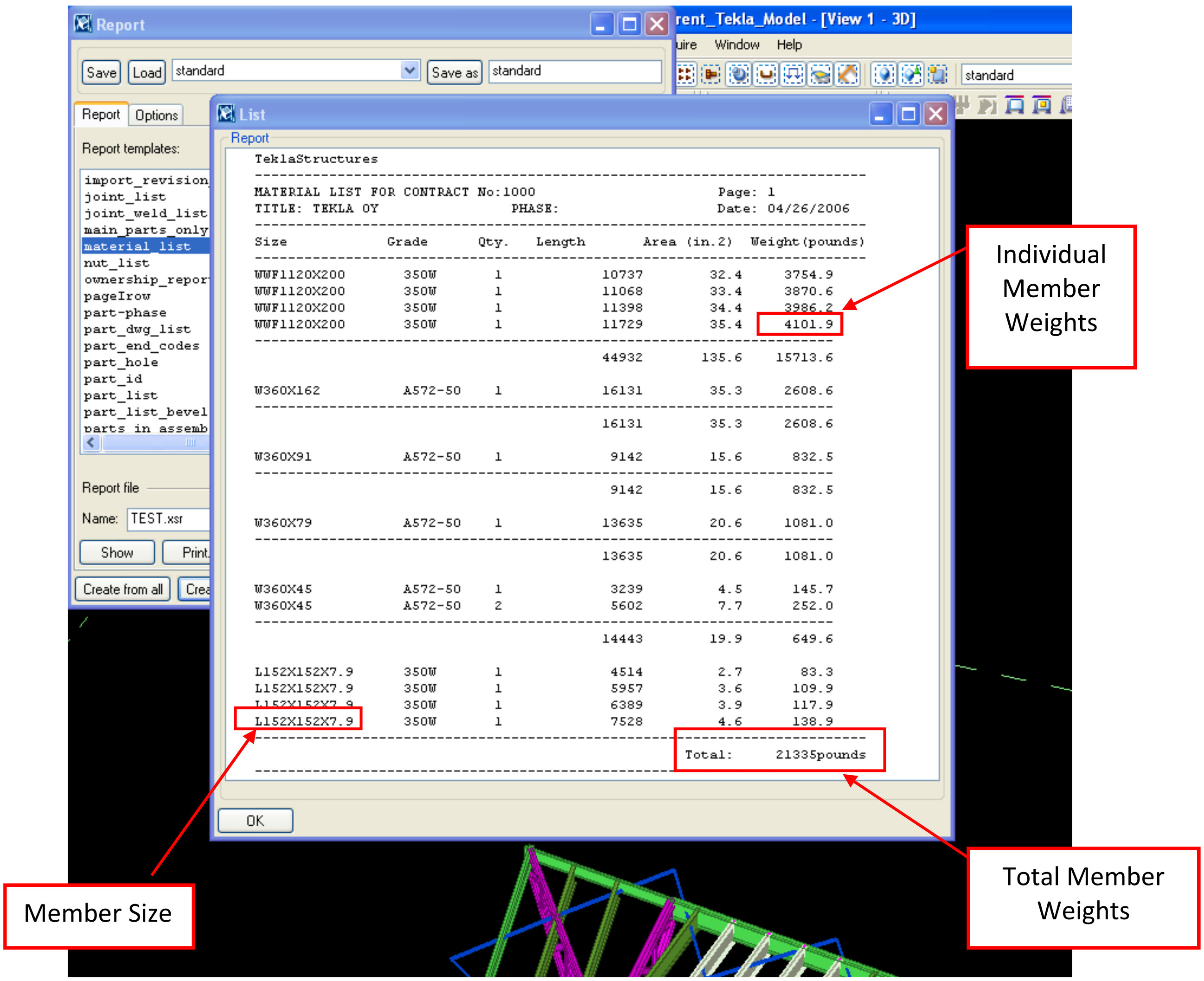


Figure 78: A report that was generated from the highlighted members listing sizes, individual weights and total weights.

Cost estimates were derived by applying a unit rate cost to the associated steel weights and adding for such factors as connection details and contingency. Weights were checked on a weekly basis to make sure that the structural engineer's design was on budget, and to keep the client abreast of any large variations. The difference between the estimated and actual material weight of the project was very small as the original estimator had vast experience in large steel projects. The unit price of steel had just gone through a large rise in price up to the start of the design stage of the project. However, from the start of design through the time steel fabrication bids were submitted, the unit price of steel remained fairly stable.

4D Coordination of Steel and Concrete

Normally erection of the steel and pouring of the concrete for a building would be planned from the 2D structural drawings. On this project, erection planning was accomplished using 4D modeling in Navisworks Timeliner. To create this model the structural engineer and general contractor had to go through a number of steps that are summarized below:

1. The structural engineer initially had to divide up the steel model in Tekla into segments that matched the zones of steel erection (Figure 79). The engineer also modeled the concrete in zones previously defined by the contractor based on planned pours.
2. The structural engineer exported the individual segments (steel and concrete) of their 3D model into a format supported by Navisworks Timeliner.
3. A total of 130 models were then imported into Navisworks and linked to a schedule that consisted of both the steel erection schedule (created by the steel fabricator) and the concrete pour schedule (created by the General Contractor) for creation of the 4D model (Figure 80).

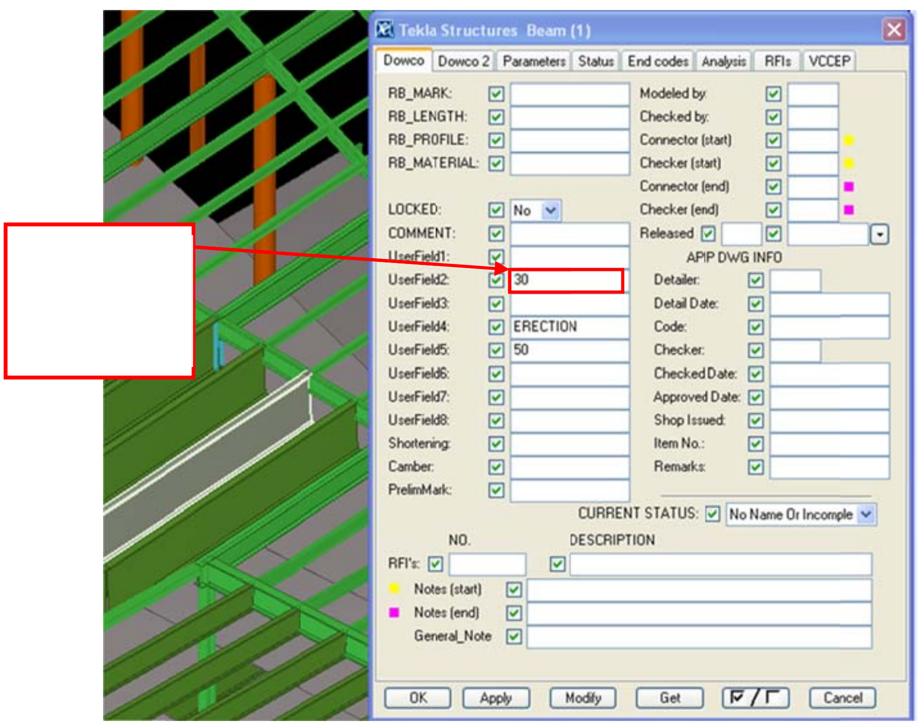


Figure 79: Division numbers were assigned to the steel in Tekla Structures to support exporting to Navisworks Timeliner for 4D modeling of steel and concrete work.

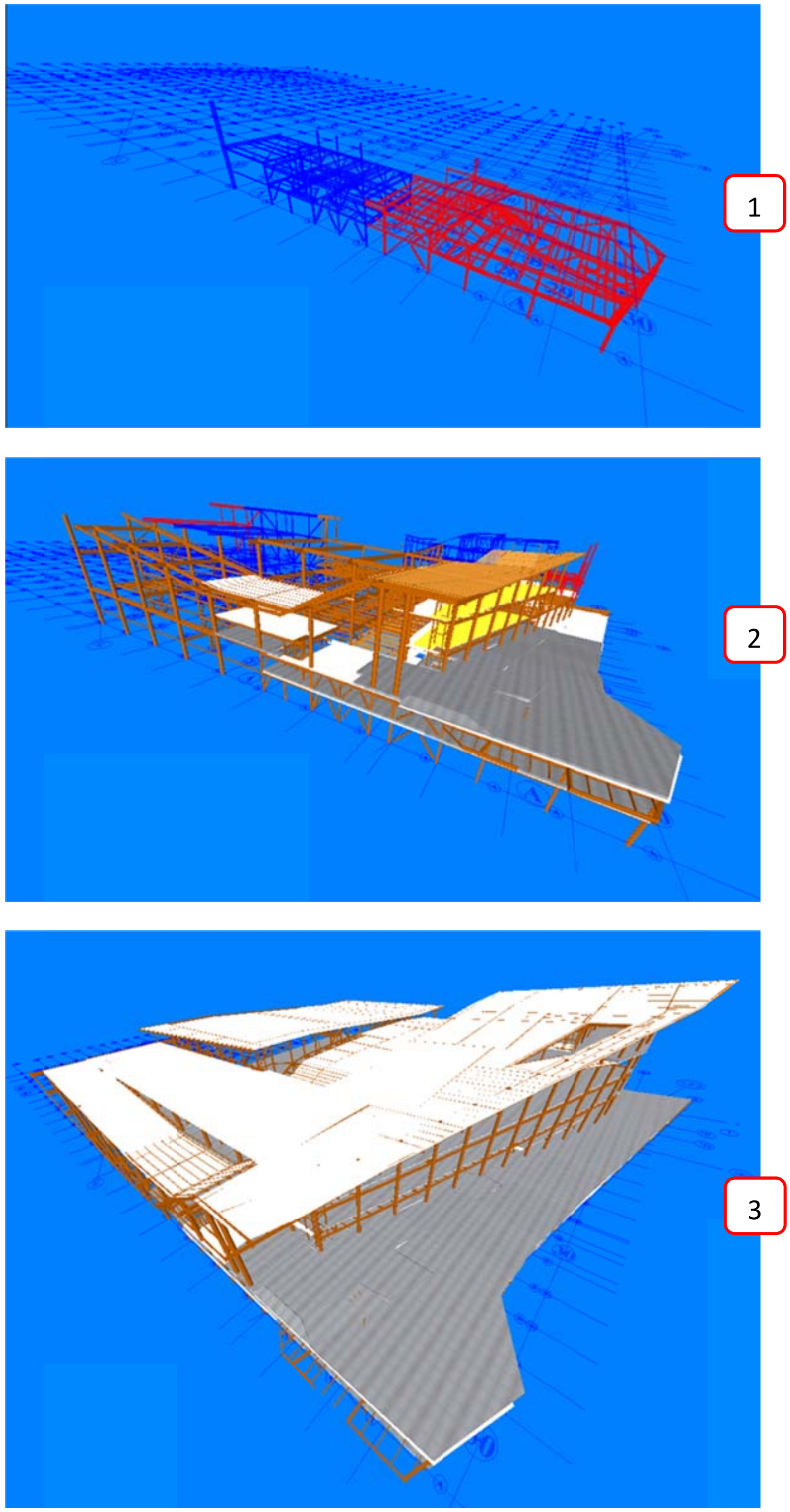


Figure 80: 4D visualization showing: (1) two zones of steel erected; (2) approximately half the steel structure and concrete pours constructed; (3) the completion of the steel and concrete structure.

4D Analysis for Temporary Bracing

The final stage consisted of the structural engineer using the 4D model to review the structure for stability purposes. This task involved reviewing the model at different times during the construction period to establish when temporary bracing was required for maintaining the structure's stability. The requirements for temporary bracing were communicated through 2D marked up viewpoints that were exported directly from the 4D model (Figure 81).

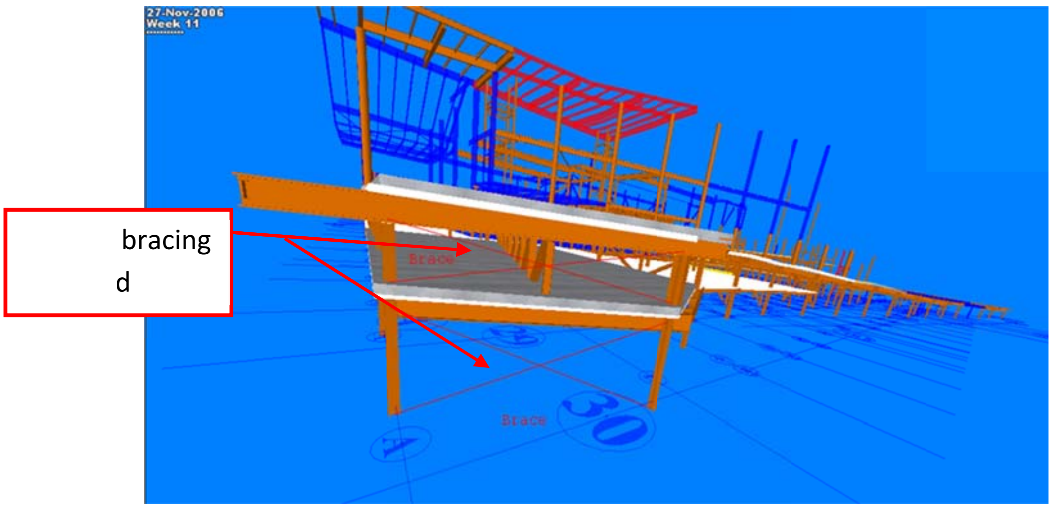


Figure 81: Engineer steps through the 4D model to identify where temporary lateral bracing is required during construction.

Issuing the 3D Structural Model

Issuing the structural model involved a very systematic process that included tracking members by phase numbers, colours, and issue numbers. These items were key in maintaining a fast-tracked pace on the project.

<u>The following process was followed in order to issue the 3D structural model:</u>

1. Engineer creates the model with correct sizes and geometry
2. Engineer releases the model in defined sectors for steel detailers to connect and create shop drawings
3. Model is tracked using numerous methods including *phases*, *colours,* and *a sector layout and issue numbers* which will be discussed further:

   - Phases: Each member in the model had a phase added to it to keep track of the changes that occurred since the previous issue, such as phase 1 = 'deleted member', phase 2 = 'new member', phase 3 = 'profile changed', etc. (Figure 82).

   - Colours: Due to the fast-tracked nature of this project, the design was broken up and issued in smaller packages that were colour-coded to identify the status of design for each member. This colour-coded status indicated which members were correct, which members were almost complete (correctly sized members with incorrect geometry), and which members were on hold (members with incorrect sizes and geometry) (Figure 83). These colours gave the detailers a clear visual of which members could be worked on (finalized members), which members could be used for material take-off (almost complete), and which members must be left untouched (on hold). The most important part of this colour-coding scheme was the members that were correctly sized with incorrect geometry. These members were crucial because the sizes enabled the detailer/fabricator to order the steel long before it got detailed ensuring material availability.

- Sector Layout: a sector layout was first established showing which areas would be released at a specific point in time (Figure 84). The sector layout shows what steel is released in a specific sector (issue). The simplest steel to fabricate was released initially since it included the largest volume, followed by the smaller amount of more complex pieces of steel.
- Sector Issue Numbers: once the sector layout was established the sector (issue) numbers were assigned to the members within each specified sector. These numbers were input into the member's properties in a specified attribute box titled "issue #" (Figure 85). By entering the issue number in the attribute boxes of a group of members you can easily select a certain sector using a 'select filter' and issue it to the detailer. The members are exported as a small Tekla model that the detailer can import into their large Tekla model. Also using filters, you can identify if there are any mistakes in how the sectors were defined. The lead structural engineer would go over each individual sector before it got issued, to look for incorrect sizes or geometry.

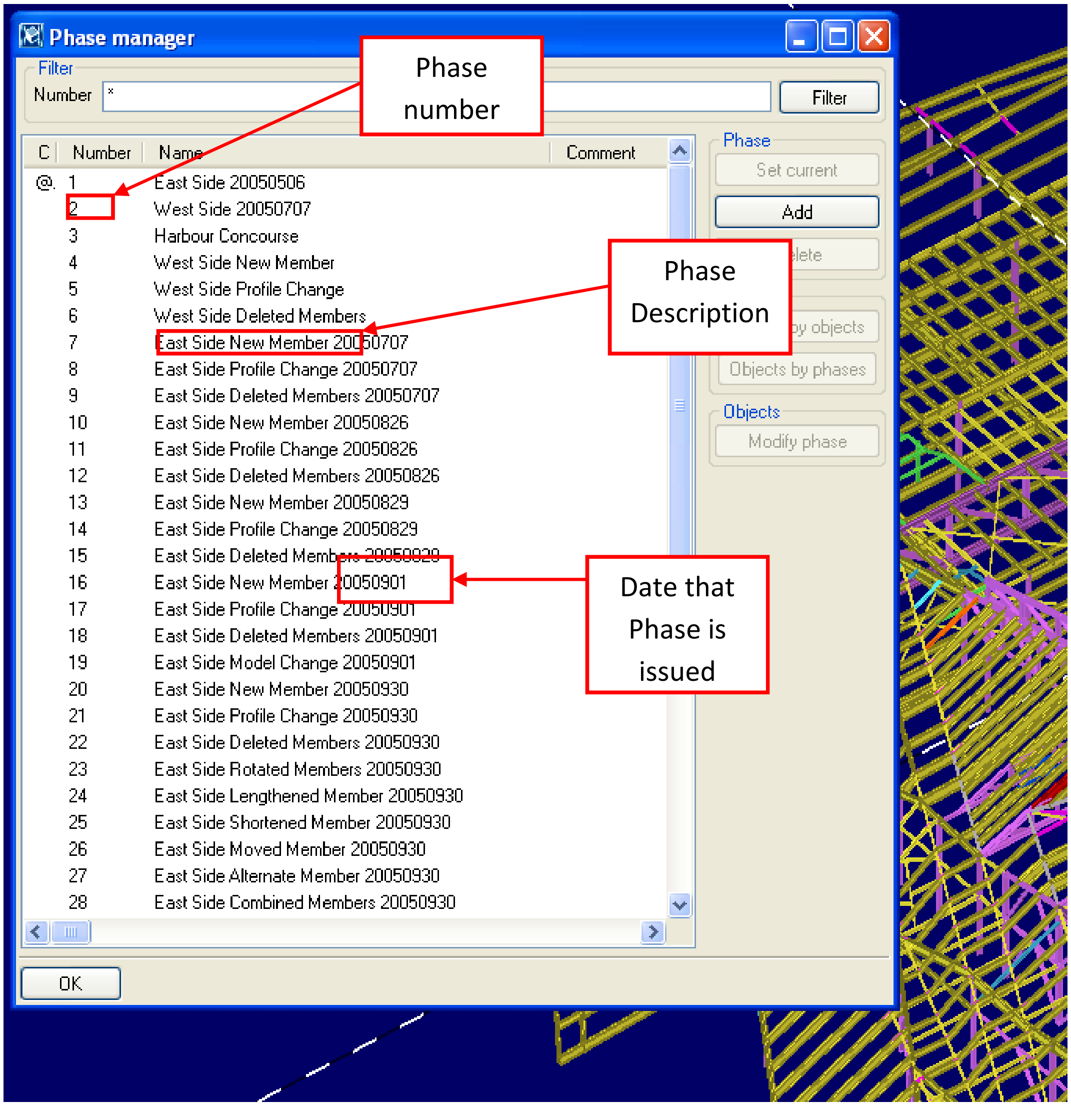


Figure 82: List of the different phases that were used in the model. With each phase there is an associated phase number, phase description, and issue date.

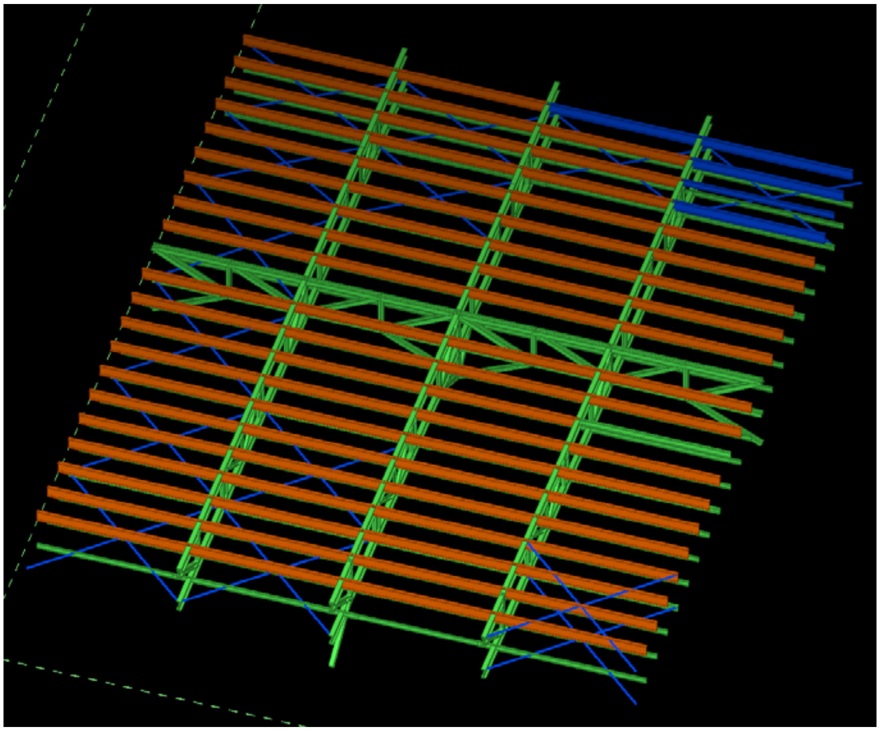


Figure 83: This group of members makes up a sector that will be issued to the detailers. The colours let the detailer know which members they could work on and which ones they should leave alone.

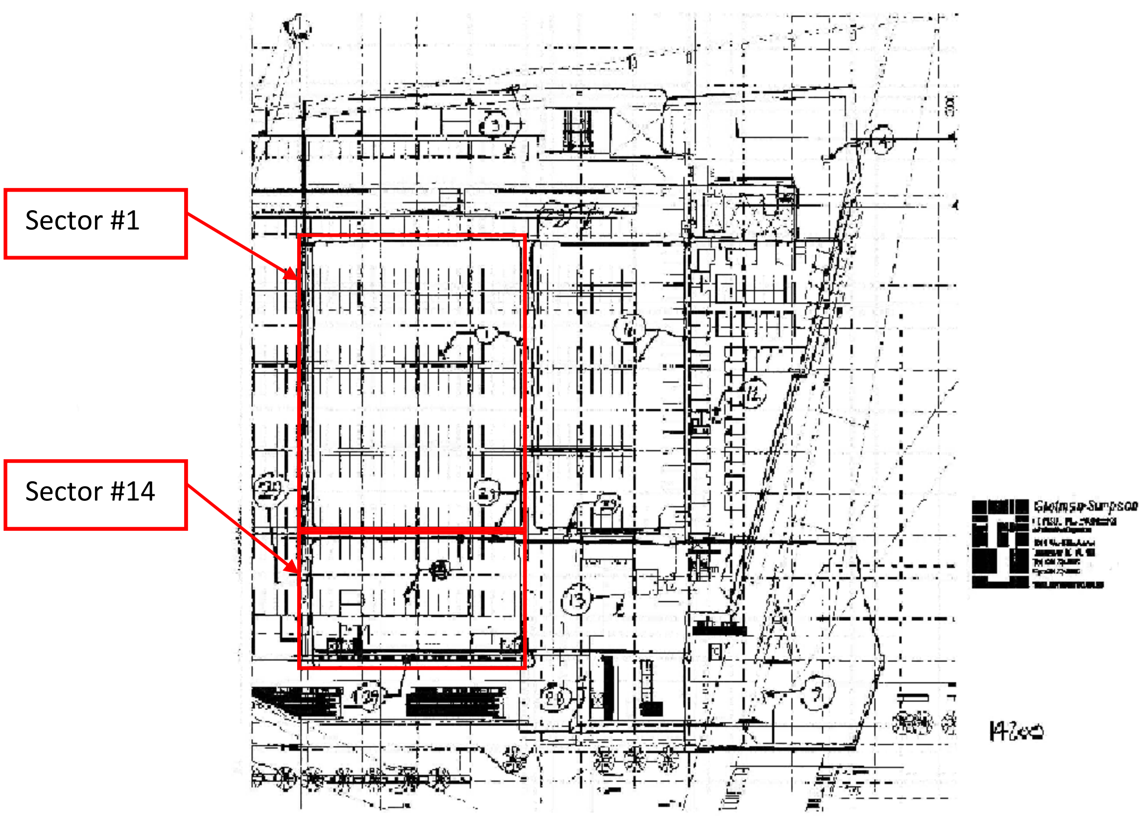


Figure 84: Sector layout plan that shows specific sector numbers (1, 14, etc.) for areas of steel.

