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THE POTENTIALS OF BIM: COMMUNICATION, COORDINATION, AND COLLABORATION

The goal of this study is ultimately to discover and document various methodologies for integrating and linking numerous documents to one 3D Model. Through this investigation, I hope to successfully document, step-by-step, how such integrations can be implemented and utilized to increase the efficiency of BIM modeling. Virtual 3D modeling is no longer sufficient for the Architecture and Construction industries. Project members and owners are demanding a more cohesive methodology for communicating throughout the design and construction processes, and even into post-project occupancy. Throughout the design and construction of a project, there are numerous models each illustrating a different system within the building such as an Architectural model, a Mechanical model, a Structural model, and so on. Having separate models can hinder the construction process by slowing down communication between offices. With holistic BIM modeling, the communication process can be revitalized and revolutionized by merging all models into one cohesive and integrated model with access to all necessary documents and information used both during the construction process, and after the building has been completed.

Brief Title:

Analysis of Architecture and Construction Software for Determining Integration Capabilities within an Architecture Firm

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Paper Title:

The Three C's of Building Information Modeling: Communication, Coordination, and Collaboration

Abstract:

The goal of this study is ultimately to discover and document various methodologies for integrating and linking numerous documents to one 3D Model. Through this investigation, I hope to successfully document, step-by-step, how such integrations can be implemented and utilized to increase the efficiency of BIM modeling. Virtual 3D modeling is no longer sufficient for the Architecture and Construction industries. Project members and owners are demanding a more cohesive methodology for communicating throughout the design and construction processes, and even into post-project occupancy. Throughout the design and construction of a project, there are numerous models each illustrating a different system within the building such as an Architectural model, a Mechanical model, a Structural model, and so on. Having separate models can hinder the construction process by slowing down communication between offices. With holistic BIM modeling, the communication process can be revitalized and revolutionized by merging all models into one cohesive and integrated model with access to all necessary documents and information used both during the construction process, and after the building has been completed.

Introduction

Today, the Architecture, Engineering, and Construction industries are undergoing an exciting evolution that has been needed for hundreds of years. The Design and Construction industries have recently been criticized as being unproductive and lacking innovation by individuals both within and outside of the industries. According to the *US Department of Commerce*, the Construction Industry is one of the most unproductive industries as the Productivity Index of the Construction Industry has *decreased nearly twenty-five percent* since 1964. Comparing this to the average of “all other non-farm industries” which has *increased nearly 125 percent* since 1964 shows how dire the situation truly is. Architects, engineers, and builders have more or less constructed buildings in the exact same manner for thousands of years. There have been minor improvements to the process, but nothing considered truly innovative. A majority of the improvements have been to the material technology and manufacturing processes, but the actual design and construction process has remained relatively the same (Weisberg, 2008). With all of our technological advancements, the industry as a whole has not truly benefited when compared to other industries.

Since computers were first conceived, potential uses for them have continued to be realized, and recently, computer technology has made its way into the AEC industries. This has created opportunities for efficient processes, and potentially leading to the first *Construction Revolution*. Architectural and Construction computer aided design first appeared at the end of the 1970s when a book by William J. Mitchell entitled *Computer-Aided Architectural Design* hit the shelves and was a huge hit. Various 2D drafting software were developed to streamline repetitive tasks. The technology was utilized by an elite few with a majority of the industry clinging to their “old ways”. During the 1990s, computer technology exploded and its development advanced at an unprecedented rate (Weisberg, 2008). As the technology became more affordable, more firms began to catch on, causing the technology to be further developed. 3D modeling soon followed, and as computer technology

continued to develop, the AEC industries began to transform. Today, CAD drafting has evolved into BIM modeling which incorporates much more than lines and 3D geometries. This has led to increased collaboration and recently, has caused a revision of the entire design and construction process. There is no doubt that technology has played an integral role in this progression, and it may end up being the savior of the building industries.

Discussion

The research was conducted in conjunction with North Dakota State University and R.L. Engebretson Architects in Fargo, North Dakota. The goal was to aid R.L. Engebretson in adopting a greater use of BIM technologies in integrating various documents and information such as operation manuals, specifications, maintenance forms, cost estimating, schedules, et cetera.