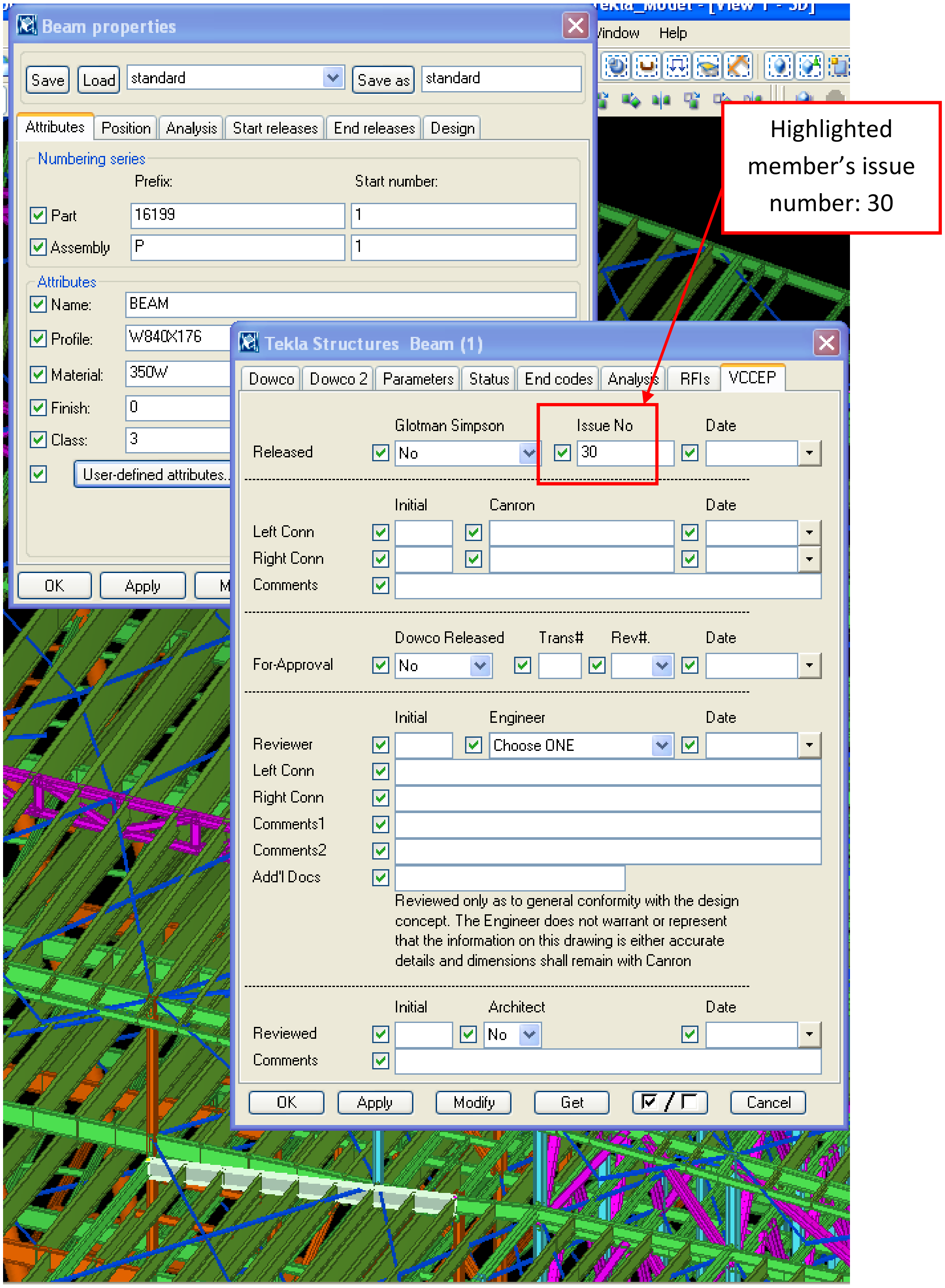


Figure 85: Issue numbers were assigned to members within a specific sector area (e.g. any member in sector 30 was assigned the issue #30).

'Virtual' Shop Drawing Approval Process

The shop drawing approval process was a paperless procedure that involved checking the 3D model. This saved valuable time because the engineer no longer had to look at thousands of individual shop drawings, then find that shop drawing on the steel detailer erection drawing, and then compare it with the engineer's structural drawings.

After the model was detailed, it needed to be approved by four consultants:

1. Architect: Checked the correctness of the geometry, which was accomplished by overlaying their architectural Revit model with the engineering Tekla model.
2. Mechanical Engineer: Checked for clashes between the mechanical systems and the structural systems.
3. Contractor: Evaluated the design for constructability. After establishing constructability, the contractor could start planning the erection procedure.
4. Structural Engineer: Checked for correct member size, grade of material, and moment connections as required.

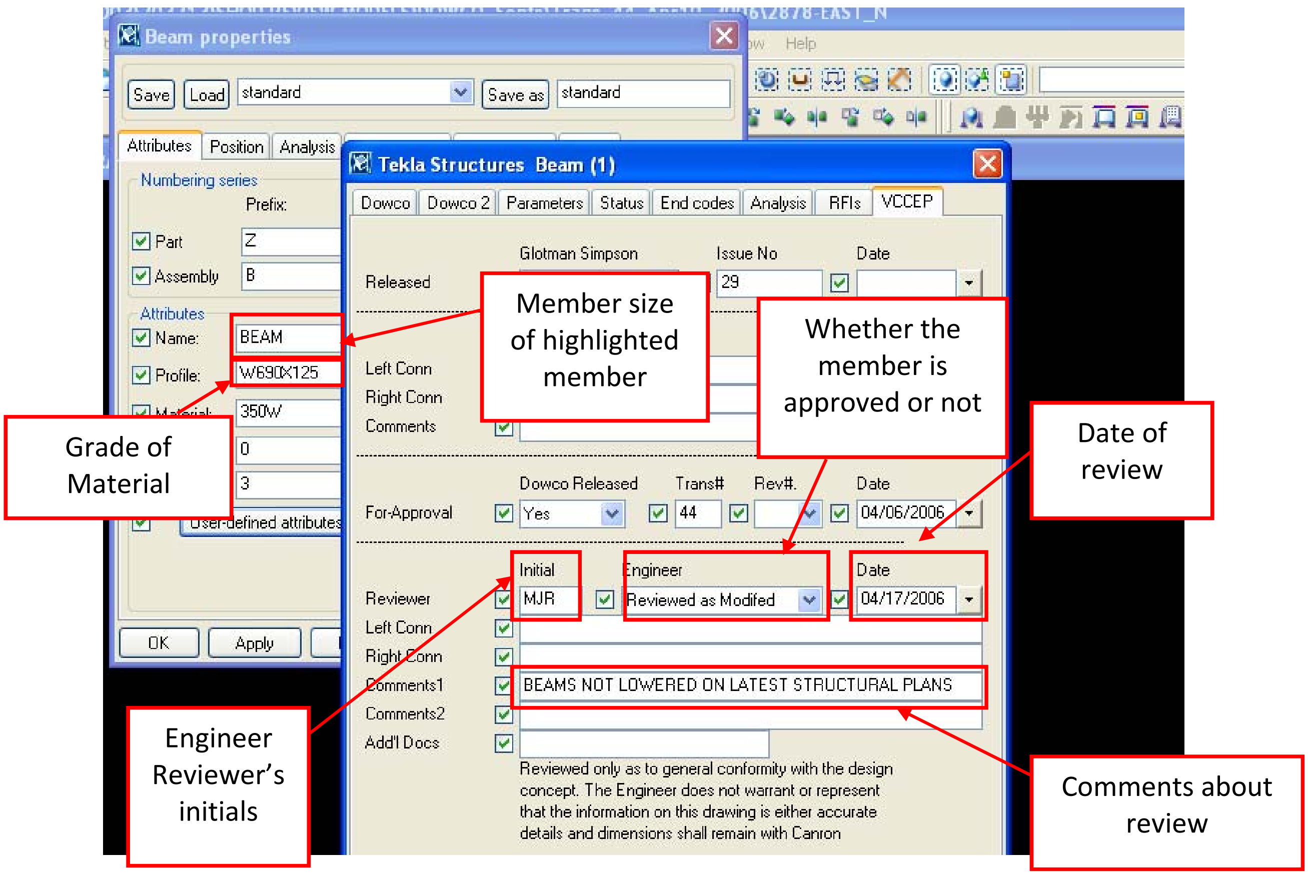


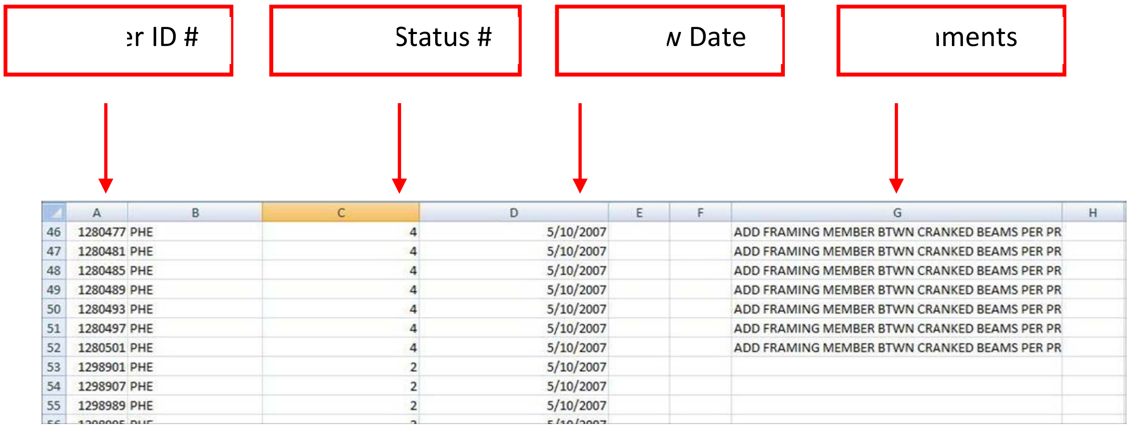
Figure 86: Virtual approval process - for each member in the model, the engineer had to enter their initial, whether they approve the member or not, the date of review, and any comments.

Figure 86 shows the different information input into the model as part of the virtual shop drawing review. The following describes the process that was followed:

1. The approver input their initials, stated whether the member was approved or not, and added their comments in each member's properties box.
2. A spreadsheet summarizing the Engineer's review for approval was created. (Figure 87). This spreadsheet showed the member ID number, stated whether the member was correct or not

(review status), listed any comments attached to the incorrect members, and provided a date for when the member was reviewed.

3. These comments were then associated with a certain colour in the model to provide a visual representation of the status of the project (Figure 88).



	A	B	C	D	E	F	G	H
46	1280477	PHE	4	5/10/2007			ADD FRAMING MEMBER BTWN CRANKED BEAMS PER PR	
47	1280481	PHE	4	5/10/2007			ADD FRAMING MEMBER BTWN CRANKED BEAMS PER PR	
48	1280485	PHE	4	5/10/2007			ADD FRAMING MEMBER BTWN CRANKED BEAMS PER PR	
49	1280489	PHE	4	5/10/2007			ADD FRAMING MEMBER BTWN CRANKED BEAMS PER PR	
50	1280493	PHE	4	5/10/2007			ADD FRAMING MEMBER BTWN CRANKED BEAMS PER PR	
51	1280497	PHE	4	5/10/2007			ADD FRAMING MEMBER BTWN CRANKED BEAMS PER PR	
52	1280501	PHE	4	5/10/2007			ADD FRAMING MEMBER BTWN CRANKED BEAMS PER PR	
53	1298901	PHE	2	5/10/2007				
54	1298907	PHE	2	5/10/2007				
55	1298989	PHE	2	5/10/2007				

Figure 87: Report generated from the model summarizing the review of each member.

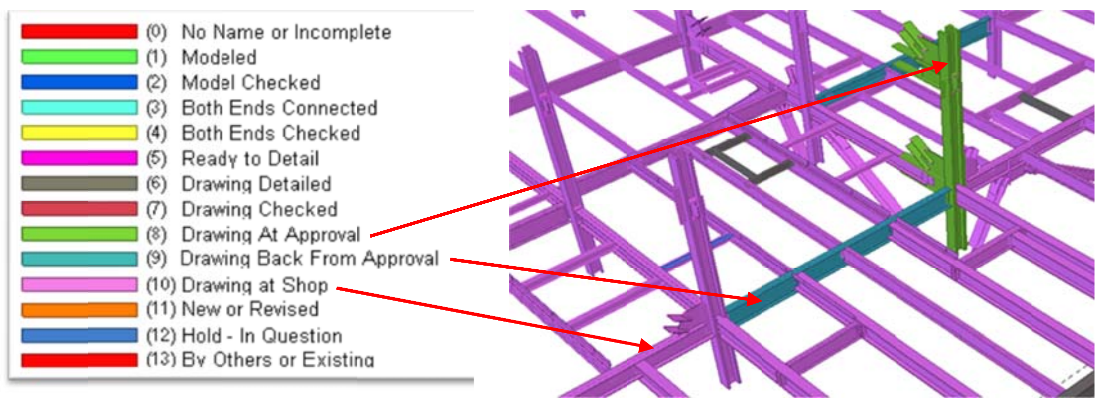


Figure 88: Visualization of the reviewed model.

Information Exchange

The models were shared using an ftp site maintained by the architect. Email was also used for the exchange of models, especially in the virtual approval process. One of the main benefits of this process was the fact that the approval drawings could be sent to all the consultants at one time instead of hard copy drawings having to go from one office to various locations.

3.4.3 ORGANIZATION

Contractual Relationships

There were no special contractual relationships between the parties that detailed specific BIM requirements. The project was of a traditional Design – Bid – Build form. However, the project was different in the sense that the model played an important part in how this project was tendered. The model was important in the following two areas: 1) the Steel Fabricator and the Detailing team had to use the same BIM software (Tekla Structures) that was used by the structural Engineer, in order to facilitate the contract drawing submission process and the shop drawing review process, and 2) the Steel Fabricator and the Detailing team received the 3D model with the contract drawings at the bid stage to help facilitate a shorter tender period by allowing automatic quantity take-offs and providing better visualization of the project.

3.4.4 PROCESSES

Project Execution Planning

In terms of the use of BIM in the design phase, there was no exact plan of how to use BIM but more of a mandate that 3D modeling must be conducted by all participants. This resulted in models being exchanged on a regular basis between all of the consultants especially the architect, the structural engineer and the mechanical engineer.

In the approval phase of the project, PCL created a detailed flow chart of the virtual approval process (Figure 89) that was used as a guide by all the consultants and trades involved in the process.

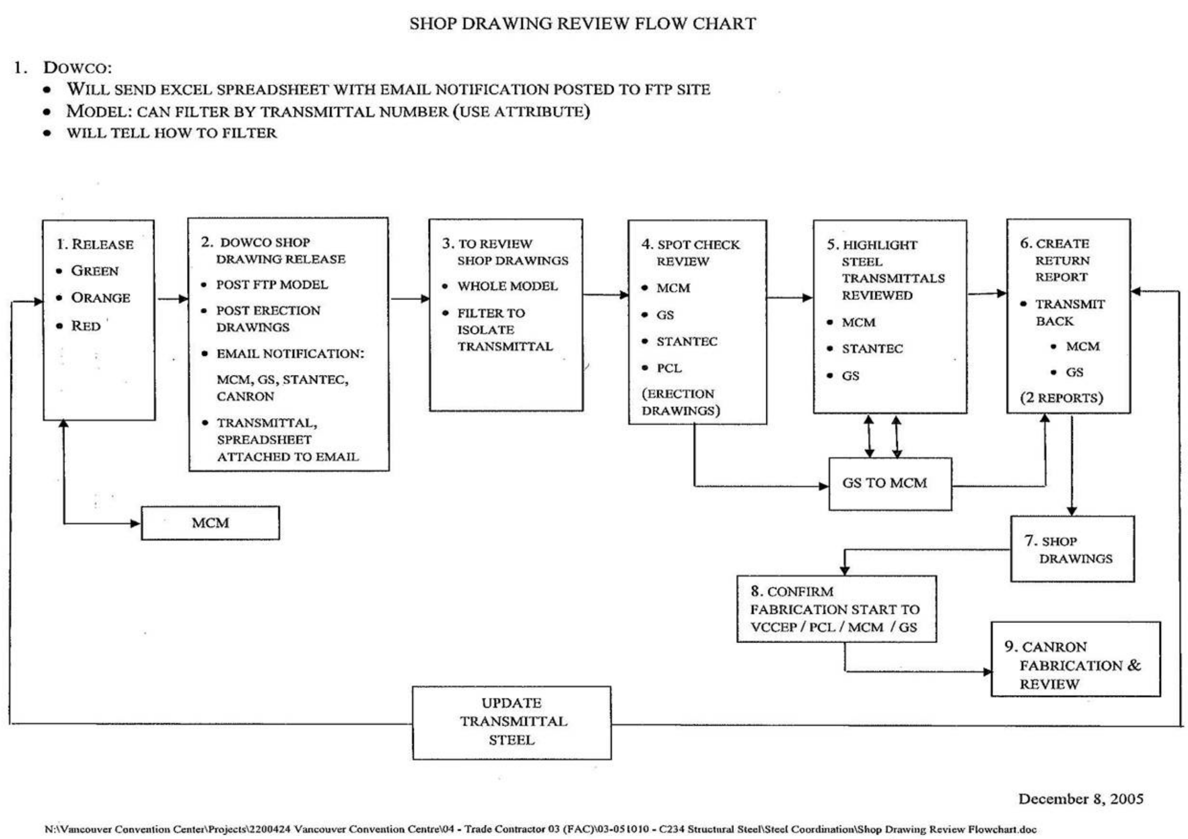


Figure 89: PCL's shop drawing review flow chart used as a guide for conducting the Virtual Approval process

Workflows

One of the main issues encountered on this project was the subject of model ownership. This came into play in the workflows because the structural engineer released their structural steel stick model to the steel detailer to model in connections and create shop drawings for fabrication. On this project, the process of model ownership consisted of the structural engineer releasing their model at the tender issue. Between the tender issue and the award of the contract to the steel fabricator and detailer, the structural engineer continued to develop the model. Once the job was awarded the model was passed off to the steel detailer in order to create an advanced bill of material to pre-order the raw steel. The model was then returned to the structural engineer to finalize the design before issuing for construction.

3.4.5 EVALUATION

The following sections outline the benefits, challenges and lessons learned with particular emphasis on the scope related to the design and construction of the steel structure.

Benefits

- **Understanding the complex geometry during the design phase:** The senior structural engineer was able to identify design issues much earlier by using the structural BIM model.
- **Elimination/major reduction of shop drawing:** The virtual approval process eliminated the use of shop drawings during the review process though shop drawings were still created for steel fabrication purposes. Because of the virtual approval process, shop drawings were created after the model was checked which eliminated rework that often results when the physical shop drawings are used in the approval process.
- **Increased coordination among consultants during design phase:** Working with the 3D models facilitated open coordination and communication between all the consultants.
- **Improved coordination between design and construction:** The mechanical trade was able to develop the as-built 3D models of the central plant and mechanical piping throughout the building. The contractor used this model for clash detection purposes with the Architectural and Structural models.
- **Increased ability to fast track the project through area releases:** The structural model was initially issued in individual segments which matched the steel erection scheme.
- **Able to identify changes in design more quickly:** The visualization and enhanced collaboration enabled by BIM allowed the project team to identify design changes and visualize potential impacts more efficiently.
- **Automatic quantity take-offs of the steel structure saved considerable time:** The structural model contained material weights that were exported and used with the most recent unit cost data to help verify budget compliance throughout design.
- **More accurate bids:** The structural model was issued with the drawings in the tender package, which enhanced the accuracy of the bids and shortened the time required for bidding.

Challenges

- **Lack of clarity concerning who owned the model:** The model was originally issued with the drawings at the tender stage of the project. The model was further exchanged a number of times before the issue for construction. Clear hand-off procedure with pre-planned timelines would have improved the process and saved confusion.

- **Clarity in scope of modeling:** The scope of the structural model was not clearly defined at the outset of the project. The general consensus was that a structural engineer must only release a stick model, which means only the main pieces (i.e., beams, columns, bracing, etc.). There were many details that needed to be added to the model, including connections, escalator supports, stair stringers, hand rail, edge angles, etc. Clear scope of the modeling is required to communicate which party is responsible for modeling the details.

- **Additional coordination is required:** Because both the model and drawings were issued together, and only the elevation drawings were issued directly from the model, the other 2D drawings had to be compared and checked with the 3D model.

- **Additional time may be required:** BIM probably took more time than it would to create 2D drawings for a project. However the improved collaboration, improved visualization, and improved reduction in RFI's far outweigh the early increased time and costs in the design phase.

- **Training is required for all involved:** Training and experience in BIM was essential for the success of the project. If project participants do not have adequate modeling experience, employment of model consultants is highly encouraged. For the structural engineering firm, there was an experienced structural modeler employed. In terms of the Architect, they had not performed 3D modeling previous to this project, however, they employed a BIM consultant to help them implement the software in their office and on the project.

- **Changes to the 'plan' may require changes to the model:** Often during the construction phase, unofficial sketches or solutions are incorporated in the field. It is imperative to include these modifications in the model to ensure accurate representation.

Lessons Learned

- **Make sure model ownership is discussed early on:** Model ownership can become a contentious issue if adequate attention is not paid. For example, it is very important to show to what scope and level of detail the consultant will contribute to the model, and at what point that model is handed off to the downstream discipline. On this project, the model was passed back and forth between the structural consultant and the fabricator, which may have been avoided if there was a clear point of hand-off.

- **Be wary of growing pains for all parties involved: Adequate time** needs to be planned for companies to learn new software and learn new ways of working when it comes to Building Information Modeling. There will be times when problems arise, but it's important to be willing to push past these issues.

- **The contractor should be selected early.** It is important for the contractor to be chosen early on in the design phase to ensure that they are working closely with the consultants and adding construction knowledge during this phase.

3.4.6 BIBLIOGRAPHY

Chami, Camille. (2009) *Vancouver Convention Centre West Broadcast and Media Center for the Olympics.* Accessed on November 24, 2011. Retrieved from http://www.archinnovations.com/featured-projects/civic/vancouver-convention-centre-west/

Naturally:Wood. (2010) *Vancouver Convention Centre: Commerce, Public Space and the Environment.* Case study. Accessed on November 24, 2011. Retrieved from http://www.naturallywood.com/sites/default/files/Vancouver-Convention-Centre-Cdase-Study.pdf

3.5 UNIVERSITÉ DE MONTRÉAL with ARCHIDATA (QUEBEC)

This project was chosen as a 'best practice' case study for the following reasons:

- It provides an excellent example of BIM use for Building Operations and Management.
- It demonstrates a variety of ways that BIM can be used for an owner with a large real estate portfolio.
- It illustrates the usefulness of BIM data geo-referenced and integrated in an intelligent Virtual Plan room.
- It demonstrates the value of using 'open standards' like IFC to provide an application-independent solution for working with BIM.
- It utilizes an innovative approach to facilitate the reuse of legacy data .

3.5.1 PROJECT DESCRIPTION

This case study focuses on the application of BIM for Operations and Planning for a large owner, the *Université de Montréal (UdeM).* UdeM worked very closely with ArchiDATA to develop the campus model to support a variety of facility management functions (Figure 90). ArchiDATA is a software developer and service provider that offers an innovative technology for converting 2D CAD drawings to BIM, as well as a system for space management and building operations. The vision of the UdeM is to adopt BIM to optimise operational efficiency and provide better access to the building information on campus. The Buildings Branch, Direction des Immeubles (DI), is responsible for operations, planning and space management on campus. They manage a real estate portfolio of about 80 buildings scattered across the university's 700,000 m^2 campus. ArchiDATA was chosen as their technology of choice because it offered the capability to keep plans up-to-date and to generate reports on modifications of the buildings on a periodic basis. This project is an example of advanced BIM use for building operations management.

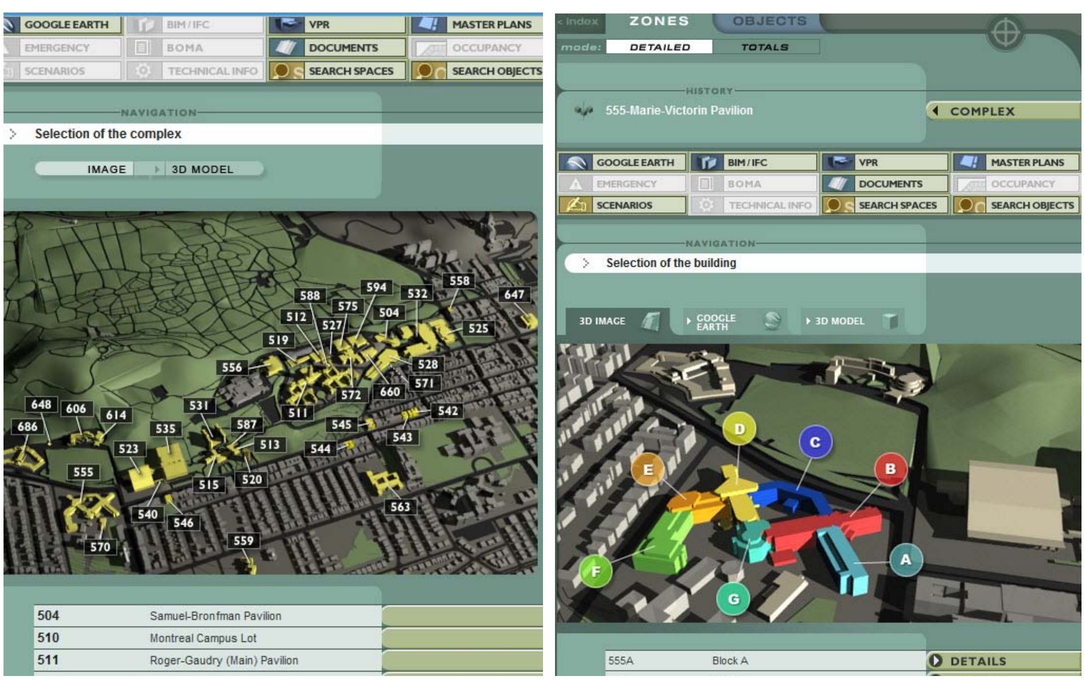


Figure 90: Model of the main campus of Université de Montéral.

UdeM: The Owner's Perspective

The initial mandate was to eliminate paper plans and to automatically generate reports for the Ministry of Education. From there, ArchiDATA was requested to produce a BIM for building operations management. The long-term objective of UdeM is to provide necessary information to all the users through the 3D BIM environment (Figure 91). There are several ArchiDATA users at the UdeM, including the building owners, the building operation managers, planners, security and fire prevention, the project managers and about 100 university staff users. There are also about 130 external users such as architects and engineers who use the system on a regular basis.

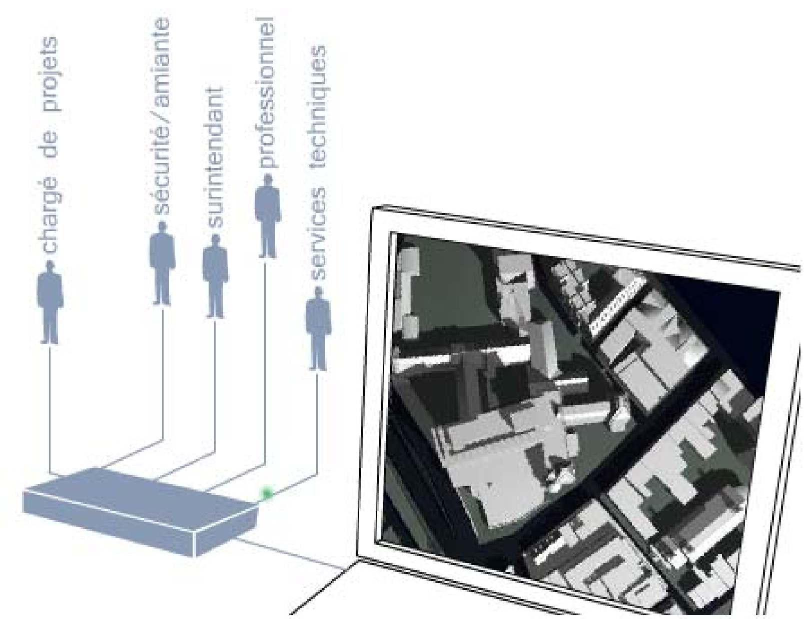


Figure 91: UdeM vision of the BIM environment.

BIM guidelines and specifications will be drafted to ensure proper and consistent BIM development and integration with the existing UdeM repository. Any new project on campus will most likely be delivered using BIM and will follow these guidelines and specifications. BIMs used during previous construction phases will be modified slightly to suit the purposes of Building Operations. ArchiDATA will be responsible for performing these modifications and for creating the Master Plan. The users will be able to view 2D plans, however, these will be 'intelligent' 2D models as ArchiDATA adds a GIS layer on the AutoCAD plans.

The task to convert 2D paper or electronic drawings to BIM started in 2005. The initial data entry work took a number of months and required several employees. Now, only one person is needed to keep the BIM up-to-date and to generate the necessary reports.

There is no deadline set for the complete BIM adoption. The administration supports this plan but cannot impose it quickly, partially because of the unions. Some project managers are convinced that BIM is the future, but there are several who think it is too early to adopt this 'new technology' and do not want to be 'the first' to adopt as they believe the technology is not yet well tested.

ArchiData: The Software Developer / Service Provider Perspective

ArchiDATA offers an innovative technology for converting 2D CAD drawings to BIM, as well as, a system for Space Management and Building Operations: "*ArchiDATA Inc. is a software company that has developed proprietary technology to dynamically generate accurate and reliable real estate management data from paper and AutoCAD architectural and engineering plans. ArchiDATA's Space and Plan Management Solution provides a web-based database of architectural and engineering plans where construction, property, leasing and asset managers as well as third-party professionals can access the most recent version of plans.*" (ArchiDATA Website, accessed on Nov. 2011)

ArchiDATA started about 15 years ago offering building information for space management. This information was based on 2D CAD plans. This service is targeted for building operations management where the user needs information on the space limited by walls and partitions: its use, equipment, finishes, maintenance schedules, etc. With the emergence of IFC as the open standard for BIM, ArchiData developed import/export capabilities to IFC. As a result, ArchiDATA is capable of integrating with a number of IFC-based software, such as Revit, Navisworks, and Solibri, to share and communicate various building information. The information is geo-referenced and can be seen in 3D with Solibri Model Viewer, as well as, on Google Earth.

The CAD-to-BIM convertor developed by ArchiDATA offers an alternative to laser scanning. With an already established updating procedure, the 'as-built' models created with ArchiDATA are typically kept 'current' with 90-95% accuracy levels.

3.5.2 TECHNOLOGY

According to ArchiDATA's website:

- *"ArchiDATA offers a suite of web-based modules that meet the specific needs of property managers. Hence, our clients can integrate the modules according to their management priorities during the following phases: planning, design, construction, leasing and facility management."*
- *"The ArchiDATA Solution is based on a proprietary GIS technology that provides a secure Web-based (https) Virtual Plan Room and BIM (Building Information Model- 3D). This collaborative tool enables all professionals involved in property and construction management to access building plans and technical documents."*
- *"The ArchiDATA software converts paper or AutoCAD plans into alpha-numeric data to feed leasing, facility and asset management systems to ensure best practices and enhance corporate governance. The ArchiDATA System is positioned between AutoCAD and ERPs and IWMS (Integrated Workplace Management Systems) and ensures data integrity."*

The integrated system of ArchiDATA can be used for the following purposes:

- **Unified Building and Facilities Information** – to provide secure, quick and easy access to the latest up-to-date information.
- **Space Management** – to identify, visualize, locate, and archive spaces according to their purpose; the ability to quickly generate 2D and 3D reports.

- **Facilities Management** – to identify and locate equipment on a building, floor, room or workstation even; to generate comprehensive management reports; to seamlessly integrate and exchange data with existing systems.
- **Leasing Management** – to generate color coded stacking and blocking plans of spaces with lease expiry dates and options; to generate comprehensive leasing specifications sheets with dynamic floor plans.
- **Portfolio Management** – to apply a standardized management method to all buildings, allowing managers to make comparisons; to quickly visualize and optimize all real-estate assets.
- **Project Management** – to allow setting up construction or renovation projects by distributing plans online; to create virtual work teams during the conception and execution of projects; to maintain centralized records of construction projects.
- **Scenario Planning Management** – permitting to move an entire unit to a new wing or building including people, equipment and furniture (online); to have all necessary data to plan your relocation project; to simulate variations in unit surfaces/areas.
- **Live Wayfinding** – to generate a route for a user or visitor that wishes to be directed to a service, department or room; to facilitate the updating of your signage system with ArchiDATA's Space Management Module; to link your calendar of activities to the interactive signage system.

The UdeM was mainly interested in the functionality related to operating and managing their campus, which included: Unified Building and Facilities Information, Space Management, Facilities Management, and Scenario Planning Management. The Project Management Module will also be partially used for new construction projects at the university in the near future.

The ArchiDATA platform is installed on a server, where all the plans and models of the 'Virtual Plan Room' are also stored. Those who input information into the system require copies of the program installed on their machines. Others, who are only interested in viewing the information, have access from anywhere in the world as long as they have an internet connection.

Two modules of the ArchiDATA platform are reviewed in this case study:

- The Intelligent Virtual Plan Room
- The Space and Facilities Management Module

The 'Virtual Plan Room'

The Intelligent Virtual Plan Room is a structured archiving system that includes plans from all disciplines. It offers a search engine so that information can be identified and located easily. Initially 2D CAD drawings are converted to 'intelligent' 2½D CAD drawings. 'Intelligent' information is manually added to the drawings, which includes space zones, smart tags for equipment, and fire protection systems. These 2D 'intelligent' drawings are then combined using ArchiDATA into a 3D model by providing some further user input, such as the height between the floors. The model is then geo-referenced and uploaded to Google Earth on a private server. This information can then be used for building management using Maximo, for project management using Primavera, and for design and construction management using Revit, for example.

All existing paper drawings, AutoCAD drawings (.dwg), and BIM-models are organized in the 'Virtual Plan Room' (Figure 92). Access to the Virtual Plan Room is secured and specific rights are given to each user regarding data they can view or use. The 3D IFC models created by ArchiDATA are also included in the Virtual Plan Room, as shown in Figure 93.

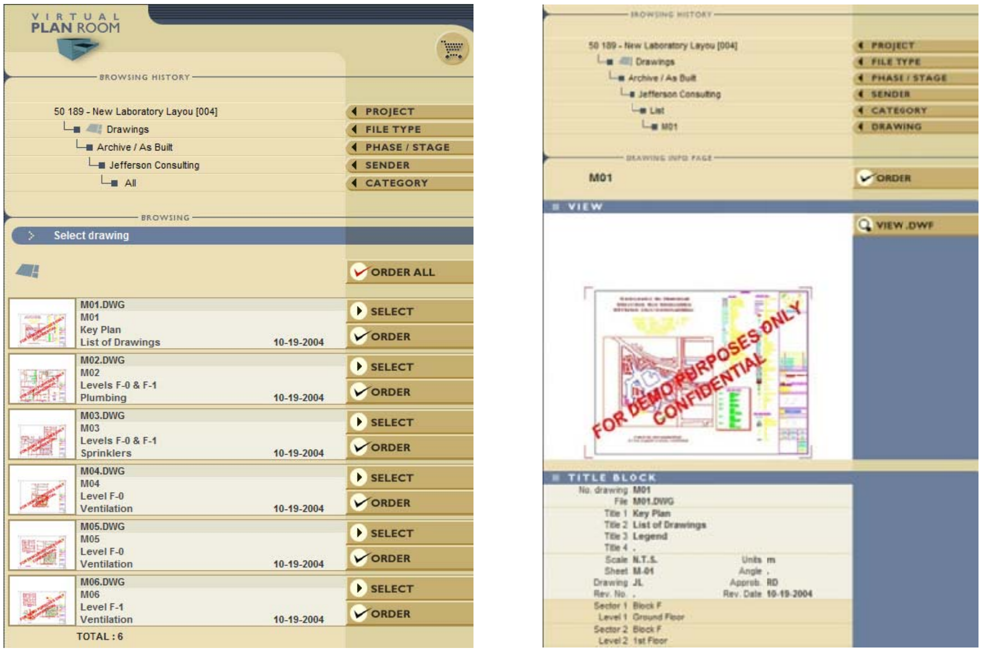


Figure 92: 'Virtual Plan Room': documents to select (left) and information on the selected document (right)

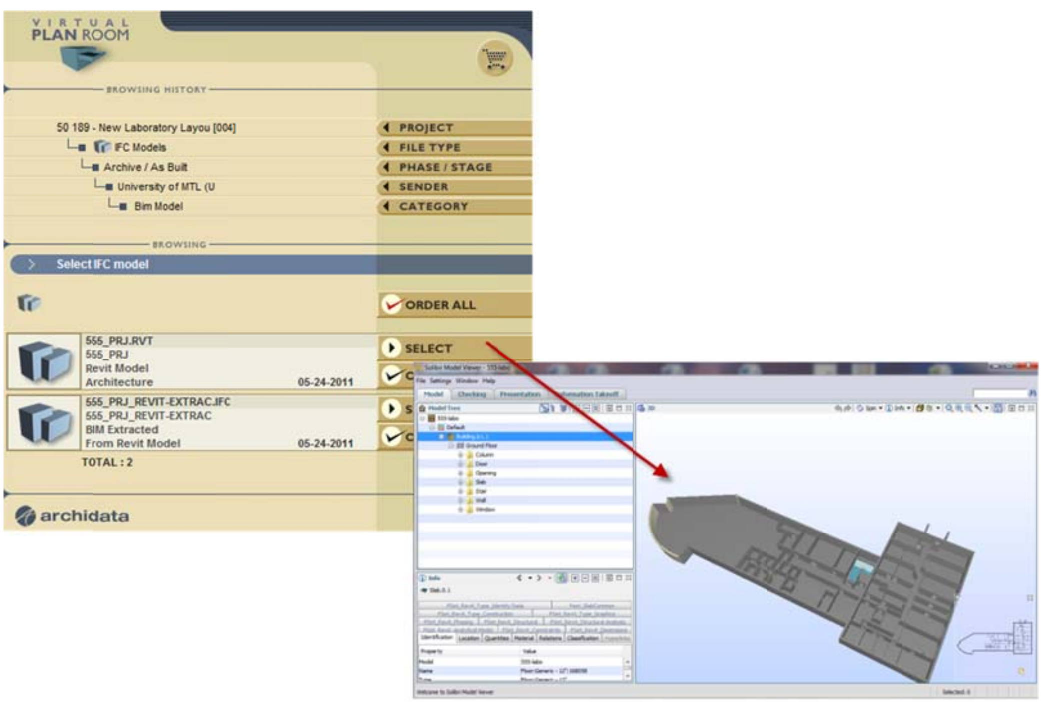


Figure 93: Created models are uploaded in the 'Virtual Plan Room'

The IFC-based BIM is created based on the extracted data. The building objects are organized according to Uniformat. The object classes comply with the IFC standard. The hierarchy of information allows navigation through a complex facility at various levels: building, zone, room and even a single piece of furniture or equipment (Figure 94). The models can be viewed with the Solibri Model Viewer at the various levels of detail (Figure 95 and Figure 96).

Figure 94: Hierarchy of spaces in a building

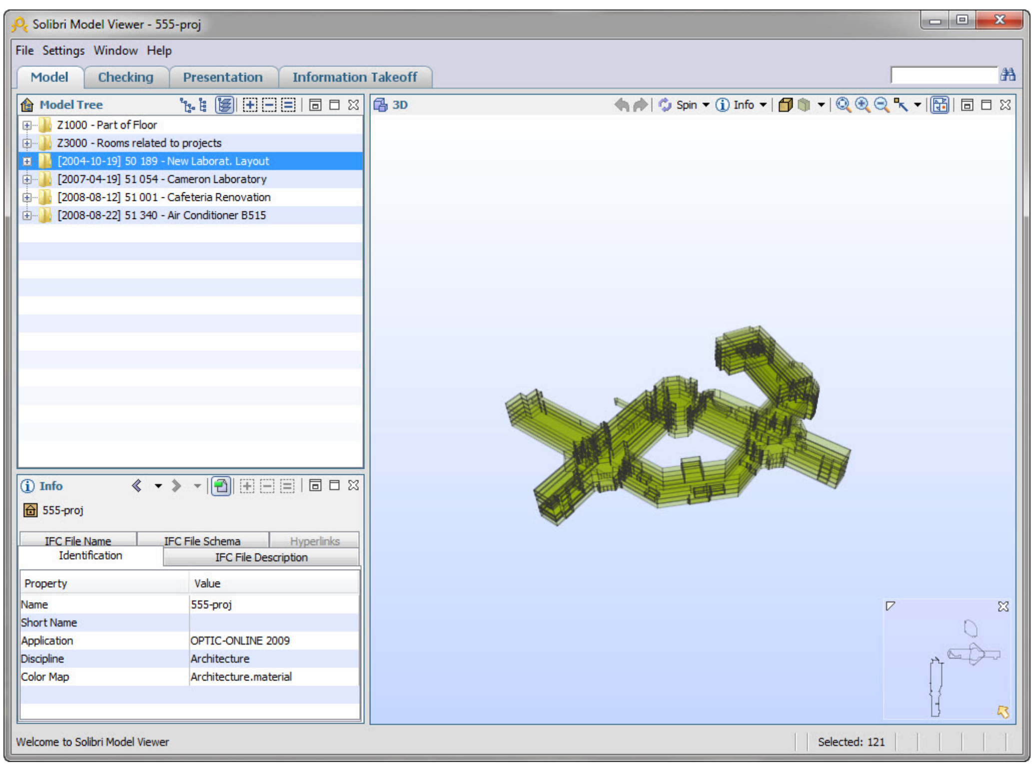


Figure 95: View of a pavilion (spaces)

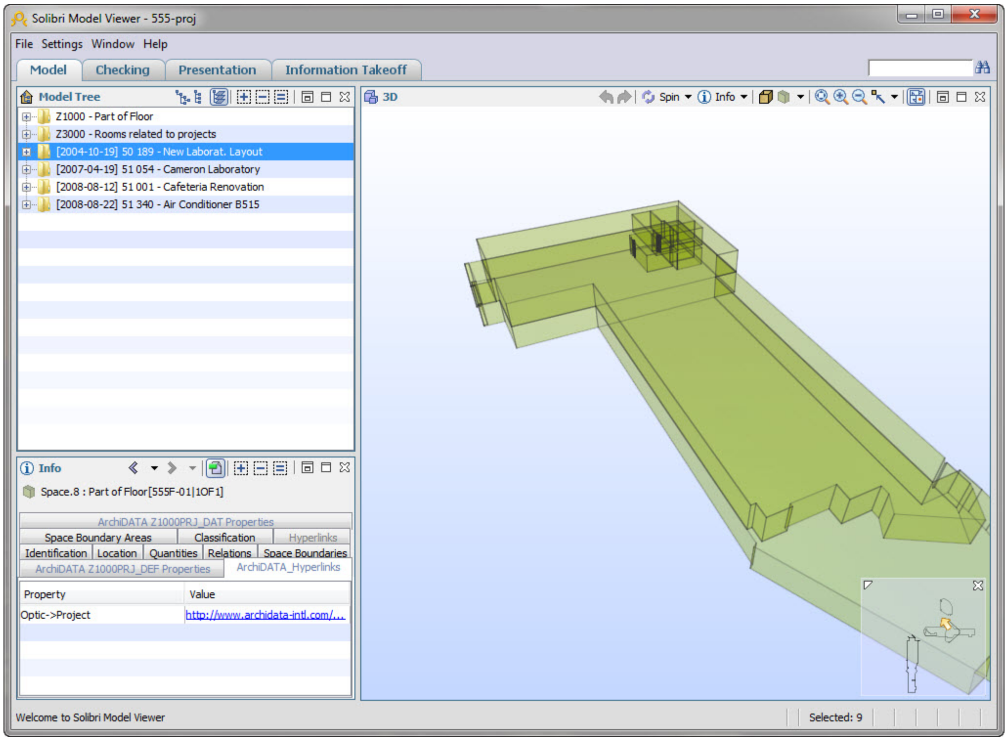


Figure 96: View of the spaces of a scientific laboratory.

The models are positioned relative to one-another with the help of geo-referencing (Figure 90 and Figure 97).

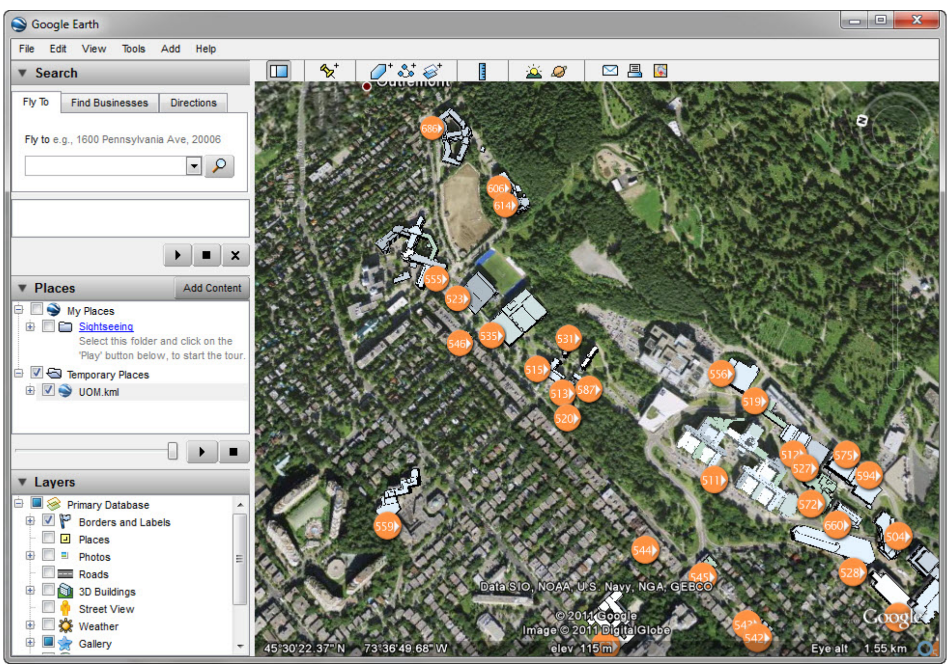


Figure 97:Overview of the main campus of Université de Montéral in Google Earth

The building can be managed through the ArchiDATA Solution which provides information at various levels of detail. A search engine and hyperlinks are available for easy navigation. The plans and the models contain hyperlinks to other relevant documents such as data sheets, photos, and specifications. This allows the document and models to be smaller in size and faster to use and the supplementary information available as external reference if needed (Figure 98).

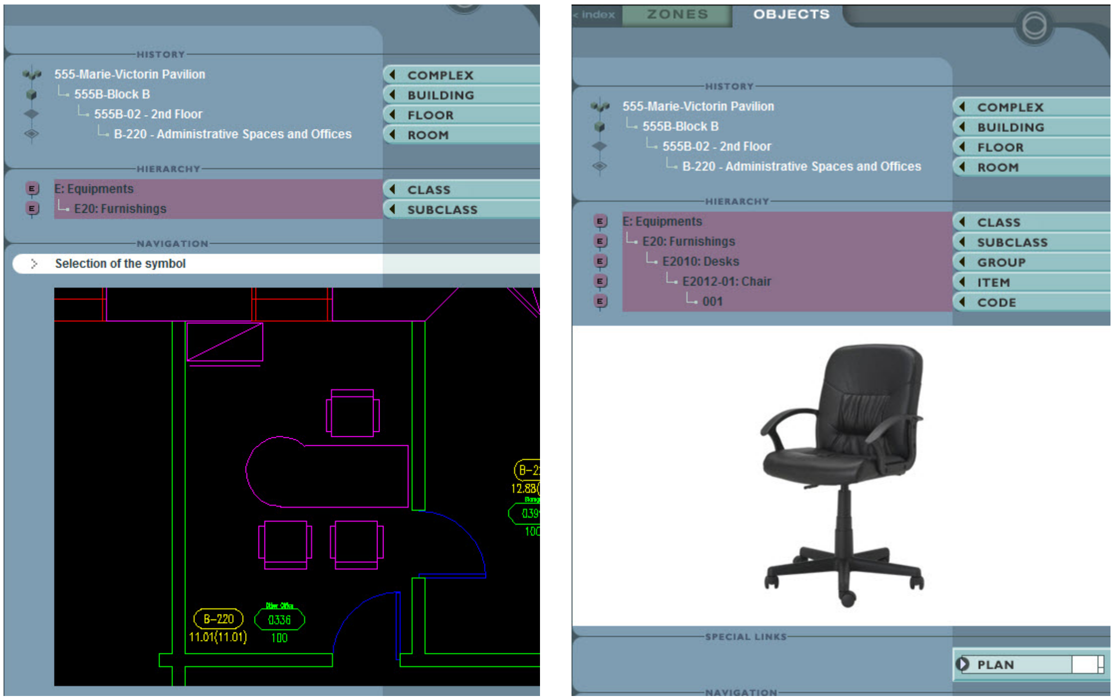


Figure 98: Hyperlinks exist for access to further information (left); information displayed as required (right).

Pictures taken in certain areas of the buildings are another example of the type of information accessible through hyperlinks (Figure 99).

Figure 99: A picture of the building interior accessible from the model through a hyperlink.

The ArchiDATA Solution is capable of generating various reports (Figure 100). The users at the Université de Montréal use this feature mainly to generate reports for the Ministry of Education of Quebec.

Figure 100: A report providing a list of selected spaces.

Another interesting use of the ArchiDATA Solution is the ‘scenarios’ tool. A ‘scenario’ is created for each modification (e.g. construction) and the original plans and models are kept for reference. After completion of the modification, the main model and the Master Plan are updated.

Owner Requirements

The Owner has requested specific terminology from the Ministry of Education and space categories defined by the UdeM be used on the drawings and in the models. The university is also planning to use BIM for future projects. Specifications and guidelines will be developed for submission to the designers and contractors. That will ensure modeling is performed in a manner that is compatible with the ArchiDATA application but not in a limiting or restrictive manner to the designers and contractors.

3.5.3 ORGANIZATION

Owner Considerations

For clients who own a large real estate portfolio, migration to a full BIM environment is a major challenge. First, the existing information is largely paper-based or available in electronic formats that are not readily compatible with today’s technology. Data repackaging and transfer can be costly operations. Second, BIM technologies used for design and construction can also be costly, require significant learning curves, and are not well-adapted to asset and facility management. Third, BIM technologies are evolving and require changes in work practices.

ArchiDATA provides a solution to deal with these challenges. It offers data conversion and transfer, a data repository with a tailored web-based application to access and use the data, and training/maintenance staff. ArchiDATA and the client worked in close collaboration through regular consultations to help with the transition.

Legal Considerations

One of the major issues faced is the resistance from the designers to hand over the BIM to the client. For example, for a new development at the UdeM which was designed using BIM, only the 2D documents were submitted to the client. As the turnover of the BIM was not mandated in the contract, the engineering company refused to do so. The main reason behind this is that companies consider the BIM as a document containing proprietary data. ArchiDATA’s approach is to exclude the proprietary data from the models using IFC protocol before turnover. This way all parties are kept satisfied.

3.5.4 PROCESSES

Existing paper and digital drawings of the buildings are used for semi-automatic generation of a BIM model. Information such as location, systems (e.g. mechanical, electrical or architectural), content (e.g. elevation, sections, details) and dates are manually input onto the 2D drawings. The drawings are then processed through the ArchiDATA Solution which analyses and extracts data from the 2D drawings. Floor heights are entered manually and the 3D representation of the building spaces is then automatically created. Plans and models are archived and managed in the 'Intelligent Virtual Plan Room'. Building operations and equipment maintenance is then handled using the BIM models. The BIM models are updated when the buildings are modified. History of all modifications is kept in 'scenarios', which also contains the original plans and models.

Model Transfer and Management

The main source of data at the UdeM is currently the Master Plan. All modifications to the BIM models are therefore entered into the Master Plan. When new building designs are completed in BIM, the requirements for the BIM model need to be clearly communicated.

The original BIM, which is typically created in Revit, will not be directly used for building operations management. This is because the original BIM contains extensive data that is not useful to ArchiDATA. Instead, a filtered model is generated containing only the necessary information. This results in a 'normalized model' which is free of any proprietary information. The original model is kept in the Virtual Plan Room and can always be accessed if needed.

Workflows

Initially there were about 5 to 6 people adding data to the existing AutoCAD plans. This data included: spaces, areas, heights between floors, UdeM and Ministry of Education categories. With the added data, the existing AutoCAD plans are converted to 'intelligent' 2D plans or to 3D IFC models which can be viewed using Solibri Model Viewer. The users interviewed mentioned that they do not use the 3D model tool as the 'intelligent' 2D plans meet their purposes.