The research began by gaining a general understanding of what BIM was, is, and what it can become. This helped acquire a working knowledge of BIM and its capabilities. To do this, information was acquired using various media including:

- i. Literature Based Sources
 - a. Physical Books and Text
 - b. Web-based Journals and Articles
 - c. Web-based Blogs
 - d. Web-based Tutorials
- ii. Video and Multimedia
 - a. Software Tutorials
 - b. Webinars
 - c. Multimedia and Video Lectures
- iii. Personal Communication
 - a. Contact and communication with R.L.E. liaison
 - b. Guidance and collaboration with Dr. Ganapathy Mahalingam
 - c. Discussion of the research with fellow classmates to gain differing perspectives
- iv. Software Analysis

In regards to the Literature Based Sources mentioned above, web-based blogs were the most useful. This is because BIM modeling is a practice-based subject, meaning, its value comes from actually using the software. As users of BIM software have questions or problems, they seek out various blogs and post their queries to open the problem up to virtually hundreds of thousands of individuals who may have found a solution to the problem. This relates to of BIM's most important aspects: collaboration. The internet has undoubtedly acted as a catalyst for the BIM industry because it allows thousands of users to instantaneously connect with others in an attempt to solve their individual problems. This has greatly eased the learning curve by offering numerous perspectives of differing experience levels in a single location. What has resulted is a connected community who is banding together to increase the knowledge base of BIM modeling in an attempt to further the technology.

BIM Overview

BIM Modeling is still in its infancy - largely unknown and under-utilized by many professionals. Some do not fully understand its true capabilities, and misinterpret BIM modeling as "just another 3D modeler"(Ibrahim, 2006). BIM modeling takes the B+M (building modeling) to a whole new level by inserting the "I" (information) within the process. It allows for improved communication, constructability, and eases the entire design and construction processes by increasing collaboration between all stakeholders. It transforms 3D modeling to 5D modeling by adding cost estimating, construction scheduling, clash detection, and facility maintenance capabilities to a single model. It gives the design teams the opportunity to literally "build" the project before it is physically constructed. True BIM modeling is revolutionizing the AEC industry by increasing communication and collaboration, reducing potential conflicts in construction processes, and increasing facility maintenance capabilities.

Currently, all of the major business models used today outdate BIM modeling, and fail to take advantage of its full potential. Because of this, a new project delivery method must be created, adopted, and implemented in the AEC industries. BIM modeling offers a rich database of information that can be shared with many project stakeholders at once. Working in conjunction with BIM modeling, a relatively new project delivery method has begun to make itself known. The Integrated Project Delivery method has the ability to permanently alter the AEC industries for the better, and to actually work with and build on BIM's strengths. There are a few major differences between this new Integrated Project Delivery compared to the traditional methods

Project Factor	Traditional Delivery	Integrated Delivery
Team	Fragmented, assembled on "as-needed" or "minimum necessary" basis, very hierarchical, controlled	Integrated entity of key stakeholders, assembled early in the process, open, collaborative
Process	Linear, distinct, segregated, knowledge gathered "as-needed", information hoarded, silos of knowledge and expertise	Concurrent and multi-level, early contributions of knowledge and expertise, information openly shared, trust and respect
Risk	Individually managed, transferred to the greatest extent possible	Collectively managed, appropriately shared
Reward/ Compensation	Individually pursued, minimum effort for maximum return, often first cost-based	Team success tied to project success, value-based
Communication/ Technology	Paper-based, two dimensional, analog	Digital, virtual, Building Information Modeling, 5+ dimensional
Agreements	Encourage unilateral effort, allocate and transfer risk, no sharing	Encourage, foster, promote and support multilateral open sharing and collaboration, risk sharing

Table 1 – Traditional vs. Integrated Project Delivery Methods

Integrated Project Delivery methods require an increased level of collaboration between teams. Project success is determined collectively, and not individually. Benefits and liabilities are shared among project teams. (InfoComm International, Building Information Modeling, date unknown)

In order for IPD to really make an impression on the industries, all project stakeholders (architects, owners, engineers, contractors, construction managers, et cetera) need to be involved from the very beginning. This will allow everybody to make informed decisions rather than "best estimates" and "educated guesses". By increasing involvement from the beginning, construction issues, for example, can be discovered sooner and fixed before construction begins. This will reduce costly change orders and save time later in the construction process (American Institute of Architects, 2010).