Fire Protection and Security Department manage the changes in their equipment, as well as, the presence of asbestos in the buildings. Specific information about each space is sent to Maximo GMAO software.

Some of the 'space information' is linked to other live documents such as the telephone directory. These documents often do not get updated regularly, which leaves the users with inaccurate or outdated information. These documents should be identified and their regular maintenance should be ensured. Data conversion is needed before uploading the information into COBA, the electronic reporting system used by the Ministry of Education of Quebec. Before ArchiDATA existed, double entry of data was required: once into the plan and another time into COBA. Now, data is only entered once using InterZone which then automatically sends it to both ArchiDATA and COBA.

ArchiDATA managers at the UdeM have already created some written procedures to facilitate communication to the users. These include procedures for data entry, drawing submissions and drawing retrieval. Some of these procedures are explained in more detail in the next section.

Procedures for Uploading a Plan into the Virtual Plan Room

ArchiDATA's InterPlan module (Figure 101) is used for uploading new and updated plans into the Virtual Plan Room.

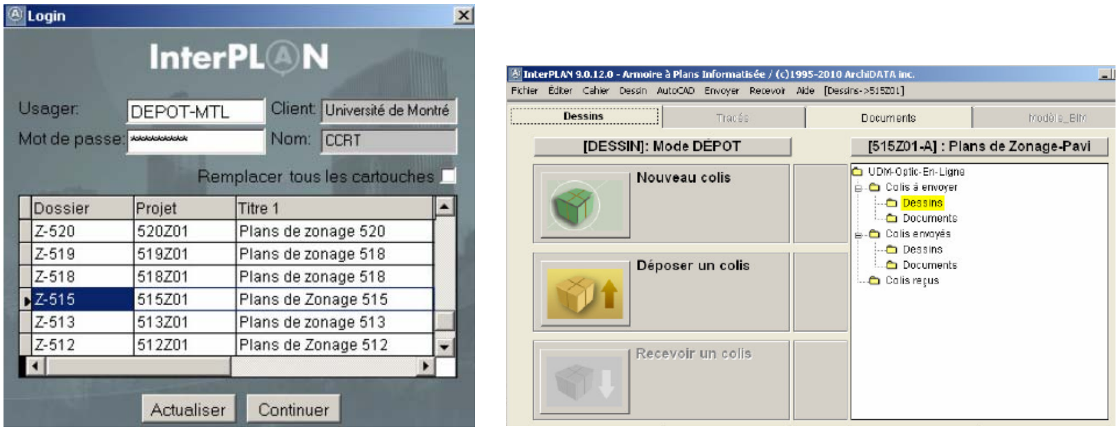


Figure 101: ArchiDATA – InterPlan module for uploading new and updated plans.

When a document is about to get uploaded, it is very important to input a certain set of information in InterPlan. Among these information include the floor and the location within the floor (horizontal and vertical axes) where the document belongs to (Figure 102). This information is required for the software to understand the relative location of this drawing compared to the other drawings uploaded. Further information is input as shown in Figure 103.

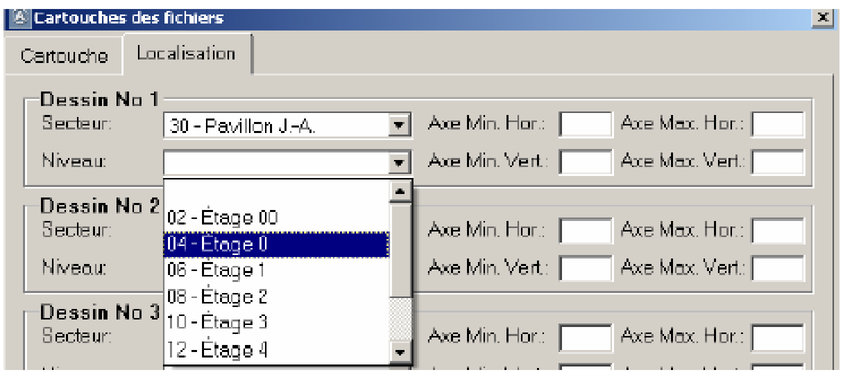


Figure 102: Requested location information upon uploading a document into InterPlan.

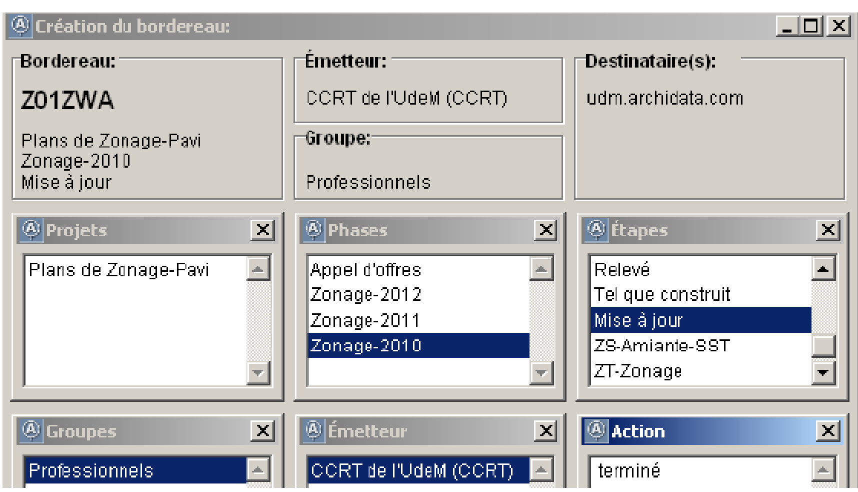


Figure 103: Requested information upon uploading a document into InterPlan.

Procedure for Converting Data from Interzone to COBA:

The user should initially make sure that InterZone contains all the latest data. All documents, from all the campuses, should be linked to one project. After some manipulations in InterZone (Figure 104), the information can be exported into text files.

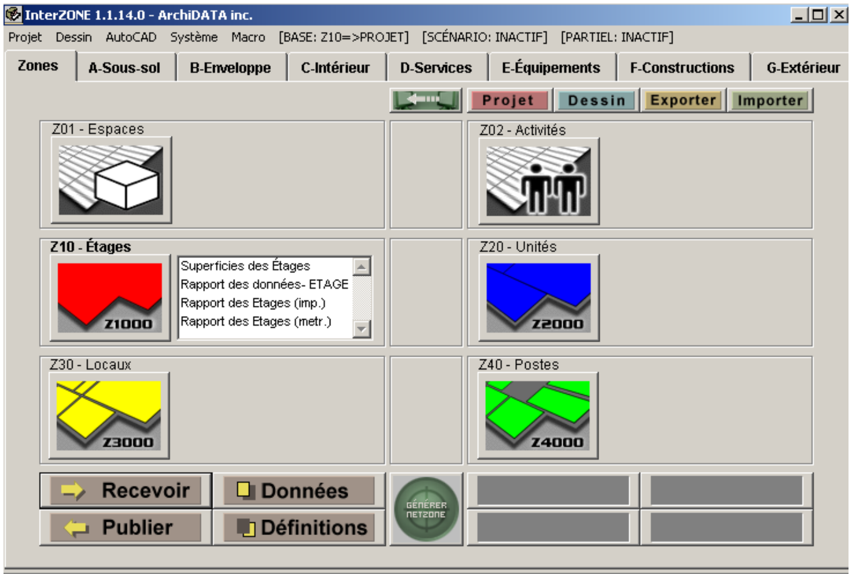


Figure 104: ArchiDATA – interface of the InterZone module.

The exported files from InterZone are then imported to COBA. After following a number of easy steps in COBA the data is ready for and accessible by the Ministry of Education (Figure 105).

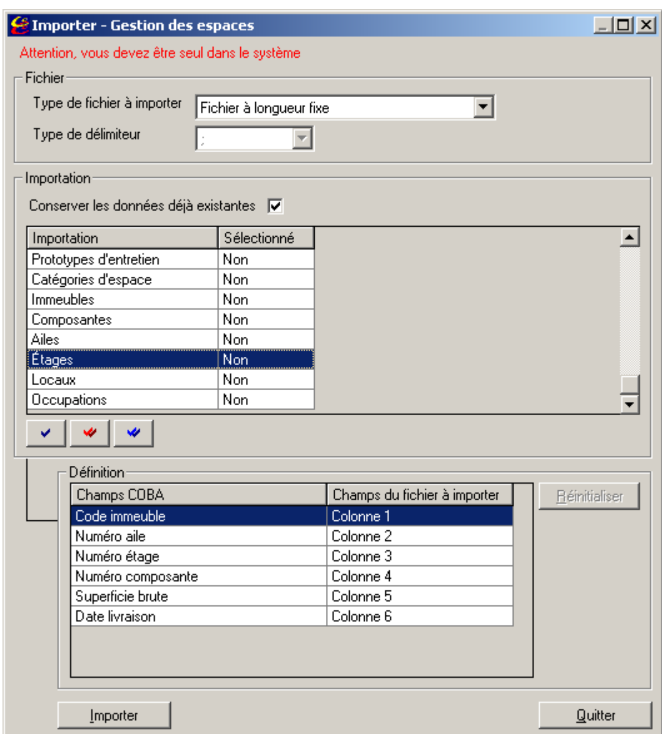


Figure 105: COBA – interface for making the data available to Ministry of Education.

According to ArchiDATA users, this procedure is at least 50 percent quicker for converting data than the traditional practice. Reports are instantly generated from COBA or from the BIM model and any requested information can be exported in Excel.

Accessing the BIM through the Intranet system

Various data can be retrieved through the ArchiDATA Building Intranet at the UdeM. Data for individual spaces can be viewed as either alphanumeric tables or as graphical representation containing 'smart tags' (Figure 106). By clicking a 'smart tag', information associated with the tag will be shown. This could be information on the web or an HTML data sheet containing a picture.

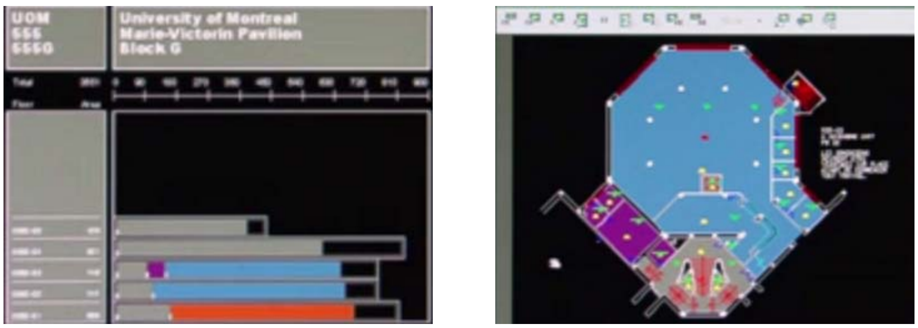
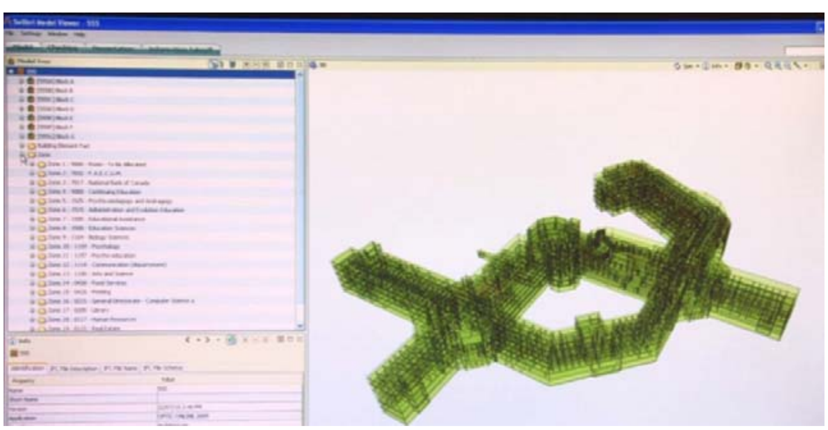


Figure 106: Occupancy – diagram and a color-coded plan.

IFC Visualisation

The IFC model files can be viewed using Solibri Model Viewer. The models can be filtered according to their uses, functions, and other such attributes (Figure 107). HVAC and fire-protection equipment symbols are placed on the exact location where the equipment is located. Each symbol has links to specific information, such as maintenance records, about the associated equipment. Further, information available on the intranet are also available on the Solibri Model Viewer.



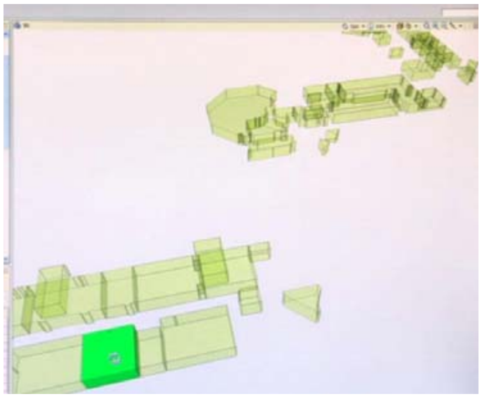
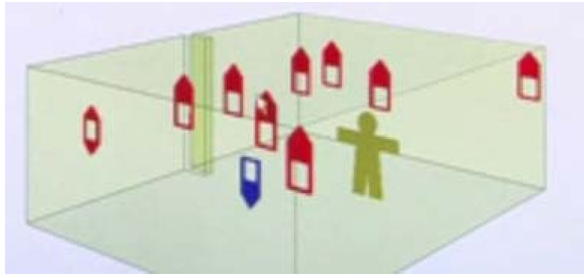
 

Figure 107: Solibri Model Viewer filtering capability – unfiltered building zone (top); filtered spaces (bottom left); filtered single space with associated equipment (bottom right)

Maintaining and Using the BIM model

The IFC models can be given to the designers when an addition to a building is planned. The designers will work on a common data-platform using the software of their choice. Once the new project is designed, the modifications to the building are added to the main BIM. Only the relevant information is added. The original models and plans are archived in 'scenarios' for future use as necessary. The exchange of information continues throughout the building's lifecycle. at

Information Exchange

Information exchange takes place between varying participants and at various levels.

Information exchange between ArchiDATA and UdeM: At the beginning, one UdeM user was at the ArchiDATA head office to configure the software and learn how it works. Currently, one ArchiDATA employee monitors the updates to the models once every 2-3 months. This person checks for any data error or inconsistencies and ensures integrity is maintained in the system. The ArchiDATA convertor will automatically signal any errors that it might find in the plans.

Information exchange between ArchDATA and designers: The ArchiDATA BIM models will serve as a starting point for new project designs. Completed design models will be filtered to remove unnecessary information before uploading into ArchiDATA.

Information exchange between the various departments at the UdeM: With the help of ArchiDATA there is now much more information exchanged between the various departments at the UdeM.

3.5.5 EVALUATION

This project is an excellent example of BIM use for Building Operations and Space Management.

Benefits

The following highlights some of the benefits of employing ArchiDATA:

- The UdeM now has a unified information platform for plans and data for all its buildings.
- All information is up-to-date to a much larger extent than before (approximately 95%).
- ArchiDATA saves time and money for data entry.
- Data extraction is partially automated.
- Buildings are geo-referenced and can be visualized and manipulated in 3D.
- Information about the building equipment and their maintenance records are available within the unified model.
- The users find ArchiDATA to be a superb program.

Lessons Learned and Future Requirements

The following provides some lessons learned and a path forward:

- Some users believe that the system could be more user-friendly. They are asking for a more defined and an easier data entry system.
- Another way to improve the platform is to have a better system of signalling which information is considered necessary. That is to find a system which obliges the different stakeholders to use the ArchiDATA solution. According to the users, this is the only way to make BIM truly integrated.
- They are working to automate some of the extraction of relevant data when creating the BIM. 2D plans will automatically be generated from Revit.
- In the future, master plans will be replaced by a BIM model as the main reference. Coordination between stakeholders will be much better and work will not be duplicated.

3.5.6 ACKNOWLEDGEMENTS

We would like to thank Geneviève Tremblay and Dominic Dubuc of ArchiDATA, as well as Jean-Philippe Cyr and Robin Bélanger from the Direction des Immeubles of the Université de Montréal for their time and input.

3.5.7 BIBLIOGRAPHY

Websites referenced :

- http://www.archidata.com

3.6 COARCHITECTURE ARCHITECTURAL PRACTICE (QUEBEC)

The architectural practice of Coarchitecture features the following 'Best Practices':

- Integrated design process
- Environmental optimisation of the design from the very beginning of the project
- Owner involvement
- BIM used for architecture, structure and MEP.

3.6.1 PROJECT DESCRIPTION

This case study focuses on the use of BIM related tools from an architectural firm's perspective: Coarchitecture, city of Quebec. Coarchitecture specializes in the design of high-performance buildings. Their aim is to use BIM early on in their projects for design optimisation and improved collaboration between disciplines. Two specific projects are chosen as examples to illustrate the different stages of BIM maturity: 1) a Building for a Biotechnology Company in Ste-Foy at the beginning of the BIM adoption process and 2) the Desjardins Headquarters in Levis. Further to the BIM evolution at Coarchitecture, we will highlight some emerging best practices they are developing to optimize the conceptual design process using design and simulation tools. Committed to sustainable buildings, Coarchitecture performs energy and user-comfort analyses at the very beginning of the design process, thus allowing these factors to have a major impact on the project's architecture. Specific simulation tools are used, as performance simulations are still not well integrated with BIM software.

Company Description

Name: Coarchitecture (previously Hudon Julien Associés).
Location: Quebec, Canada
Size: Approximately 35 employees
Disciplines:

- 1 mechanical engineer
- 15 architects, several with expertise in low energy buildings and bioclimatic architecture, natural lighting, and LEED accredited professionals, and
- 15 technicians.

External collaborators: A landscape architect and an interior designer are regular collaborators of the company.

Additional Details:

- Integrated design process (IDP) is a regular practice at Coarchitecture.
- Performance simulation (energy, light, and thermal) is performed early on each project.
- Since 2007 the company has used BIM for their projects.

Philosophy of the Company:

- Sustainability in social, economic and environmental aspects.
- Integrated design process (IDP).
- Software simulation of building performance (on urban level, landscape, user comfort, reduction of energy use, etc.):

- Special attention to user's comfort: natural light, views to the exterior, glare control, thermal comfort, quality of air.
- Optimization of the energy efficiency of the building: reduction of energy needs (high-performance envelope, thermal mass); simulation of energy performance of passive and active systems from the very beginning of the IDP; search of synergies between systems; conceptual alternatives simulation.
- Natural ventilation combined with the principle of air stratification.

Project 1: BIOTECHNOLOGY BUILDING FOR GLAXOSMITHKLINE

Timeline:	2006 -2011
Location:	Quebec (Sainte-Foy)
Total built area:	3,623 m^2, administrative building
Client:	Biotechnology Company
Architects:	Coarchitecture
Structural Engineer:	SDK
MEP:	Mécanique-électrique, Pageau Morel Associés
Contractor:	Verreault

Context

The client initiated an architectural competition with the desire to build a distinctive office building that was examplary in energy performance. LEED Gold certification is targeted. The proposal from Hudon Julien Associes won the competition. The exterior envelop of their building design is innovative (Figure 108), as well as their interior design. Interior work spaces are organized around an atrium that offers transitional interactive zones promoting collaboration (Figure 109). 3D visualization tools and Building performance simulations were extensively used from the very beginning of this project.

Figure 108 Rendered Image of the Biotechnology Building

The objective was to design a building that would become an architectural reference for Nordic climate – a lighthouse building, which was evident from the complete transparency of the main façade. Due to this transparency, the warm atmosphere created by the interior wooden structure, can be felt from the outside.

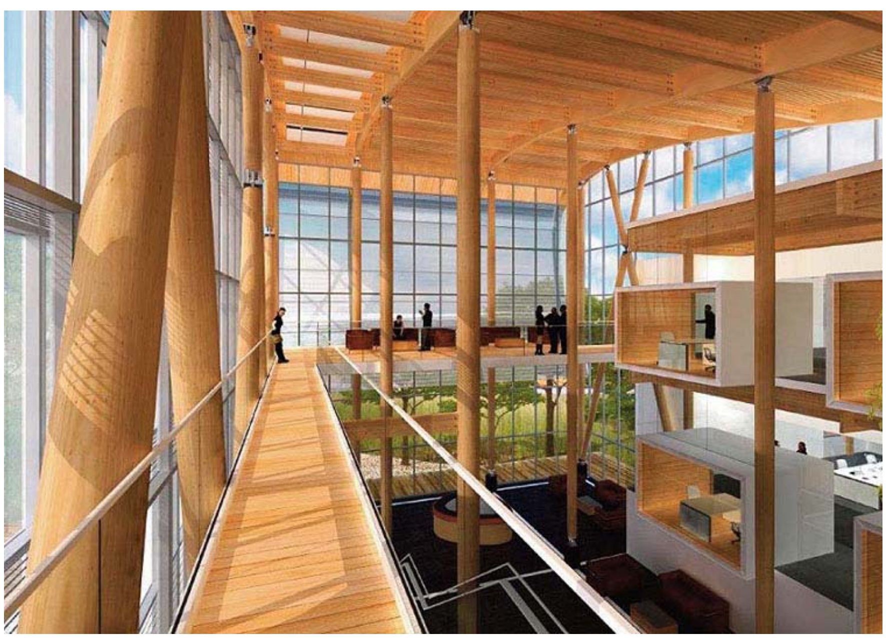


Figure 109: Interior view of the Biotechnology Building

Sustainable Building Strategies

Form and orientation of the building: To avoid overheating, the architects designed a long building with its long facade facing south allowing efficient use of sun shading. This façade is comprised of two layers of glass which significantly increases thermal resistance and integrates solar occultation making the indoor environment comfortable for the occupants. The building structure is made of certified wood, which is the most ecological option and offers a warm and rich interior atmosphere (Figure 110).

Figure 110: Interior's wooden structure (left); Exterior's double façade (right)

Ventilation: The domed roof over the atrium creates stratification of hot air, ensuring removal of stale air and heat recovery (Figure 111).

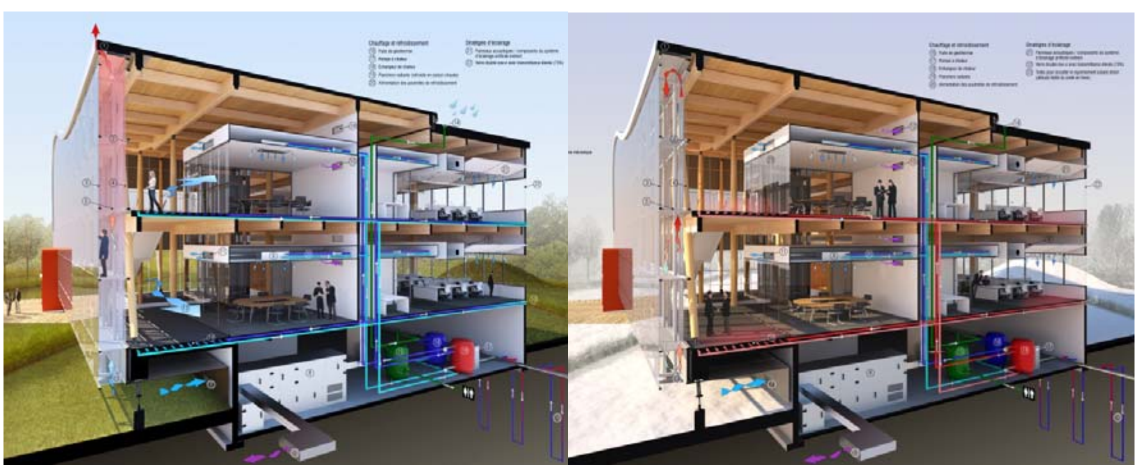


Figure 111: Ventilation and cooling during the Summer (left); Ventilation and heating during the Winter (right)

Thermal comfort: A radiant heating system compensates for the cool floors along the large windows during the winter months. The occupants would have their lower bodies warm and their upper bodies cool. These are the conditions that ensure maximum comfort which in turn improves performance on the workplace.

Optimisation of energy consumption: The application of these best practices for sustainable architecture allowed improved occupant comfort while reducing energy demand. They made use of a double-skin façade with heat conservation or natural extraction when needed.

Mechanical systems: The architects recognized that it takes fourteen times more energy to move air than to move liquids. From the geothermal wells, then, the heated liquid circulates in the floors and the cooled liquid circulates in the chilled beams of the ceiling. This system is used for the first time in Quebec. In addition, the mechanical systems have been designed so as to leave the roof free of mechanical equipment, preserving the aesthetics of the architectural concept (Figure 112).

Figure 112: Interior view to the roof structure.

The principle of dynamic thermal mass can also be easily integrated by simply adding a bank of energy (water tank or phase-change material) in the residual spaces in the basement, further improving the energy efficiency of the building, assessed at 55%.

Site: the building is embedded within a 'green' landscape as shown in Figure 113. The site, thus, provides an ideal space for external meetings, relaxation and physical activities.

Figure 113: Biotechnology Building site layout

Project 2: DESJARDINS HEADQUARTERS IN LEVIS

Timeline:	2008-2011 (construction begun mid-August 2011)
Location:	Levis, Quebec, Canada
Total built area:	28,000m^2, administrative building
Delivery mode:	construction management
Client:	Desjardins Sécurité Financière
Structural Engineer:	BPR
MEP:	Mécanique électrique/Roche
Contractor:	Pomerleau

Context

The project included restructuring of Desjardins' Headquarter campus in Levis, Quebec and an additional 1,000 new work places. A better working environment for the employees is expected, as well as providing better public spaces for the surrounding residents through interventions at the urban level.

In this project, Coarchitecture used building performance simulation from the outset of design. Revit Architecture was used after the form of the building was relatively decided. The Revit platform was used for design integration with the other disciplines – civil, structure, and MEP.

The restructuring of the campus is a good example of contribution to urban intensification. The project provides numerous measures encouraging the use of alternative transportation for Desjardins' employees, including a 'metrobus station' for 5,000 employees, links to bicycle and pedestrian paths, internal storage for bikes, special parking for car-pooling, and close services such as restaurants, a convenience store, and gym. The project will also improve the aesthetics of the campus by adding a 'green' landscape and increased pedestrian security (Figure 114).

Figure 114: Campus of Desjardins Headquarters

The project targets LEED-NC Gold and uses the following strategies to achieve it:

Efficient water management: the target was to lower water consumption in the building by 40 percent.

Green roof: the new building has two green roofs (Figure 114). One, with vegetation, will be over the basilar and extends beyond the office tower. The other is a reflective type of roof that is above the tower where it will not be visible. These measures are encouraged by the LEED system will help reduce heat islands on the campus.

Waste management: As part of LEED certification, the project will divert 75% of its waste from the city landfills. In addition, the new building will be equipped with an avant-garde waste-recycling system that will be maintained throughout operation. Compostable materials from the cafeteria and work areas will be collected.

3.6.2 TECHNOLOGY

Scope of Modeling

The scope of modeling varies depending on the project phase.

Coarchitecture creates simulation models during the conceptual stages of the design to evaluate different options. As the project progresses and decisions are made, the models become more detailed. Figure 115 shows snapshots of natural light simulation performed during the conceptual stages of the Biotechnology project. Specific models, such as the natural light simulation shown in Figure 116, were made in order to satisfy the requirements of the LEED certification.

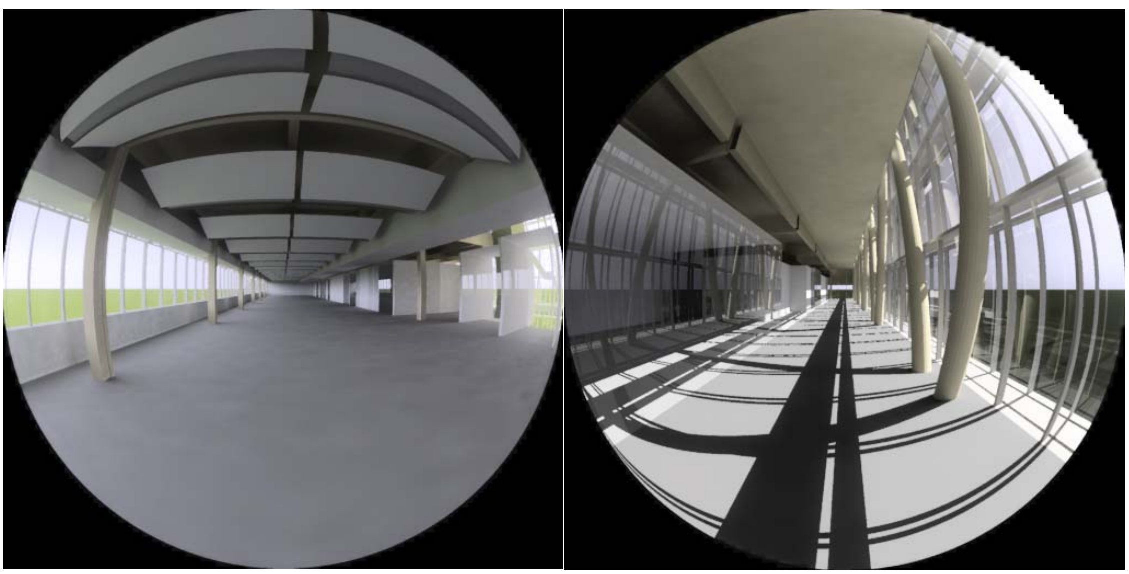


Figure 115: Natural light simulation at conceptual stage of the Biotechnology project: North side (left); South side (right).

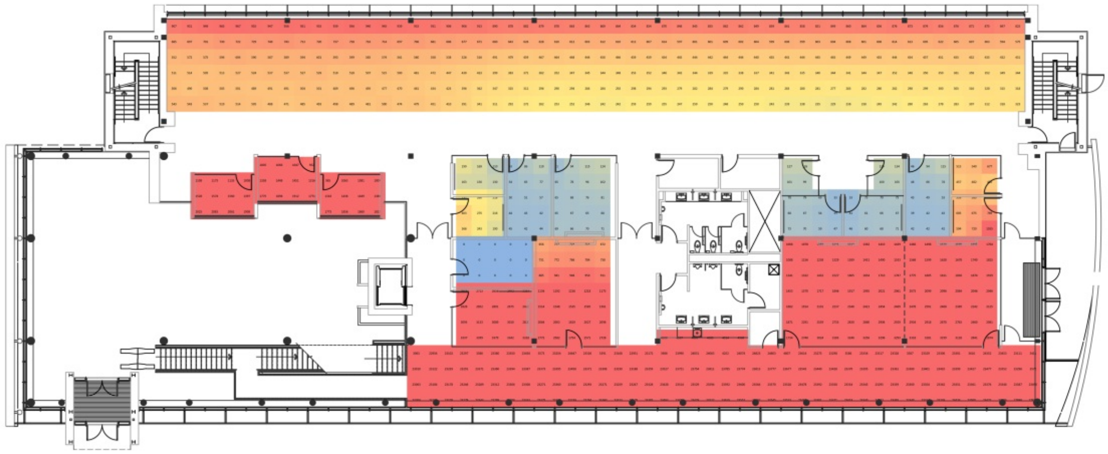


Figure 116: Natural light simulation for LEED credit (Biotechnology project).

A detailed Revit model was created for project coordination and for generation of construction documentation, as shown in Figure 117.

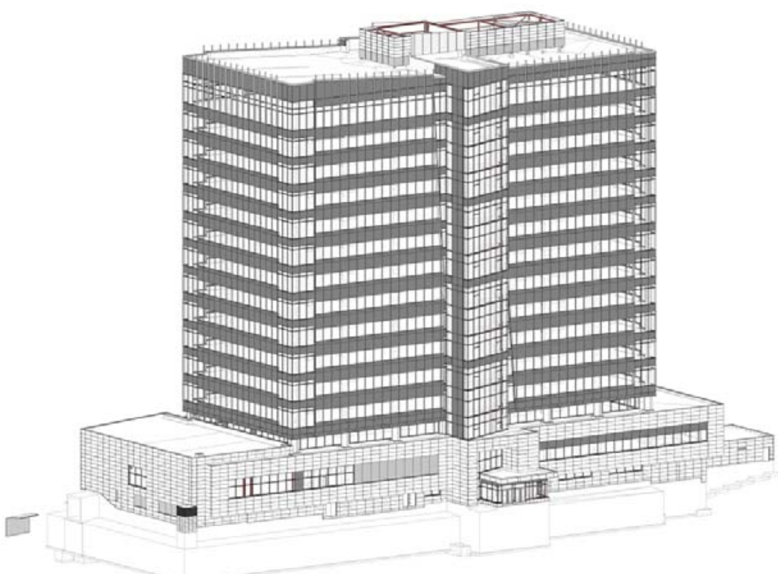


Figure 117: Revit model of the Desjardins Headquarters building

Level of BIM

Based on DPR's 4 levels of BIM, the models created by Coarchitecture are typically Level 1 or Level 2. Based on AIA levels of detail, depending on the stage and the purpose of the models, they range between LOD-100 to LOD-300.

Technology Used

The following presents the various software and tools that are typically used by Coarchitecture during its projects:

Architecture:

For preliminary design and form generation the following software are used:

Preliminary design: Sketchup and AutoCAD.
Photorealist rendering: Sketchup, LightWave and Photoshop (for the final ambiance).
Energy simulation: eQuest and Derob (simulation of thermal mass effect).
Light: Radiance, DaySym, and Ecotect.

Even though the model has to get re-created in each of the above software separately for a specific analysis, the architects find it worthwhile to do so. At about 10-15 percent into the project, and only after some key decisions are made, the model is created in Revit where further details are added. The following sections describe the energy and light simulations in more detail.

EQUEST:

Simple and quick models are typically created in eQuest where alternative designs are compared based on energy consumption. It is not the purpose to obtain the exact value of the building's energy consumption, but to optimize the form, orientation and envelope of the building. At the Biotechnology building project, models were made in Ecotect, Radiance and DaySym to simulate natural light.

Derob-LTH:

Derob-LTH is "*a dynamic and detailed energy simulation tool originally developed at Austin School of Architecture, University of Texas and further developed at Lund Institute of Technology. It has accurate models to calculate the influence of solar gains and shading devices on the energy balance in the building. The building is modelled in 3-D, a necessary condition for accurate calculations of the distribution of solar insulation and temperatures in the room and its surfaces. DEROB-LTH can manage rooms with irregular geometries, buildings with several zones and calculate peak loads, energy demand, temperatures and thermal comfort for a building. HVAC components can however not be modelled*" (Derob-LTH Website, Accessed on Nov. 2011).

Coarchitecture uses this software to evaluate the impact of shading devices on the energy consumption for the cooling system (Figure 118) and on the temperature of the curtain window glazing (Figure 119).

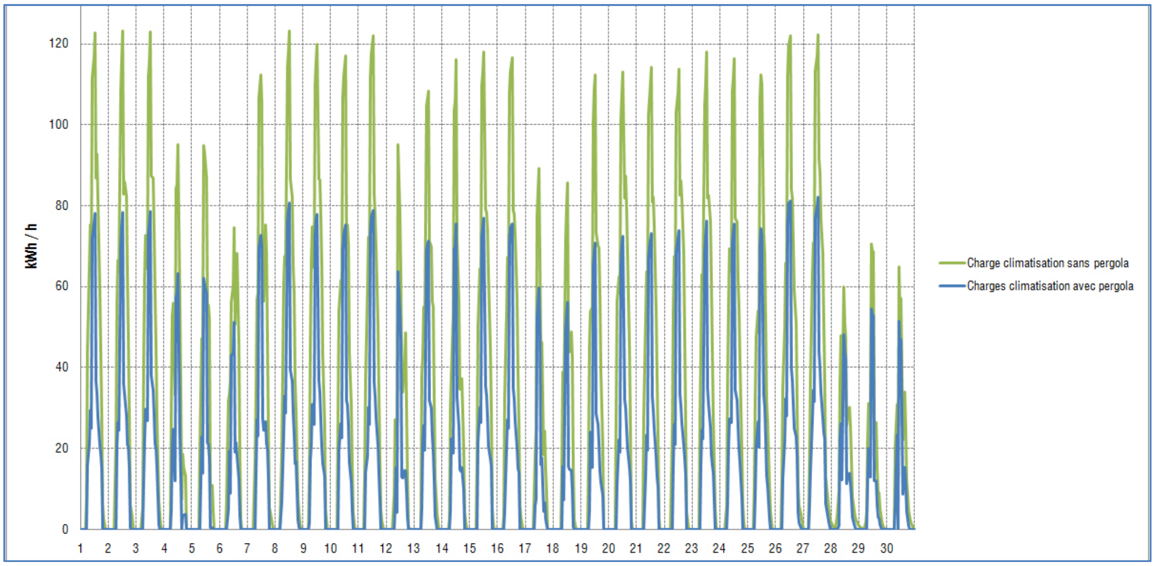


Figure 118: Cooling energy consumption in the cafeteria in June with (dark) and without (light) exterior pergola

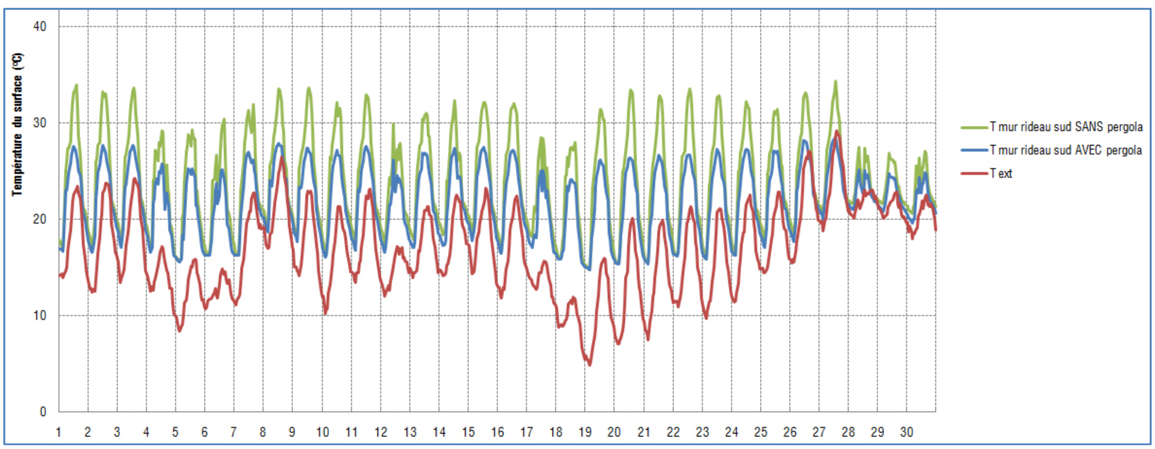


Figure 119: Temperature of the surface of the curtain window glazing (oriented to the South) with and without exterior pergola.

Ecotect

Ecotect, according to the US Department of Energy, is a "*complete environmental design tool which couples an intuitive 3D modelling interface with extensive solar, thermal, lighting, acoustic and cost analysis functions. ECOTECT is one of the few tools in which performance analysis is simple, accurate and most importantly, visually responsive. ECOTECT is driven by the concept that environmental design principles are most effectively addressed during the conceptual stages of design. The software responds to this by providing essential visual and analytical feedback from even the simplest sketch model, progressively guiding the design process as more detailed information becomes available. Its extensive export facilities also make final design validation much simpler by interfacing with Radiance, EnergyPlus and many other focused analysis tools.*" (US Department of Energy Website, accessed on Nov. 2011)

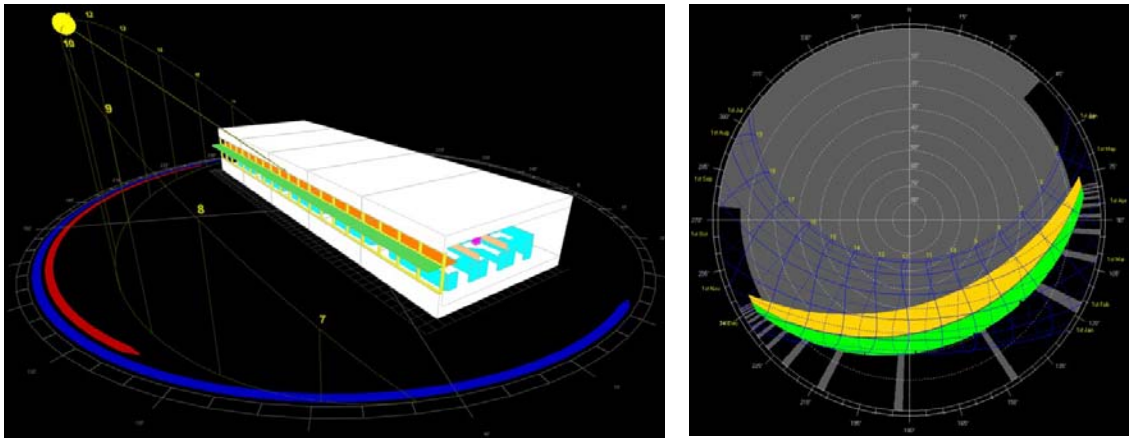


Figure 120: Left - Study of shading and reflecting devices: the model; Right - occultation from the shading (green) and effect of the tablet (yellow).

Radiance

Radiance is an “*advanced lighting simulation and rendering package. It calculates spectral radiance values (luminance & color) and spectral irradiance (luminance & color) for interior and exterior spaces considering electric lighting, daylight and interreflection. It is used by architects and designers to preview illumination, visual quality and appearance of design spaces.”* (US Department of Energy Website, accessed on Nov. 2011) Natural as well as artificial light renderings and graphics help in decision-making during the building design process. Figure 121, Figure 122, and Figure 123 show some examples of the type of analysis that could be done in Radiance.

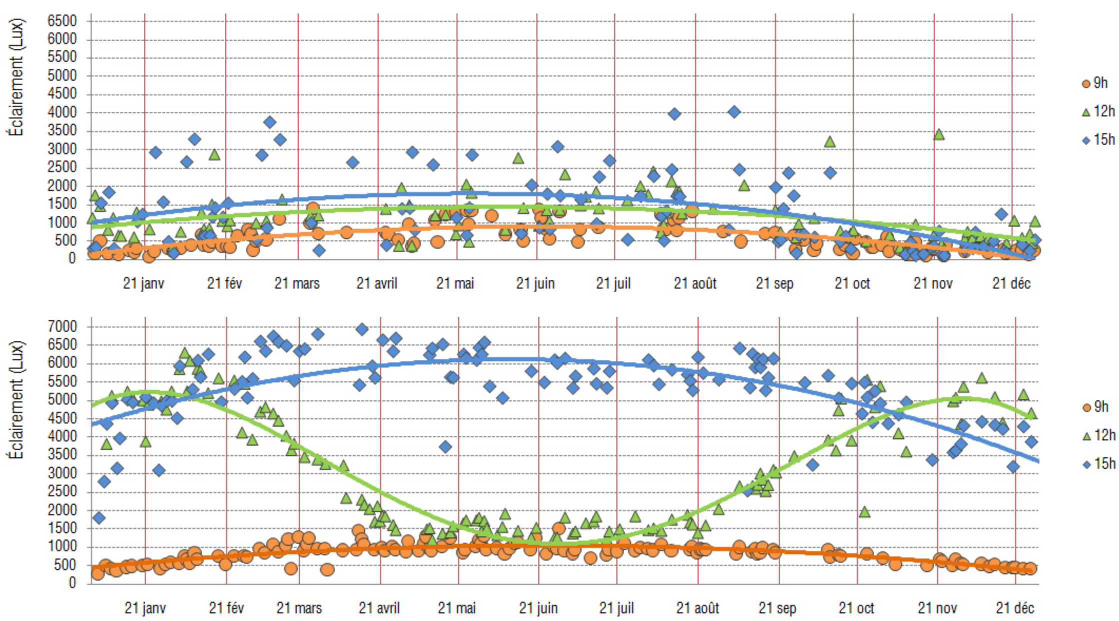


Figure 121: Graphics generated with Radiance: comparison between a cloudy (above) and a sunny (below) sky illumination on an office (S-W).

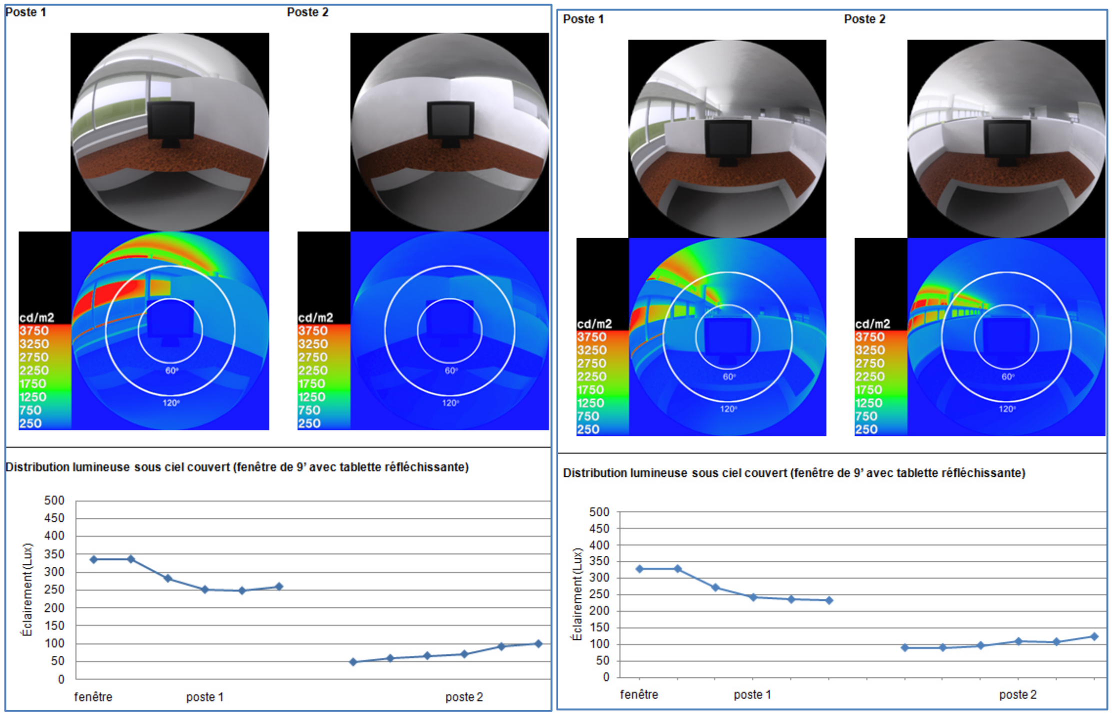


Figure 122: Comparisons of natural lighting (Radiance): reference (L) and recommended (R) workplace.

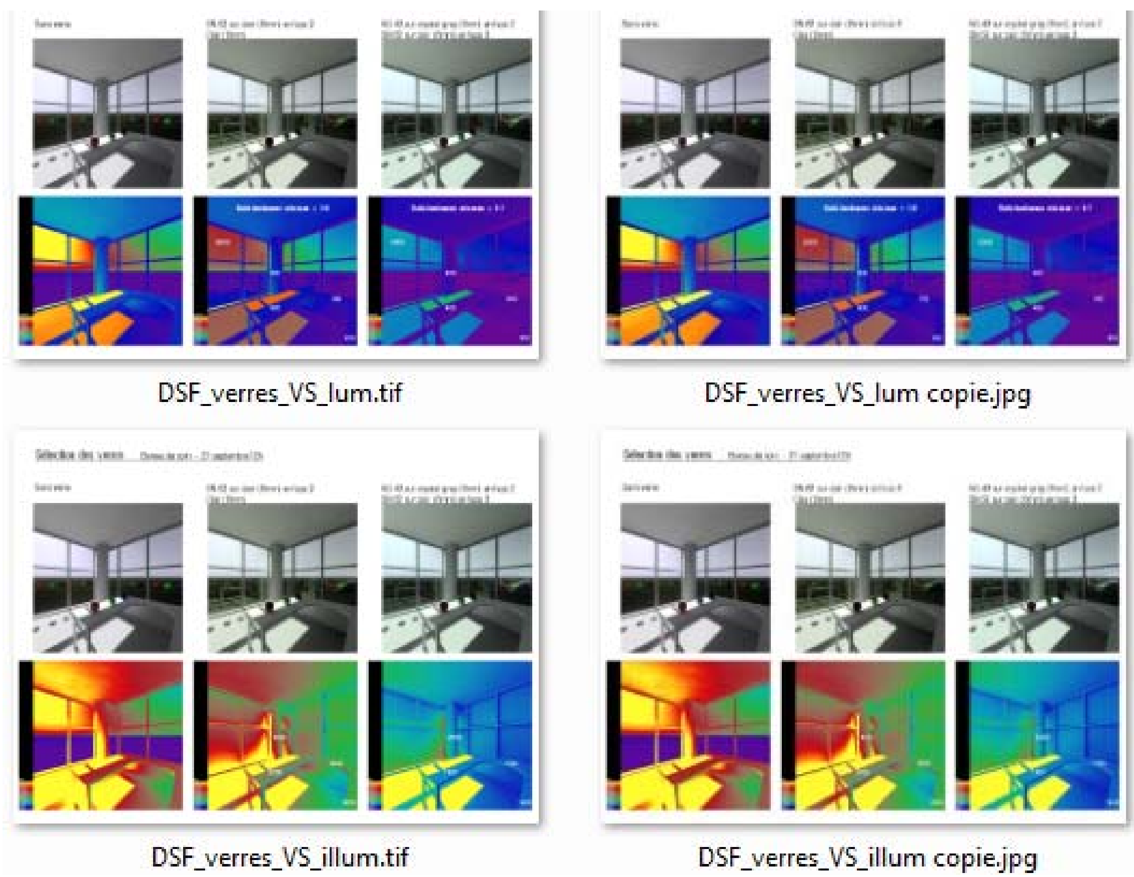
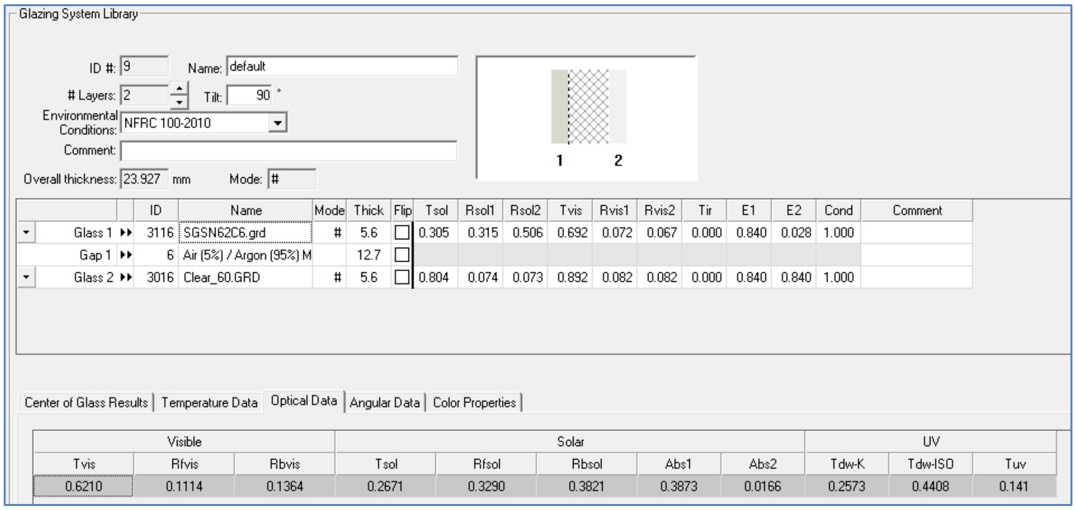


Figure 123: Comparison of natural lighting between using different glass for the windows (Radiance).

Window

Window is open source software developed in a research laboratory (LBNL) at the Berkeley, University of California. It calculates thermal performance of fenestration products and analyses heat transfer.