IPD will require more time spent on the front end of the project - which may require rethinking the project's fee structure. Because more hours will be spent sooner in the process, fees may need to be increased at the beginning, and later decreased due to a streamlined finish to the project. The typical Construction Documentation phase will be drastically reduced, if not eliminated altogether, because the "construction documents" will be worked out throughout the entire process. Constructability issues will be brought up immediately which will inevitably make more accurate drawings sooner in the process.

Principles of IPD:

1. Mutual Respect and Trust
2. Mutual Benefit and Reward
3. Collaborative Innovation and Decision Making
4. Early Involvement of Key Participants
5. Early Goal Definition
6. Intensified Planning
7. Open Communication
8. Appropriate Technology
9. Organization and Leadership

(American Institute of Architects, 2009)

Figure 1 – Principles of IPD

The AIA has created a list of 9 "Principles of IPD" that highlight characteristics of IPD.

(American Institute of Architects, 2008)

Challenges to BIM

One of the single greatest challenges within the industry is the interoperability of various software and software versions.

As of now, there are numerous BIM software available (Revit, AutoCAD, ArchiCAD, Navisworks, etc.) and they do not always "communicate" with one another. This greatly hinders the collaboration process if team members do not use the same software. As annual software updates are released by their publishers, collaboration issues may arise if one project team chooses to upgrade and another does not. For BIM modeling to realize its true potential, and for it to really gain fire, software interoperability issues must be resolved.

Legal issues may be one of the greatest barriers to the future of BIM.

Because numerous project members and teams may have the ability to alter the model, it is difficult to decipher who has copyright to the model itself. Ownership of the model raises further questions regarding liability. If an error occurs in the design or construction processes and numerous project teams make alterations to the model, it is difficult to decide who is responsible for the error. Did the architecture office make the mistake? Did the contractor make the mistake? Did the engineers? Or was it simply an error on the construction site? Many new legal issues will have to be resolved before BIM modeling is adopted by the entire industry.

BIM models can become too bulky and unmanageable.

One of the bottlenecks in the advancement of BIM modeling is computer hardware. This is because once all necessary parameters and information are included within a model, the file size can become massive. In order to simply view a model such as this requires top of the line computer hardware that many firms cannot afford.

BIM modeling offers a completely new methodology for delivering design and construction services.

Because of this, the entire design and construction process must be redefined to fit the new model of project delivery. This will include altering the design phases to reflect how BIM modeling can improve the process as a whole – requiring more time spent on the front end of the project.

In order for BIM to truly take off, all industries need to begin to utilize its capabilities.

BIM's full potential will be realized when all AEC industries begin to use it for integration purposes. BIM will not be much use if only one industry (i.e. Architecture) uses it because BIM is about interdisciplinary information sharing and exchange.

General Implementation Advice

Level of Development Tracking

Keeping a record of the LOD can add an extremely useful dimension to the BIM model. The LOD lets users know what the model elements and information can be relied on for. The higher the level of development, the more accurate and reliable the model information (BIMForum, 2013).

There is a distinct difference between Level of Development and Level of Detail however.

Level of Detail - describes how much detail is put into the model, and can be thought of as an INPUT to the Level of Development.

Level of Development - degree to which geometries and attached information has been thought through, or the degree to which users can RELY on the model and associated information. The Level of Development can be thought of as the overall OUTPUT (BIMForum, 2013).

LOD 100	element represented with symbol or generic representation.
LOD 200	element represented as generic system, object, or assembly with approximate quantities, size, shape, location, and orientation.
LOD 300	element represented as specific system, object, or assembly
LOD 350	element represented as specific system, object, or assembly and interfaces with other building systems
LOD 400	element represented as specific system, object, or assembly with detailing, fabrication, assembly, and installation information.
LOD 500	element is a field verified representation.