Coarchitecture uses Window for detailed analysis of the window glazing depending on the layers of composition (Figure 124).



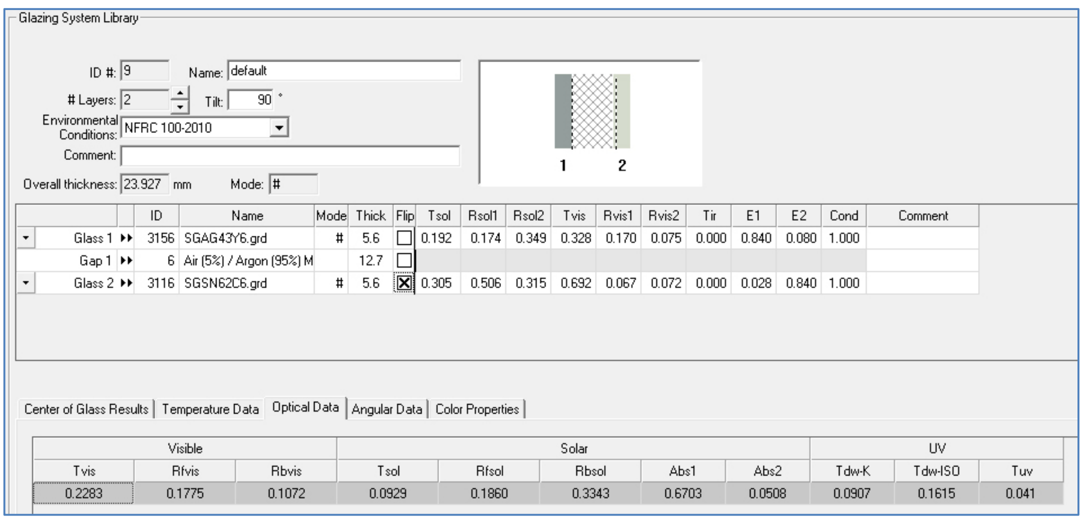


Figure 124: Properties of a window glazing: tables generated with the Window.

Therm

Therm is also an open-source software developed by the LBNL. It performs "*analysis of two-dimensional heat transfer through building products and includes a graphical user interface that allows users to draw cross sections of fenestration and other building products, which can then be analyzed by an automatic mesh generator and finite-element heat transfer algorithms. Results are displayed graphically.*" (US Department of Energy Website, accessed on Nov. 2011) Therm can integrate the detailed results of the Window software and combine them with the window's frame to simulate the thermal performance of the whole window.

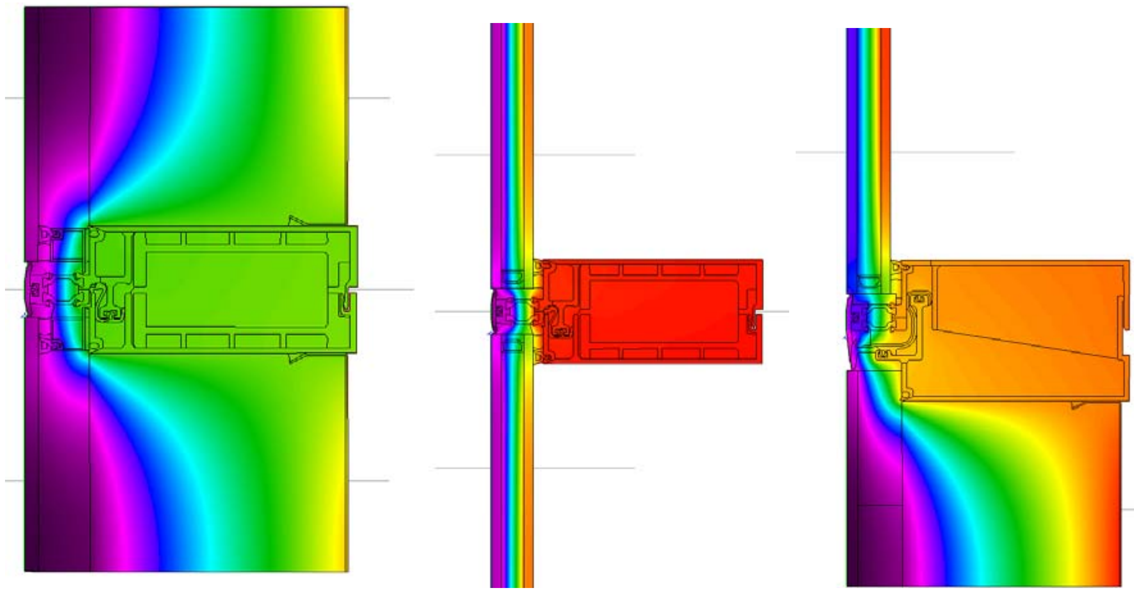
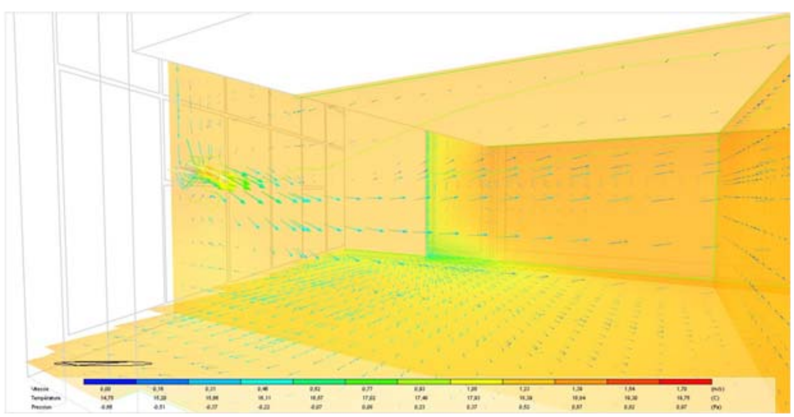


Figure 125: Graphics generated from Therm – presenting heat transfer around a window with different colors presenting temperature variations.

CFD (FLOVENT)

On the basis of Computational Fluid Dynamics (CFD), Flovent calculates airflow, heat transfer and contamination distribution for built environments.

Coarchitecture uses this software to determine airflow direction, speed and temperature as well to calculate quantity of air movement from one space to another (Figure 126).



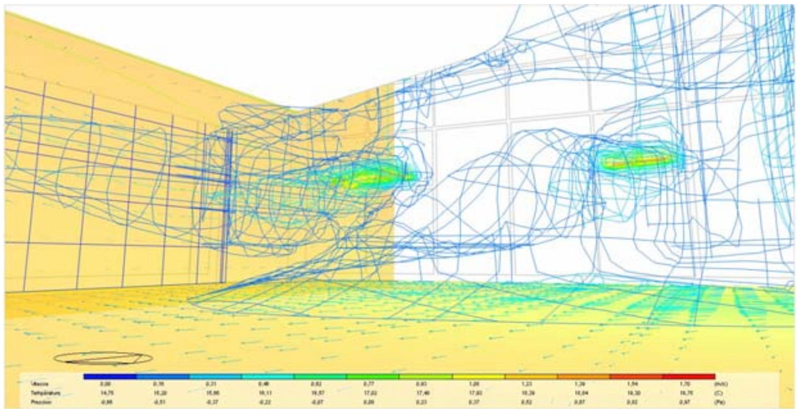


Figure 126: Spatial representation of speed and temperature of air near an open window: speed vectors (above); speed contours (below)

Revit

Revit Architecture, Structure and MEP were used for design coordination, for generation of construction documents, as well as, for clash detection (Figure 127).

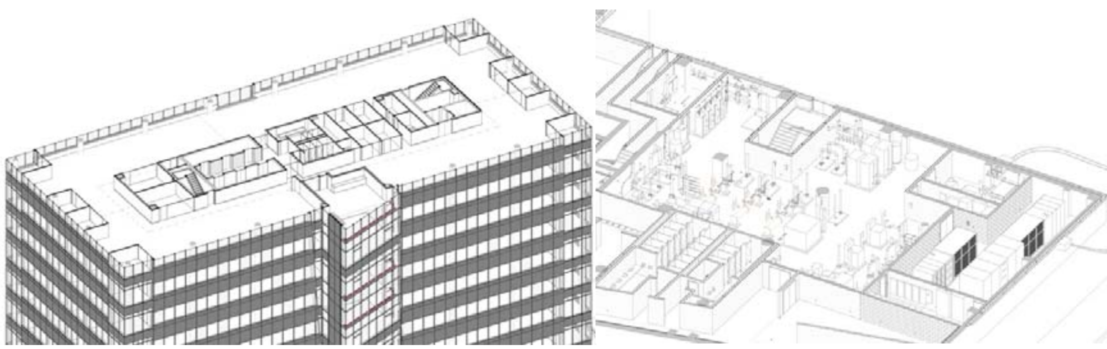


Figure 127: Combined Revit model.

Structural and MEP

The structural engineers have been using BIM since 2006. In the case of the Desjardins Headquarters, the project was originated in BIM after the establishment of the structural system. Models were synchronized with other disciplines for design coordination and clash detection. The MEP designs were also modeled in Revit. All professionals underlined the advantages of working on a common model.

Clash Detection – With Revit

Revit was used for clash detection between the various design models: Architecture, Structure and MEP (Figure 128). Although Navisworks is considered to be superior software for clash detection, they found clash detection with Revit to be very beneficial in increasing design quality and reducing conflicts.

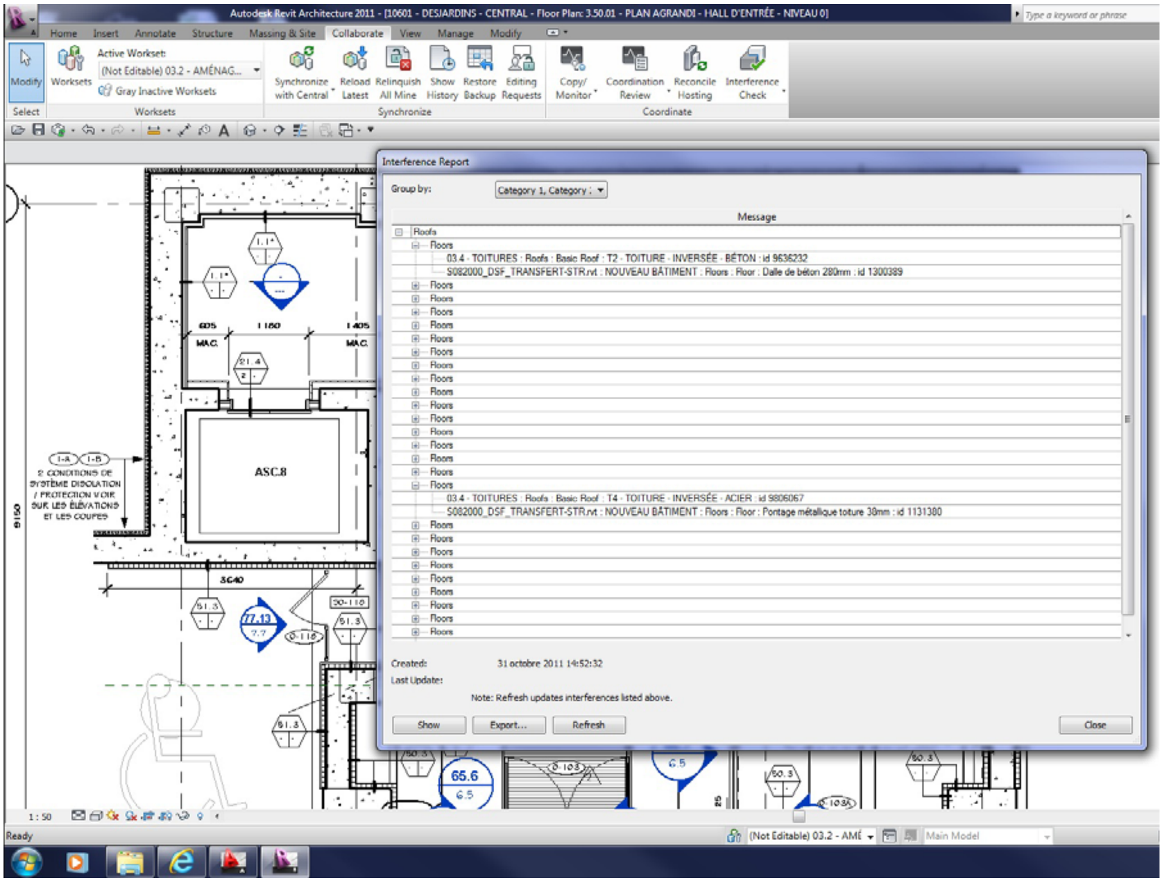


Figure 128: Interference report for Clash Detection from Revit.

Information Exchange

The company has the appropriate number of Revit licences, but finds the price of the software rather high. Lack of compatibility with previous versions is also at times problematic.

A secure SharePoint site is set up for information exchange with external collaborators. Files were updated every Friday at noon and were updated more frequently when necessary.

Coarchitecture maintains the model in several Revit versions concurrently to be able to collaborate with the various companies independent of the version they use.

3.6.3 ORGANIZATION

Coarchitecture strives to employ an integrated design process on all of its projects. IDP is used internally between Coarchitecture's different discipline specialties and externally with other project participants and clients.

During the competition phase for project award, the team will sometimes incorporate the mechanical systems within the architectural design. Energy consumption and user comfort analysis is performed for various alternatives. The mechanical engineering firm is often on the competition team. This is not ideal as the IDP process requires involvement and collaboration of the key project players from the outset.

The specific requirements and the maturity of the client are extremely important for a project. A client concerned with the comfort of the user will be more focused on developing innovative solutions and would be inclined to pay more for simulations of building performance. Such clients also have a more long-term perspective on profit and are ready to invest more now with the expectation of saving more in the future.

BIM Expertise

Coarchitecture has been using Revit as their BIM platform since 2007. In 2007/2008 Coarchitecture tried to use Revit from the outset of every design process but found it very heavy, which they said was ‘killing the creative process’. However, it should be noted that the conceptual modeling module of Revit has been considerably developed since the 2009 version. Currently, Coarchitecture starts employing Revit after preliminary design is complete. The structural and mechanical disciplines are normally part of the BIM process.

Training of the Team

Currently at Coarchitecture fifteen people use Revit with varying levels of proficiencies with 1 to 3 years of experience. Back in 2007/2008 the company was considered as a pioneer in BIM technologies in Quebec and were faced with a lack of available expertise. Now, they organize half-day courses in their office instructed by BIM experts. They have noticed that ‘green’ professionals straight out of school are both familiar and enthusiastic about BIM. Further, it seems to them that those without AutoCad experience are able to develop BIM expertise quicker.

3.6.4 PROCESSES

Project Execution Planning

The organisation at Coarchitecture is rather ‘horizontal’. Architects and technicians work together throughout the design process with the technicians less present at the beginning of a project and the architects less present towards the end.

There is a Project manager for each project. No BIM manager is needed as each team manages its model in a specific way. According to Coarchitecture, BIM managers are only required when either the project members are not well trained in BIM practices or when the client is going through a BIM adoption process. At Coarchitecture, modeling is performed based on a set of office standards to ensure conformity and consistency.

A ‘Work Group’ develops the standard for office practice. This group meets every two weeks to brainstorm and further develop the standards. Further, one person from each project team has the responsibility to ‘clean’ the model, as necessary.

There is no BIM execution plan for each project. But at the beginning of each project, there is a coordination kick-off meeting with the engineers of the team. Common parameters of the project, software versions to be used, axes, levels, work sharing and phases are among the themes discussed.

Workflows

In the first stage of the IDP, Coarchitecture integrates active and passive systems on a preliminary basis. Thus, they can capture the synergies between the various building systems and add value to the project. To achieve this goal without sacrificing the aesthetic quality of the architecture in the context of IDP, they schematically simulate the building performance of each conceptual alternative. By comparing them, without seeking to establish their actual consumption, it is possible to optimize the design and to ensure good energy performance, occupant comfort and harmonious integration of the mechanical system in the form of the building.

Defining and optimizing the functional program of the building is a major prerequisite for the success of the project and often allows saving resources. This is best resolved during design workshops (charrettes).

Charrettes are organized for each project Coarchitecture is involved in. Normally they include the client, the operations manager, the engineers (structural, electrical, mechanical and civil), and, the landscape architects. During the charrettes, SketchUp is most often used. Simulations done by the mechanical engineer of Coarchitecture are also manipulated in real time during this process in order to discuss the building orientation, glazing, and sunshades. E-Quest is also often used for the calculation of the energy charges of the building.

In some cases, Coarchitecture undertakes research and development on specific topics in order to find the best design option (e.g. sun-occultation system for the windows).

The model in Revit is most often constructed based on plans imported from AutoCAD, or 3D models started in SketchUp.

BIM Standards

Common parameters of the project are established at a coordination meeting at the beginning of the project. BIM Standards are being developed for the office, containing object libraries and templates. This process is very time-consuming.

Coarchitecture shares their BIM model in the consortiums and with the other disciplines involved in the project. This allows late technology adopters to profit from the early adopters.

Internally, they have a centralized Revit model and the coordination is in real time. On every Friday noon, the members from the external companies upload their models on a SharePoint site. The external models (structure, MEP) are then combined with the master model.

3.6.5 EVALUATION

The following sections summarize the benefits and challenges:

Benefits

Based on interviews with the project participants, the most important benefits from utilizing BIM-enabled technologies are as follows:

- Better environmental and energy performance of the building
- Improved efficiency in design
- Fewer design coordination problems
- Less errors on the construction site
- Increased collaboration

Coarchitecture finds it very beneficial to work on a common model. They see BIM as a remedy for the fragmentation of the engineering and construction industry. They believe that BIM and IDP bring project participants from various companies together and promote collaboration. When observed these project participants interact as if they are all part of one company. The client is the ultimate winner as a more reliable design is delivered faster with less cost. The architects evaluate the use of Revit as not necessarily profitable for them but definitely profitable for the project. There are fewer changes and fewer errors during the construction.

In summary, BIM projects are generally characterized by:

- Improved project outcomes: fewer RFIs and field coordination problems
- Easier coordination of different software products and project personnel
- Improved efficiency, production and time savings
- Improved communication between architects and owners
- Improved quality control and improved accuracy
- Quick reaction to design changes
- Keeping pace with competition and others in the marketplace
- Positive impact on winning projects
- Discovery of design errors and omissions before construction
- Clash detection and avoidance

Challenges

The biggest challenge for Quebec is to involve the bigger clients in the BIM process. For now, their interest is quite low and the advantages are not yet clear to them. General Contractors and subcontractors also need to become involved and contribute to the collaborative process and the modeling creation.

3.6.6 ACKNOWLEDGEMENTS

Special thanks to Normand Hudon (Architect) and Sébastien Vachon (Technical Team Lead) from Coarchitecture for providing valuable information for writing this case study.

3.6.7 BIBLIOGRAPHY

Autodesk Ecotect Analysis, Web, 4 Oct 2011.
<http://usa.autodesk.com/adsk/servlet/pc/index?siteID=123112&id=12602821>

Coarchitecture, Portfolio, Web, 4 Oct 2011.
<http://www.coarchitecture.com/fr/portfolio/administratif/entreprise-en-biotechnologie-a-quebec>

Derob-LTH, Web, 30 Sept 2011. <http://www.ebd.lth.se/english/software/derob_lth/>

FloVENT, CFD software, Web, 6 Oct 2011. <http://www.mentor.com/products/mechanical/products/flovent>

Radiance Synthetic Imaging System, Web, 5 Oct 2011.<http://radsite.lbl.gov/radiance/HOME.html>

Therm, Web, 5 Oct 2011. <http://windows.lbl.gov/software/therm/therm.html>

Window, Web, 6 Oct 2011. <http://windows.lbl.gov/software/window/window.html>

3.7 CAPITOL THEATRE (ALBERTA)

This project was selected as a ‘best practice’ case study for the following reasons:

- Progressive coordination minimizing interferences
- Digital shop drawing reviews
- Use of Virtual Requests for Information
- The level of detail modeled for select systems
- Extensive information sharing and exchange
- Use of the ‘open standard’ IFC file format for information exchange and coordination with a Single Purpose Unified Revit

3.7.1 PROJECT DESCRIPTION

The new Capitol Theatre is an authentic replication of the original 1920’s “Allen Brothers” Cinema that once stood on Jasper Avenue and 100 Street in Edmonton (the original building is shown in Figure 129). This 2-story, 14,000sf (1300m^2) recreational facility is one of many projects for Fort Edmonton Park. It is a new 243 seat facility that includes state-of-the-art sound, lighting and F/X. A 4D theatre is also available for modest live theatre productions, cinema and speaking engagements.

Figure 129: The original historic Capitol Theatre building

Capitol Theatre was a fast-track project, with only 12 months from the start of design to opening night. Construction began in the summer of 2010 and the facility was completed on schedule by late summer 2011. The base building construction budget was $7 Million.

The following organizations were involved with the delivery of the Capitol Theatre project:

- **Client:** Fort Edmonton Management Company and City of Edmonton
- **Architect**: Allan Partridge - HIP Architects (now with Group2 Architecture Engineering Ltd.)
- **Structural**: Stantec Consulting
- **Civil**: V3 Companies
- **MEP**: Williams Engineering Canada
- **Construction**: PCL Management Inc.
- **Steel Contractor:** Supreme Group

The design team collaborated to push modern methods of construction in the local marketplace utilising BIM. In the ***Design Phase,*** a Revit Architectural model was developed, and the architect acted as the BIM manager. Early decisions were made on the foundation design and the superstructure. To mitigate against potential schedule slippage, the steel fabricator was appointed as a 'Design-Assist' role to participate in the project specially for constructability purposes. Together with the architect and the engineer, they elaborated the model to create a 'virtual' steel model of the building in Revit, down to the connection bolts. The modeling of the architecture and structure was completed using a variety of BIM-enabled technologies.

The steel fabricator played the role of BIM manager in the ***Detailed Design Phase*** due to their experience with BIM-enabled technologies, software interoperability, and steel detailing. Knowing "how" building components will be built allows for design development while there is still time to explore alternatives accordingly. The steel fabricator was recommended to the client due to a previous successful experience on a complex project.

3.7.2 TECHNOLOGY

The architect acted as a prime consultant and used Revit Architecture to build the model. The Structural engineering team designed the building model using Revit 2010 and used SAP 2000 for design analysis and sizing. Revit products were also used to create the BIM for the MEP systems. The BIM was created and kept current in a Single Purpose Unified Revit (SPUR) central file with access provided to the team through Riverbed technology. The steel fabricator, however, used Tekla and had to create importable IFC (Industry Foundation Classes) files for uploading to the SPUR. The original Tekla file sufficed for use with the CNC machine for fabrication. The fabricator's Tekla model became the focal point for structural design development and it was the fabricator's Tekla model that was shared with the SPUR to communicate the detail design of the structure.

Technology Used

Table 13 provides commonly used software on the Capitol Theatre project:

Table 13: Commonly used software on the Capitol Theatre project

Application Area	Software Tool
BIM Model Generation Tools	
Architecture	Revit Architecture 3D Studio Max Civil 3D and digital scanning of surrounding buildings
Structural	Revit Structure Tekla Structures
MEP	Revit MEP
Fire Sprinkler	AutoSPRINK VR
BIM-Related Tools	
2D	SprinkCAD
Fabrication	Tekla Structures
Detailing	Tekla Structures
Analysis Tools	
Structural	ETABS SAP 2000
Coordination	Navisworks
Survey Control	Trimble
Quantity Take-Off	Quantity TakeOff 2011

Scope of Modeling

The initial architectural model was developed by the Architect using historical records and was the basis of feasibility studies and conceptual design. The architect, as the BIM manager, assigned 'worksets' within the SPUR file to the Structural, MEP, and speciality design engineers. Each discipline was then given rights to control the building components (i.e. 'workset') specific to their discipline. For example, the architect was not able to move the structural columns in the model without the permission of the structural engineer. The purpose was to preserve model integrity and ensure accountability. The Revit model was current through the construction phase of the project.

The Structural engineer modelled the building's primary structural system, including pile foundations, concrete pads and footings, slabs, and the primary steelwork, including columns, beams, bracing, flooring systems, roofing deck systems and the primary components of the staircases. The fabricator further developed the model by adding the connection details resulting in a 'virtual' model consistent with what was to be built on site.

The MEP systems were designed in the SPUR model using the Revit model created by the Architect. The architect assigned the related worksets to the building systems engineers. The mechanical team subdivided the Revit Model to each floor and then into zones for easier manipulation and analysis of the HVAC system. The MEP designs were imported to Tekla for constructability analysis, which included ensuring adequate clearance for air ducts and clash-free routes. In addition, miscellaneous components to support the MEP systems (i.e. metal support for ducts, lighting and sound fixtures) were added to the prefabrication metal work which saved time and increased quality and safety on the construction site.

Level of BIM

This section provides information on the Level of Detail achieved in the models based on DPR's definition of the 4 levels of detail.

Structural: the structural engineers mainly achieved a **Level 3** model. With details added by the steel fabricator, a **Level 4** model was achieved the steel structure.

MEP: the design engineers achieved a **Level 2** model. A **Level 3** model was achieved when more detail was added during the coordination phase for reducing RFIs and changes on the field and improving site logistics.

The models were detailed to a level that allowed for detailed 4D simulations, creation of 3D as-built models, and the ability to pull accurate quantity trends.

Model Development

Essentially two BIM virtual environments were setup for the purposes of this project. This was mainly a result of having two experienced players on the project: the architect and the steel fabricator. **Error! Reference source not found.** shows how these two models and the various other discipline models correlated.

First BIM (the SPUR)

During the design phase, the SPUR file (Revit Architecture) created by the architect was used. Coordination was rather smooth as the Structural and MEP engineers also used Revit products. Tekla was also used, which is IFC certified and interoperable with Revit. Revit Structure was, however, not compatible with SAP 2000 which had to be used for conducting structural analysis and members sizing. Once the structural analysis was undertaken, the member sizing was manually input into the Revit Structure model. Full inter-operability was hence not achieved between the BIM and analysis tools.

Enhanced BIM

The manufacturing Tekla 3DMM model is interoperable with CNC systems (Computer Numerically Controlled) used for fabrication of steel. The Tekla platform communicated not only with the CNC machine (for cutting and fabricating steel), but also with Revit Architecture. While Revit Architecture provided an interoperable platform for the architect to coordinate with Revit Structure, Revit MEP and speciality production files (e.g. lighting and furniture), the Tekla platform provided the same for the steel fabricator.

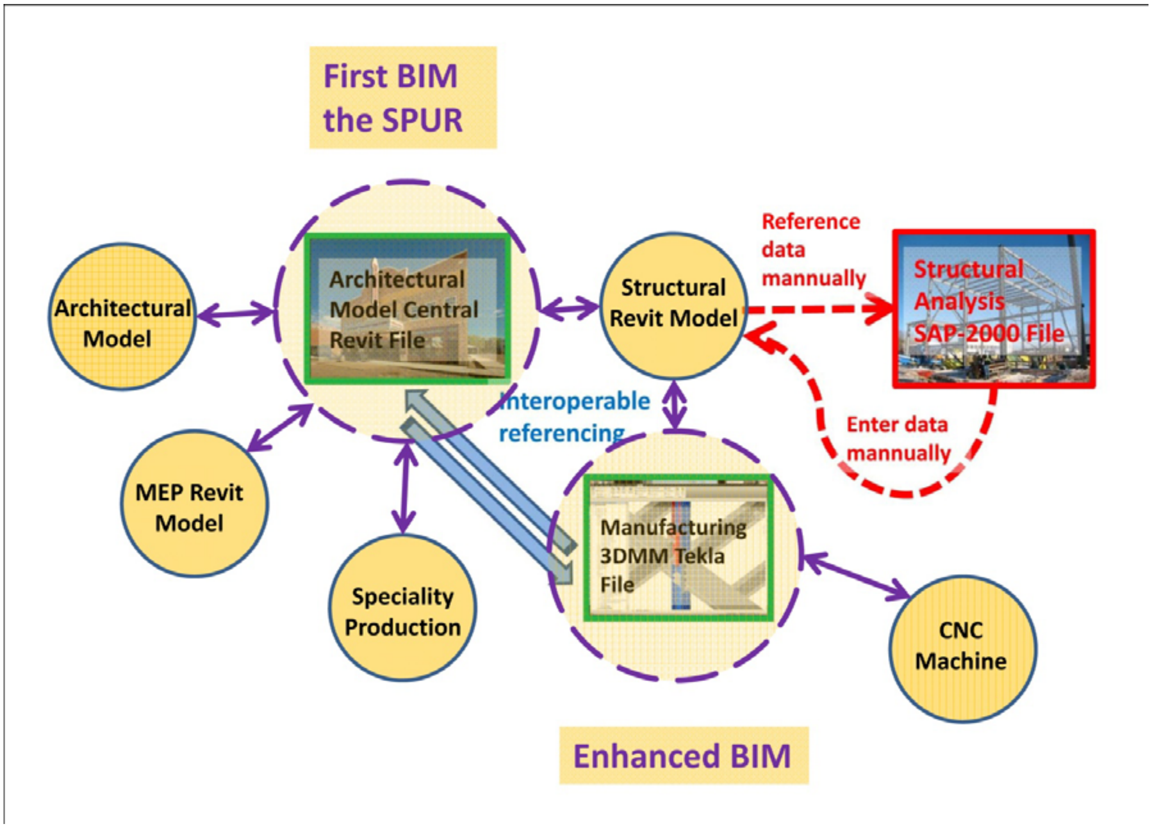


Figure 130: Diagram of the used models and their correlation.

Uses of Models

The following sections describe the different ways that the BIM was used on this project.

Structural Design and Steel Detailing

This design models were used mainly to communicate with the client, validate the spatial program, conduct site verification, and to create 2D and 3D drawings of schematic design, design development and construction documents.

One of the most important uses of Enhanced BIM on this project was the capability of structural detailing required for the steel fabrication shop. By modeling the structural details, conflicts with the architectural and MEP systems were identified early on which in many instances resulted in resizing of the structural member. This model was also beneficial in adding miscellaneous steel work that helps constructing building components for all disciplines. Figure 131 is an illustration of a steel detailing component that was fed back into the Revit Structure model.

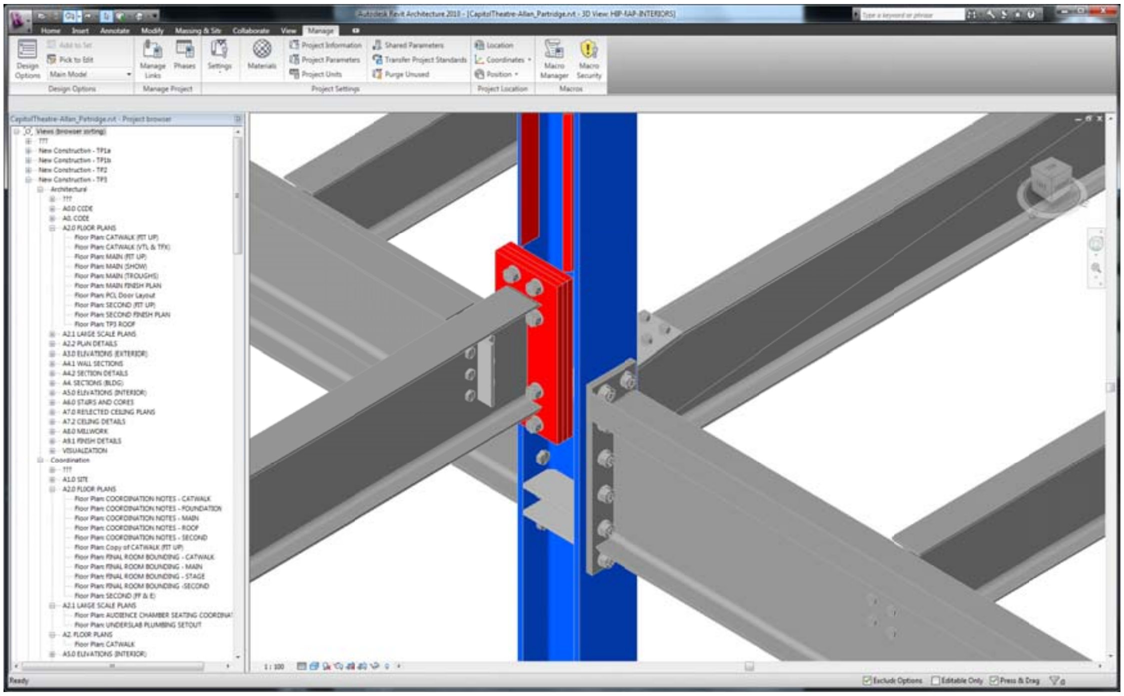


Figure 131: Detail of structural steel work that was incorporated into the Revit Structure model.

Construction Coordination

During the construction phase, the Tekla model was exported to Trimble equipment for utilizing GPS positioning on piles and foundations for ensuring accuracy (Figure 132). The steel fabricator played a leading role during the construction phase in coordinating the building components detailed design information and sequence of construction between the key trades. The steel contractor, Supreme Group, had the ability to effectively receive, filter, process and execute information from varying sources. They were also able to advise on the most efficient path forward by receiving the information early and exploring different options, which helped mitigate potential impacts. This process picked up errors that would have delayed the steel erection by at least a week when discovered on site, and the technology was quickly adopted into work flow.

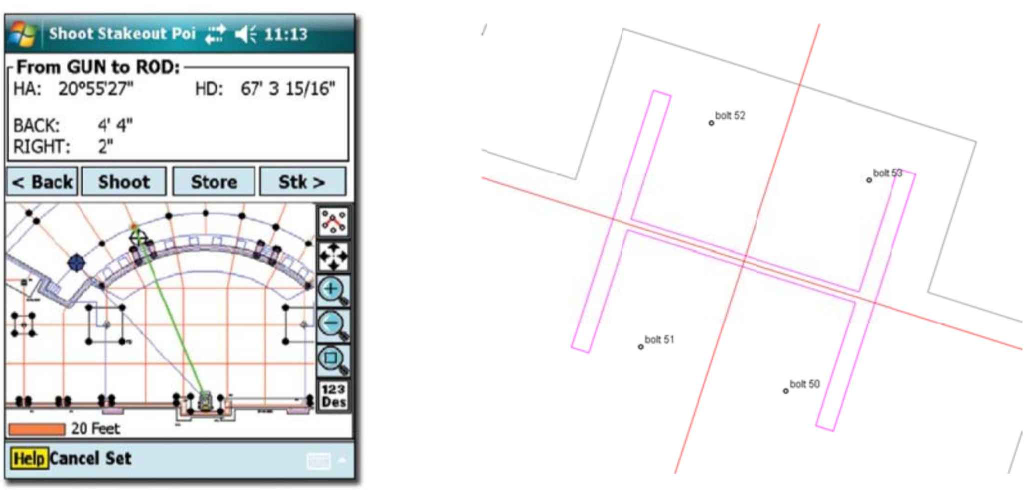


Figure 132: Trimble used to verify anchor bolts prior to finalization of base plates.

Clash Detection

Clash detection was performed using the SPUR with both Revit Architecture and Revit MEP models, as well as, the Tekla IFC file. The architectural model was used extensively to coordinate between MEP, the structure (fabrication model rather than the design model) and the building envelope. The MEP 3D components for the construction phase were also adjusted using the IFC (exported from Tekla) model after coordination with the Steel Fabricator. Clash detection and visual audit of the construction elements were routinely conducted. Information was quickly communicated with appropriate project members for timely decisions, which allowed for immediate change implementation. In traditional project delivery modes, only experienced team members can detect anomalies, whereas on a BIM platform, even modelers can perform such quality control tasks to an extent. Figure 133 shows the model with the structural design model turned off and the IFC model (exported from Tekla) imported back into the SPUR.

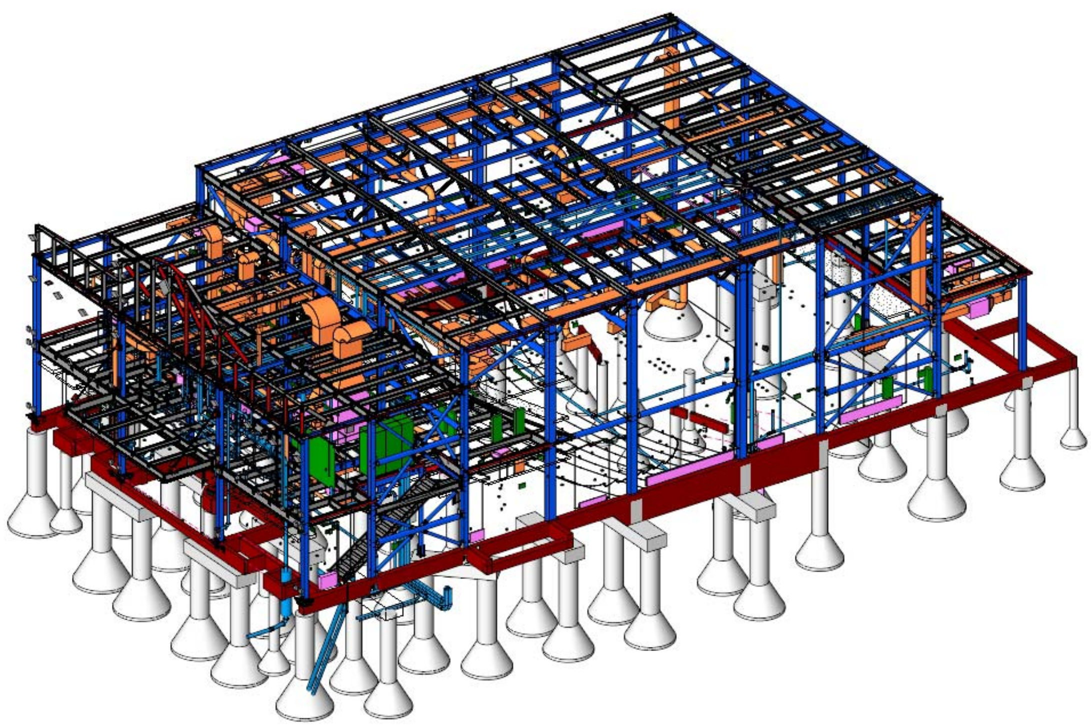


Figure 133: Tekla Model (integrated into BIM) that allows easy visual auditing of all design components

Identifying Potential Coordination Problems

Owning worksets within the model was rather a unique approach to coordinated design. Often each discipline works on their discipline-specific model in isolation, with integration taking place on a periodic basis (e.g. weekly) for multidisciplinary coordination and conflict resolution. On this project, there was one model (i.e. the SPUR), which included all disciplines. The designers could therefore see the designs completed by other disciplines as they were progressing with their own discipline's model. Integrity of data was also maintained as each discipline could only modify the model components related to their own design. In other words, only 'view' access was granted to model components of other disciplines. Hence, not only the number of 'field' conflicts was reduced by coordination and conflict detection, but also the number of 'virtual' conflicts was reduced as they were recognized immediately, rather than waiting until the next multidisciplinary model integration.

Quantity Takeoff

Quantity TakeOff 2011 was used for exporting material quantities from the model.

Virtual Request for Information (V_RFI)

RFIs were viewed rather differently on this project. Instead of having the mindset that fewer RFIs represent a better project, they considered V_RFIs as positive communication tool. A V_RFI template was devised which relies much less on descriptive paragraphs but rather on model shots of the conflict at hand (Figure 134). These V_RFIs were considered as perhaps multi-directional compared to the traditional linear contractor to consultant flow.

CAPITOL THEATRE VIRTUAL REQUEST FOR INFORMATION		Comment	V_RFI# M001
`1. Missing, Interference or Conflicts	X	East Auditorium Ventilation branch duct clash with Storm Drainage main	
2. Field Conditions			
3. Interpretation/Suggestion			
Element ID's		5902472, 6013112, 6013326	

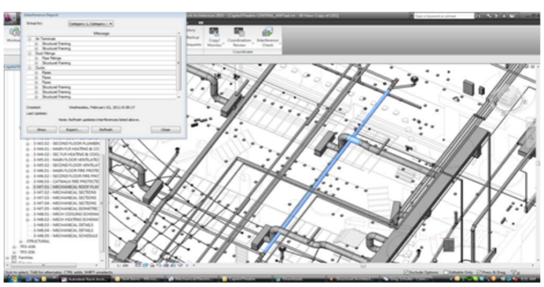
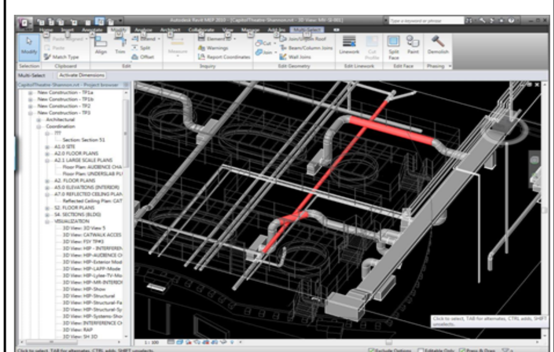
Pre Screen Capture	Post Screen Capture
	
Issued by: Drew Teal - PCL	Issued by: Chad Musselwhite – Williams Engineering Canada
Date: February 2, 2011	Date: February 17, 2011
Comment:	Comment:

Figure 134: Virtual Request for Information Template

4D Simulation of the Construction Process

The Construction Manager used the BIM with its own worksets to establish a rudimentary 4D approach by linking some elements into the construction schedule.

Integrated Deliverables

They were able to use the fabrication model to eliminate general interference, coordinate deflection locations, which was invaluable for building envelope coordination (Figure 135).

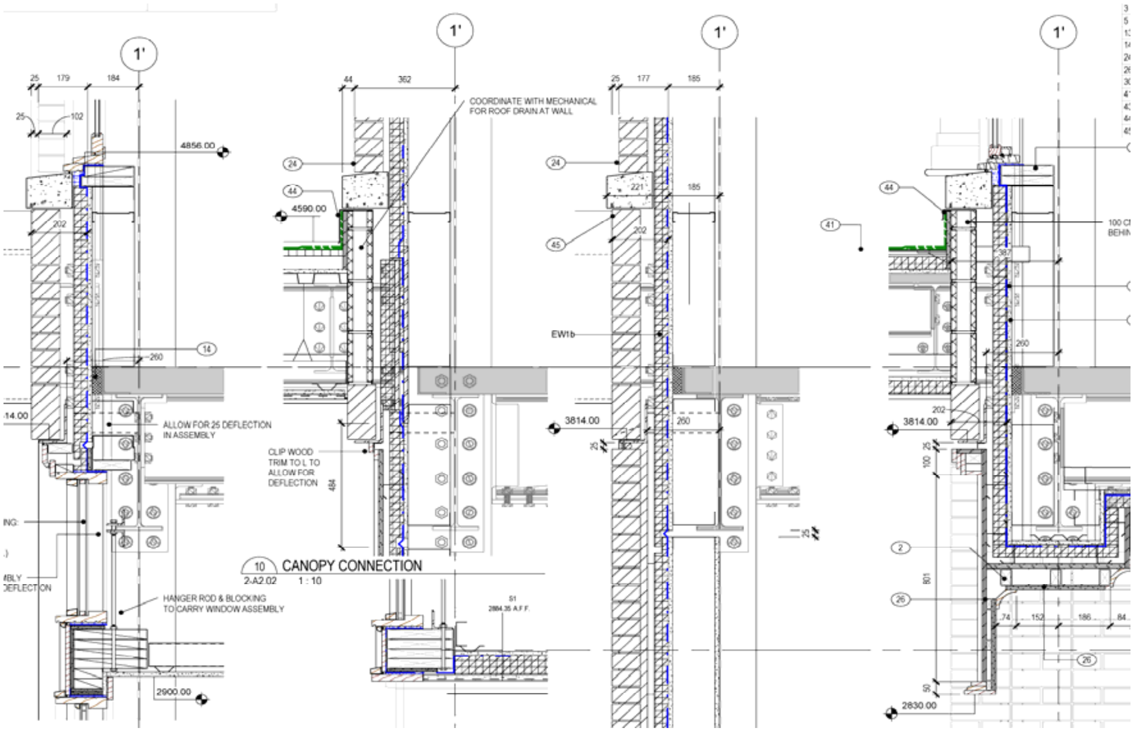


Figure 135: Integrated deliverables enhanced coordination of related systems, such as the building envelope.

Information Exchange

On this project, the architect correctly understood the true value of BIM as *information* (i.e. metadata) rather than falling into the modelling mindset. The information infrastructure was focused on a Data Centric approach versus a Document Centric approach. In other words, the focus was on the act of building and not creating documents. Having this concept in mind, the information available in the virtual world mimics the real world activities.

To achieve the Data Centric approach, a WAN system was setup, optimized and coordinated with IT. The system only uploaded the changes to a saved Revit file back to the servers. Further, a robust Navisworks technology was adopted.

The Tekla model was periodically exported (as an IFC file) and was integrated with the SPUR to minimize potential field conflicts. The steel fabricator accessed the central file using Revit Structure to coordinate with the architect. Multidisciplinary BIM coordination was performed using the central file model except for the CNC. CNC was used for steel fabrication and was connected and interoperable with the Tekla model only. There were no paper shop drawings created on the Capitol project as it was all handled digitally.

3.7.3 Organization

This section describes the levels of BIM maturity of each of the firms, the contractual relationships and legal considerations.

BIM Maturity

BIM expertise of the different parties involved in the project is as follow:

- Architectural Team 8 years
- Structural Team: 5 years
- MEP Team: 3 years
- CM : 3 years

Contractual Relationships

The architectural and engineering contractual relationship was a modified AIA Integrated Project Delivery (IPD) and depended on RAIC documents 7 and 9. CCDC 5A was used as the construction management contract.

The contractual relationship was established as a modified traditional AEC approach of Design Bid Build with IPD-lite. The actual design and construction relationship, due to BIM implementation, was a fast track integrated design process. In reality, it was closer to Design-Build relationship as the design assist on structural steel was completed before completing demolition and hazmat, and before completing the Construction Documents to reduce risk associated with renovations. The CM budgeted the building at SD, DD and CD.

The main difference between IPD and traditional project delivery practice is bringing on board, at early stages, all disciplines including the contractors and fabricators. This requires a type of contract that is different in its arrangement in order to accommodate early contributions from all parties. The contract in this case study did not include such clauses for this early contribution, nor did it include shared-risk, shared-reward clauses.

Legal Considerations

There is often ambiguity in BIM-project contracts with respect to 'ownership' of the models and drawings. In traditional practice, designers are used to own the 2D drawings produced by their discipline, whereas on BIM projects, the 'ownership' of elements of the BIM and 'snapshots' of progress in the Revit environment are more complex and require careful consideration during contract negotiations. On this project, the ownership of all data contained in the BIMs and other deliverables created, remain the property of the client.

In practice, an IPD arrangement presents a blurred line between the responsibilities of the consultants, sub-consultants, contractors, and sub-contractors. For example, consider a structural steel fabricator, which has typically been a sub-contractor paid by the general contractor, becoming part of and contributing to the design. Upon completion of design, there will be ambiguity with regards to the amount of compensation the fabricator in entitled to for design efforts. Further ambiguity exists regarding the entity that the fabricator should seek reimbursement from. In this case, it's not clear whether it is the general contractor or the owner who is responsible for compensation.

On the Capitol Theatre project, the fabricator contributed considerably more resources and effort to the design phase than anticipated. The fabricator, however, was not able to recover all of its associated design costs. We understand that a certain degree of coordination and also creation of a 3DMM are typically part of a fabricator's role. If coordination efforts were properly balanced between the engineer and the fabricator, the 3DMM should have been shared through BIM without major impact to the fabricator's typical workload.

3.7.4 Processes

Project Execution Planning

The established processes on this project allowed for a larger number of entities to be included and participate in the design process. Important modifications to design were made earlier during the design phase as all major players were present. Constructability reviews and the coordination process proved invaluable to the project. The building models and files were coordinated and checked by both the architect and the designer at the fabrication shop. Figure 136 shows the different BIM enabled interactions between the different stakeholders on this project.

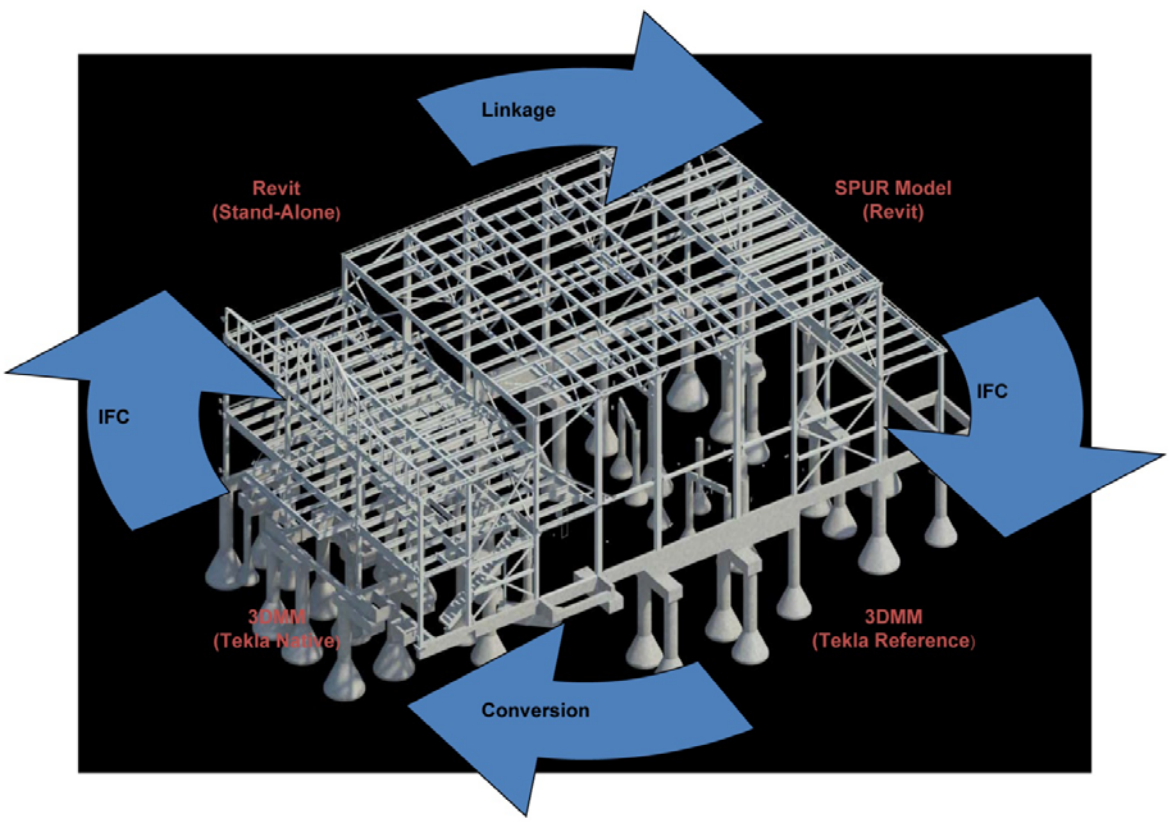


Figure 136: Interaction between the different models on the Capitol Theatre project

Process Efficiency

From the view of organizational considerations, the Capitol Theatre project was not set up in a way that allowed for efficient use of BIM. The collaborative process that BIM brought to the project resulted in a faster than anticipated progress during the design phase. At the time when the steel design was at a stage ready for fabrication there were still no contracts in place to allow for that. No contracts existed between either of the steel fabricator and the general contractor, or between the general contractor and the owner. This resulted in a cease of progress for 6 weeks in order to negotiate the contracts needed for moving forward. This process took longer than the 4 weeks that took to progress from 30 percent design drawings to shop drawings.

Further, the efficiency of the process was affected by the lack of interoperability found between SAP2000 and Revit Structure 2010. As previously mentioned, the model components were transferred from Revit Structure to SAP2000 for member sizing and load analysis. The resulting member sizes did not however get communicated back to Revit Structure seamlessly. In fact, each member sizing had to be manually input back in Revit Structure which proved time consuming and inefficient. The evolution of the Revit model did not lend itself to subsequent reiterations between the two models. With proper planning, interoperability issues such as this one can potentially be minimized.

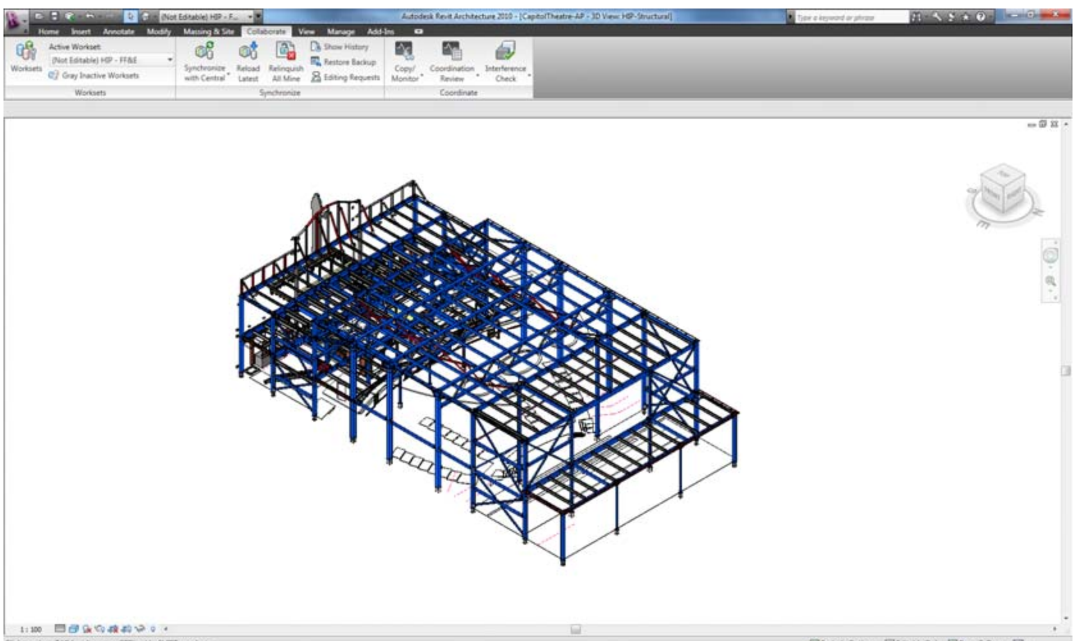


Figure 137: 3D structural model in Autodesk Revit

Planning BIM Uses and the Role of a 'BIM Manager'

The Prime Consultant suggested BIM to the extent of their expertise and experience based on previous projects. While the project had two BIM environments running concurrently, interoperability and high level of coordination helped establish the roles and the extent of each model. The Revit architecture model played a major role in the overall coordination during the initial stages of the design. The Tekla model was crucial in streamlining and carrying out activities related to structural design and detailing. The Tekla model was used until the final stages of steel manufacturing and building construction. The IFC exported from the Tekla model ended up being the primary BIM for all coordination between architecture, MEP, and the speciality designs as it also provided support and solutions to the construction methods.

Workflows

Find below the workflows and processes used to develop the models:

- Architect/Civil/Structure team was involved early to design the civil, sub-/super-structure and the general building envelope systems.
- Development of tender packages followed to facilitate both fast track and budget/schedule risk mitigation.
- Design-Assist process started to evolve the structural steel design model into the structural steel fabrication model.
- Sign-offs were completed by the client and the team on the fabrication model.
- Architect/MEP team developed the fit up package and mitigated coordination risk by performing frequent clash detection exercises.
- MEP team was involved early to determine 'head end' sizes with no considerable detail.
- Integration of rigging and F/X is possible as these specialists work at a Parametric Solids Modeling (PSM) level which is compatible with BIM.
- Utilized BIM for the process of 3D control and scheduling on site. Virtual RFI process was adopted to virtually 'design/construct' the major scope of work. Further, 2-week work package integration was achieved.

Information Exchange Process and Protocols

The architect created the SPUR that allowed for live information exchange by all BIM players including structural, MEP and the speciality designers. Each could access and make changes to their sections (i.e. worksets) of the model based on authority granted. The Tekla model, on the other hand, communicated the SPUR, Revit Structure and the CNC machine for production.

The models in Revit were subdivided per floor and into zones for easier manipulation and analysis by the mechanical team for HVAC design. The Tekla model did not need subdividing because working and analysis was quick enough with the entire model.

1.1.1. Evaluation

Even though the process and implementation faced challenges, positive results were accomplished due to the following:

- The team players understood the requirement for BIM implementation and supported the idea even though the owner did not ask for it.
- Two different organizations with the necessary expertise managed the BIM at different stages in the project.

- The team players were motivated, engaged in the project, and had a high degree of trust and mutual respect.
- The considerably well-established methodology of work (technical skills, workflows, etc.).
- The joint expertise in design, technology, management and construction of the team.

Benefits

BIM was defined by the stakeholders, in the interview session, as a tool that fosters collaboration. The following list provides some of the key benefits realized as a result of using BIM on this project:

- Significantly reduced Request-for-Information and Change Orders: the project was finished with 0 RFIs and 4 Change Orders (2 of which were cost savings).
- On budget (i.e. only 0.5% over budget) and on schedule delivery of the project.
- Efficiency during the design stage resulted in a significant time saving as erection of structural steel started 4 months earlier than the traditional practice.
- Process started in July based on 50% DD model – 10% budget at risk was established where Structure Steel finalized at 8% additional cost which is 2% lower the anticipated risk.
- 85% cost reduction compared to traditional practices for construction of metal connections, metal frames, and other miscellaneous elements.
- All drawing deliverables were done digitally (i.e. paper shop drawings were not created).
- Reduced Architectural and Engineering time in CD/CA compared to a comparable project delivered through traditional practice.
- Budget and schedule risk mitigation on 75% of the budget – structure, MEP and envelope.
- Focused ‘two week look-ahead’ meetings rather than chasing individuals to correct problems (i.e. more proactive and less reactive).
- Very few surprises were observed as considerable coordination took place in the virtual design/construct environment with the AEC team before construction/assembly started on site.
- Increased on-site safety as accuracy of design was higher.
- Higher level of pre-fabrication, resulting in higher quality and better productivity.
- No litigation.

Challenges

BIM was proposed as a tool that could minimize inefficiencies and reduce project cost and schedule. This was achieved on the Capitol Project through the collaborative integrated process that enabled real time communication and conflict resolution. However, the contract clauses regarding scope and reimbursement were based on more traditional design and delivery models. This resulted in the design team absorbing some of the cost associated with the condensed design and construction schedule that BIM allowed for. The steel fabricator ended up taking full responsibility for the creation of the structural model detailing. Not only coordination was carried out, but constructability analysis was also performed to maximize the extent of the pre-fabrication. This resulted in reduced construction cost and schedule, and improved site safety.

The following provides some of the challenges on this project:

- While the SPUR file allowed the design team members to collaborate effectively, it was not compatible with SAP 2000 and CNC fabrication.
- Tracking progress and understanding the changes in the model were often difficult to understand. 2D documents were used for documenting progress and communication purposes.

Lessons Learned

Implementation of BIM on the Capitol project proved quite beneficial. However, there is much room for improvement. The following offers some lessons learned:

- Early engagement of all essential parties, particularly those responsible for construction, on a BIM process is vital.
- Combining a traditional CAD process with BIM is risky and should be avoided as much as possible.
- BIM management expenses should be considered when bidding for BIM projects.
- Schedule and cash flow should be adjusted to accommodate for the initial integration of a BIM platform on the project.
- Interoperability and familiarity of software is crucial for successful implementation of BIM. Adequate pre-planning should be done prior to project kick-off.

1.1.2. Acknowledgements

We would like to thank the following people for their time and input:

- Allan Partridge, Principal, Group2 Architecture Engineering Ltd. (formerly with HIP Architects)
- Scott Cameron, Supreme Steel LP
- Manoj Mistry, Principle, Stantec

4 SUMMARY OF BEST PRACTICES EXTRAPOLATED FROM ALL CASE STUDIES

This section presents 'best practices' and lessons learned from our case studies and other sources. It is organized according to the three dimensions of our framework, i.e. Technology, Organization and Process. It is our belief that successful implementation of BIM requires a balance between these three dimensions. The following sections describe the 'best practices' – first summarizing the key takeaways, and then discussing the differences between what we see as 'common practice' and the more ideal 'best practice'.

4.1 TECHNOLOGY

The following summarizes critical success factors to ensure that technology will provide the expected benefits to all the members in the supply chain:

1) **Owner: Specify clear, complete, and open requirements**. The intent is to provide clear and complete requirements without limiting the software choices of the team. For example, if a Revit file is mandated by the owner, this might limit the structural or mechanical contractor's ability to fabricate from that model.
2) **Owner/Project Team: determine uses/purposes of the model**. It is important that everyone agree and commit early in the project on how the model(s) will be used and for what purpose to ensure that the 'right' model is created at the 'right time' for all intended consumers of that model.
3) **Owner/Project Team: for the uses/purposes identified in (2), determine the scope of the model and the level of detail of the modeling effort required to support each purpose**. According to DPR Construction (Sutter Health case study), the "disconnect between the purpose and how the model is created is one of the single biggest sources of frustration on BIM projects."
4) **Project Team: decide at the outset on which set of technologies to be used**. It's important to understand the technology preferences of the project team to work out any interoperability issues that may exist. Although standard file exchange formats are making this easier (e.g., IFC), these issues still persist. Another consideration is identifying the necessary level of training that may be needed.
5) **Project Team: set up the necessary information infrastructure to support the modeling requirements for the project**. BIM projects generate a significant amount of data so it is critical that the project team consider how this information will be shared and managed during the course of the project. Many have found that FTP sites are insufficient for handling the large file sizes and the degree of collaboration required.
6) **Design Team: consider downstream users of the model.** An important consideration is that the 'creators' of the models may not be the direct beneficiaries of the model. Downstream users, therefore, may need to provide input on how a model is developed to suit their purposes. For example, energy analysis requires the modeling of spaces and using the model for cost estimating may require additional properties in the model. Facility managers in particular should contribute to the scoping of the models.
7) **Construction Team: focus on modeling elements that can potentially create an issue in the field.** When assessing what to model to support construction, it is best to think about the

elements that could cause field issues rather than the size of the element (e.g., model nothing smaller than 1-1/2" diameter). Experts (e.g., DPR Construction) have found that small elements can have a big impact (Lamb et. al., 2009).

4.1.1 Discussion – 'Best Practice' Vs. 'Common Practice'

Common practice: BIM à la carte – picking and choosing a BIM application as the project progresses without sufficient thought and planning. It is quite difficult to plan when the destination is not clear. Efforts are wasted and frustration reduces team motivation and performance. *Best practice:* first identify the expected outcome, second devise a process for achieving it, third select the technology (Sutter Health, R2, Intellibuild, Vancouver Convention Centre).

Common practice: client requesting BIM without defining what they want (format requirements, types of analyses to be conducted, etc) because they don't have the expertise. *Best practice:* hire experts in the field to help owners configure and manage the BIM process (intelibuild) or outsource the management to a firm specialized in this field (Archidata/University of Montreal).

Common practice: making do, i.e. start by acquiring BIM software, asking staff to learn it by themselves and upgrade hardware when in crisis. *Best practice*: (1) define the collaborative infrastructure (Capital Theatre), (2) provide professional training and coaching to the staff (Coarchitecture), (3) have BIM managers identify the most appropriate technologies for the collaborative work (Intelibuild)

Common practice: focus on a proprietary technology from a unique vendor to reduce transfer information from 2D legacy to BIM. *Best practice:* (1) Open-BIM (i.e., Industry Foundation Classes or IFC) permits one to choose the set of most appropriate software to obtain the desired outcome (Sutter Health, Capital Theatre). (2) Sometimes BIM technology is not mature enough to do the job, especially at the front-end. It is better to choose the best-suited technologies to develop and then move to appropriate BIM technology when it will be available (Coarchitecture).

Lack of practice: BIM is great for new buildings. However, the majority or projects are about retrofitting, adding to existing. For the client, having two sets of technology (CAD and paper for existing/BIM repository for new projects) to manage their building could become a management nightmare. *Best practice:* (1) use laser-scanning technology to map the building to be retrofitted/expanded (Sutter Health). Prices are going down and expertise is building up from third parties to provide this type of service; (2) acquire services for transfer of information from legacy in order to provide data readable by BIM software through exchange protocols like Open BIM or COBIE (Archidata/university of Montreal).

4.2 ORGANIZATION

Organization is paramount to reap the benefits of BIM, however, it is the less well-managed of the three dimensions, particularly for Canadian projects. As asserted in the NIST report on the cost of interoperability, the most important benefit of BIM is for the management of the facilities. And as indicated by people from the supply chain during the interviews, it is the client who benefits from the use of BIM within the design and construction process. Therefore, best practices for maximizing BIM outcomes are:

1) **Owner: rethink the organizational structure/practices for managing its construction projects and real estate portfolio**. Owner support and leadership is critical for ensuring that BIM projects are structured in a way that both optimizes BIM for the project life-cycle and the long-term use of the BIM model for facilities management.
2) **Owner/Project Team: early involvement of all key disciplines is essential**. To optimize the downstream uses of the model, all key disciplines should provide input on its development, including the contractor, major sub-trades and members of the facility management team that will be maintaining the built facility.
3) **Owner: create the appropriate context for collaborative BIM**. Team members should be incentivized to collaborate. Proper consideration is required in terms of compensation schemes and contracts should be developed to support a collaborative BIM process (e.g., IPD).
4) **Owner/Project Team: re-think the assignment of modeling responsibilities.** Often, the models created by consultants are not suitable for construction uses. For example, the models created by mechanical consultants may not support fabrication by mechanical contractors, significantly limiting the benefits of the model. According to DPR Construction, "WHO creates the BIM is as important as WHAT you want to model" (Lamb et. al., 2009).
5) **Owner: ensure that all the members of the project team have an appropriate level of maturity in the use of collaborative BIM.** At a minimum, limit the number of firms that are 'new' to BIM, and ensure proper training is provided to those firms that are just getting started.
6) **Owner/supply chain: consider training, learning curve and resistance to change.** The transition from a traditional to an integrated project delivery is significant and there will be resistance. The important thing is to recognize that this is inevitable and to plan for it.
7) **Supply chain: redefine organizational structure and interactions within and between firms.** Firms implementing BIM need to think strategically about the BIM implementation process within their firm and develop long-term strategic plans.
8) **Owner/supply chain: document the benefits and challenges of BIM.** To facilitate and encourage BIM adoption in Canada, more case studies are needed to document the benefits and challenges of BIM implementation. Several firms in the US took a leadership position in this way, including DPR and Mortenson Construction, and this sharing of experience helped to drive BIM adoption rates.

4.2.1 Discussion – 'Best Practice' Vs. 'Common Practice'

Common practice: Solving new problems with old solutions usually doesn't work. BIM is a shared model to be worked on by teams. The traditional organizational structure is functional, meaning that work is divided in a hierarchy of functions and related tasks. Also the client requires BIM but still uses a fragmented procurement mode and does not want to pay more for this service. These don't work well with collaborative BIM. *Best practice:* (1) redefining the relationship between the client and the supply chain through an Integrated Project Delivery contract (Sutter Health) or use negotiated procurement methods like construction management (Vancouver Convention Centre, Coarchitecture), (2) define a roadmap for progressive migration of organizational structure and practices from a legacy system to BIM (University of Montreal).

Common practice: BIM proficiency is not part of the criteria for selecting the team or if it is, there is no validation process to ensure that the firms have the expected BIM capabilities and resources. *Best practice:* requiring a minimum level of maturity and measuring it using independent verification, audits or questionnaires (Sutter Health, R2).

Common practice: not measuring, sharing the information about the benefits of BIM. One of the findings in this research is the lack of efforts in documenting BIM projects in Canada. Also, little is done in measuring BIM implementation costs and benefits. *Best practices:* (1) prepare and follow up a BIM business case (Sutter Health, R2), (2) measure, document, and inform - i.e. return on investment, reduction in RFI, change orders... (Sutter Health, R2)

Common practice: consider BIM as solely added software to the cocktail of technologies of the organization. BIM is considered by experts as a paradigm shift in business practices (McGraw-Hill 2009). Integrating BIM means new and revised roles and relationships; rethinking "the chain of command" from hierarchical decision-making to self-managed teams. People fear uncertainties related to these changes. *Best practice:* (1) manage the organizational transformation related to BIM implementation so people acknowledge the benefits not only for their firm but also for the supply chain (Sutter Health, Coarchitecture); (2) manage the transition by adopting short learning curve technologies to help staff discover the advantages of adapting to the BIM working environment, i.e. using browsers as an interface to access building information and data generated by BIM tools (University of Montreal).

4.3 PROCESS AND PROTOCOLS

BIM benefits are at two levels: increase the value of the outcome (the end product); improve the efficacy and the efficiency of the process. Process and protocols must be developed and implemented to maximize these benefits.

- **Owner/supply chain: devise and agree on shared goals regarding what is expected to be achieved.** Being clear about the goals and scope of the modeling effort and managing the expectations of all parties is critical on BIM projects.
- **Supply chain: devise and agree on a BIM execution plan.** An essential first step in any BIM project is to develop a BIM execution plan. There are now many guidelines that are publically available to help project teams to craft an execution plan for their project (Refer to Section 2 of this report for examples).
- **Supply chain: clearly define roles and responsibilities including handoffs between disciplines.** On collaborative BIM projects there are new roles and a blurring of responsibilities, particularly as downstream trades start to contribute to model development.
- **Supply chain: manage workflow, dataflow and information sharing.** Due to the significant shifts in workflow and the timing of activities and decision-making, significant effort is required to manage the model development process.
- **Supply chain: manage the coordination process.** Coordinating a project with BIM requires proper management to ensure that the right models are developed at the right time, to ensure that the models 'fit' together appropriately, and to ensure that results and courses of action are properly documented and communicated.

- **Client/Project team: expert knowledge is still required to validate outputs.** BIM is only a tool. The accuracy of the models and any analysis based on these models must still be validated by experts in the field.

4.3.1 Discussion – 'Best Practice' Vs. 'Common Practice'

Common practice: prescribing the use of BIM with no defined purpose. Members of the supply chain consider that BIM is an extra effort. It is important to motivate the supply chain (and also the client team) to know why they should put this extra and determine together how far they expect/want to go. *Best practice:* shared goals and objectives are clearly defined as part of the IDP relational contract (Sutter), or in an IPD-lite organizational structure (Capital Theatre).

Common practice: a project by project trial and error process in BIM implementation and use with no process to document lessons learned. *Best practice:* deriving standard and execution plans already available from universities, associations or agencies, and update them in a regular fashion through lessons learned (DPR Construction, Mortenson Construction, Coarchitecture).

Common practice: no leader or too many leaders in managing the development and use of the model(s). *Best practice:* In collaborative, BIM the project team should function as a team with a leader that helps devise strategies, make sure that efforts are properly coordinated, and follow the plan (Sutter Health and R2 projects).

Common practice: ftp site for information sharing, which is clumsy and limited to warehousing files. *Best practice* Co-architecture: Sharepoint content management platform provides tracking of documents updates, discussion boards, calendar, etc to facilitate coordination within a team that is not collocated. Capital Theatre: electronic exchange platform. Sutter Health: Bentley ProjectWise.

Common practice: leave BIM to the hands of modellers. BIM is not an electronic drawing board but a set of sophisticated design tools. Expert judgment is required. For example, clash detection is great and is considered as one of the most value-added feature of BIM. However, it doesn't detect anomalies and can generate a tremendous amount of false conflicts. *Best practice:* formal processes and procedures are in place to manage and document the coordination process. For example, statutory clash detection and walkthrough into the model (weekly or by-weekly) involving representatives of all disciplines (Intelibuild, Sutter, R2).

5 CONCLUSIONS AND NEXT STEPS

This report has tried to show that although BIM is quite new in the Canadian landscape, there already exists a lot of information (guidelines and standards) from other countries, which are easily available from the web. However, context is paramount in construction, since there are major differences in the structure and culture of the industry from one country to another and in Canada, from one province to another. It was important to us to first capture the essence of this international effort to make sense and document on how BIM is changing our industry into an easy to understand framework; second to make them tangible through the description of cases that outline some or many of these best practices while also presenting lessons learned in thriving to adopt and implement BIM in projects.

This report should nonetheless be considered as a step towards building a mature Canadian industry in using BIM. There are major challenges ahead regarding procurement and education. To reap the full benefits of BIM, contracts encouraging collaboration and partnership such as IDP should be adopted. Proper training at the university and professional levels has to be initiated. BIM has to be built around trust and sharing. There is also a need of a cultural shift to bring closer researchers and the industry. The industry needs highly qualified personnel (HQP) to help them navigate in this new business environment. On the other hand, researchers, in order to train these HQP, need to build the new BIM body of knowledge from the lessons learned in the industry.

There are now several BIM initiatives in specific regions around the world that provide a useful starting point and a path forward for Canada. In the US, the General Services Administration's requirement for BIM since 2007 has been a significant driver in BIM adoption, which we described in Chapter 2. Critical to their success was the GSA's BIM guidelines that they developed for specific areas of application for BIM implementation. The UK initiative provides an excellent example of a thoughtful, deliberate and well-resourced process that the government can initiate to investigate the appropriate application of BIM for public projects, and to develop a long-term strategy for how to help the industry make the transition to this new way of working.

In Canada, the government of Alberta is leading the way in its initiatives to support its industry in adopting BIM, involving universities to participate in this process. Additional efforts are needed to develop a strategy for driving BIM adoption (similar to the UK's strategy report), continue to document emerging best practices in Canadian BIM projects, and to develop and formalize tools to help industry measure their performance and maturity in using BIM.

6 RECOMMENDED READING AND SOME RELEVANT WEBSITES

American Institute of Architects (2007). *Integrated Project Delivery: A Guide*, Version 1: http://www.aia.org/contractdocs/AIAS077630

Ashcraft, Howard. "*Building Information Modeling: A Framework for Collaboration*," *Construction Lawyer*, Volume 28, Number 3, 2008.

Associated General Contractors of America (AGC) (2006). *The Contractors' Guide to BIM: Edition 1*: http://www.agc.org/cs/industry_topics/technology/building_information_modeling

BIM Industry Working Group, Department for Business, Innovation and Skills (BIS), United Kingdom (2011). *A report for the Government Construction Client Group Building Information Modelling (BIM) Working Party Strategy Paper.* Available online at: (https://connect.innovateuk.org/c/document_library/get_file?uuid=6842e020-20df-4449-8817-08ce2ba9ef7c&groupId=68909.

Computer Integrated Construction Research Program (CIC). (2010). *BIM Project Execution Planning Guide – Version 2.0*, The Pennsylvania State University, University Park, PA, USA. Available online at: http://bim.psu.edu/Project/resources/default.aspx.

Cabinet Office, United Kingdom (2011). *Government Construction Strategy Report*. Available online at: http://www.cabinetoffice.gov.uk/sites/default/files/resources/Government-Construction-Strategy.pdf.

Cooperative Research Centre (CRC) for Construction Innovation. *(2009). National Guidelines for Digital Modeling*, Brisbane, Australia. Available online at: http://www.construction-innovation.info/images/pdfs/BIM_Guidelines_Book_191109_lores.pdf.

Cooperative Research Centre (CRC) for Construction Innovation. *(2009). National Guidelines for Digital Modeling: Case Studies*, Brisbane, Australia. Available online at: http://www.construction-innovation.info/images/pdfs/BIM_CaseStudies_Book_191109_lores.pdf.

General Services Administration (GSA). (2011). *3D-4D Building Information Modeling Guides*. Available online at: http://www.gsa.gov/portal/content/105075

Hartmann, Timo and Fischer, Martin (2008). *Applications of BIM and Hurdles for Widespread Adoption of BIM 2007 AISC-ACCL eConstruction Roundtable Event Report*, Stanford University, CIFE Working Paper #WP105. Available online at: http://cife.stanford.edu/sites/default/files/WP105.pdf.

Khanzode A, Fischer M, Reed D (2008) *Benefits and Lessons Learned of Implementing Building Virtual Design and Construction (VDC) Technologies for Coordination of Mechanical, Electrical, and Plumbing (MEP) Systems on a Large Healthcare Project*, ITcon Vol. 13, Special Issue Case studies of BIM use, pg. 324 ‐ 342, http://www.itcon.org/2008/22.

McGraw Hill Construction (2008). *Building Information: Transforming design Construction to Achieve Greater Industry Productivity,* Smart Market Report. Available online at: http://www.bim.construction.com/research/.

McGraw Hill Construction (2009). *The Business Value of BIM: Getting Building Information Modeling to the Bottom Line*, Smart Market Report. Available online at: http://www.bim.construction.com/research/.

Staub-French, Sheryl and Khanzode, Atul. (2007). 3D and 4D Modeling For Design and Construction Coordination: Issues and Lessons Learned, Journal of Information Technology in Construction, Vol. 12, 381-407. [Available at: http://www.itcon.org/data/works/att/2007_26.content.07145.pdf]

6.1 Some useful websites:

- Canada BIM Council: www.canbim.com/
- Institute for BIM in Canada: www.ibc-bim.ca
- buildingSMARTalliance: www.buildingsmartalliance.org
- National BIM Standard: *www.wbdg.org/bim/nbims.php*
- Journal of BIM: www.wbdg.org/references/jbim.php
- Fiatech: www.fiatech.org
- Virtual Builders Roundtable: www.virtualbuilders.org
- Construction Users Roundtable: www.curt.org
- GSA BIM Guidelines: www.gsa.gov/bim
- BIMForum: http://bimforum.org
- Engineering News Record – BIM Section: http://enr.construction.com/technology/bim/