Figure 2.1 – Level of Development

Level of Development can be split into numerous categories that depict at what stage a model element is at in the design process. Higher numbers equate to a more “complete” model. (BIMForum, 2013)

Example – light fixture:	
100	- cost/sf attached to floor slabs
200	- light fixture, generic/approximate size/shape/location
300	- Design specified 2x4 troffer, specific size/shape/location
350	- Actual model, Lightolier DPA2G12LS232, specific size/shape/location
400	- As 350, plus special mounting details, as in a decorative soffit

Figure 2.2 – Level of Development Example

The above table lays out an example light fixture as it ascends the LOD structure. (BIMForum, 2013)

Creating the BIM Model:

1. Determine if the project will utilize a Federated or an Integrated model.

“The “Federated Model” concept requires that all component models be combined for coordination only; each model creator retains responsibility and ownership for their model and work. Component models are updated by their respective creators and combined for coordination as the project moves forward”. (Construction Users Round Table, 2010)

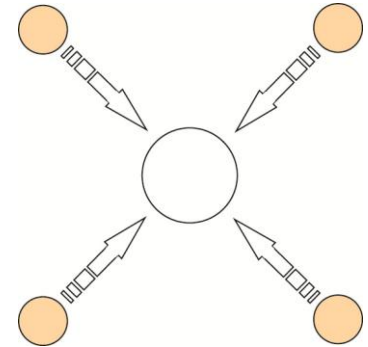


Figure 3.1 – Federated Model

All project teams have a separate model and bring them together simply for coordination. (Construction User’s Round Table, 2010)

“The “Integrated Model” concept requires that all component models exist in one model, with one entity responsible for maintaining the integrated model. The integrated model becomes better and better defined as the project moves forward. A designated party will be responsible for the integrated model” (Construction Users Round Table, 2010).

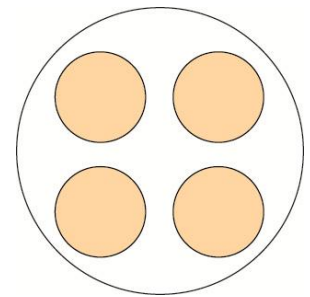


Figure 3.2 – Integrated Model

Each project team submits their associated model and create one, cohesive model that is maintained by a single entity. (construction User’s Round Table, 2010)

2. Create an overall schedule for design decisions and construction milestones.

3. Manage design changes and prevent unlimited scenario analysis.

4. Determine whether third parties will be included.

5. Create a schedule for when models will be updated and released for downstream use.

6. Determine to what extent and when 2D drawings will be needed.

7. Determine other important documentation needed to be included with the model.

i.e. Operations Manuals, Maintenance Forms, etc.

8. Determine if the project will be handed over to the client or end user. Decide to what level of detail the end user desires in the model once it is exchanged.

(American Institute of Architects, 2007)

A few tips for implementing BIM and IPD:

1. Identify a BIM Manager

This will be a full time job. The BIM Manager will be responsible for keeping track of and organizing all the information needed for the project. They will coordinate all the information gathered from within the architectural office, the contractors, the engineers, and so on. The BIM Manager should create a schedule and plan to determine and set when important events will occur - such as clash detections and model updating.

2. Create an estimated cost and time frame necessary for implementation

This should include the cost of any new and additional hardware, software, training, subscriptions, and the full time salary of the BIM Manager(s). Remember, this will be a full time job, so it will require either hiring internally or externally.

3. One-on-One

DO NOT attempt to acquire and train employees on multiple new software simultaneously! Instead, work on fully understanding and implementing a single piece of software at a time. This will alleviate a lot of stress (yes, it may be a stressful endeavor!)

4. Aim small, miss small.

To begin the implementation process, do not over do it! Begin with a relatively small-scale project and work with a few employees instead of a large team. This will help ease into the transition, and if a mistake is made, it will be relatively less costly.

5. Stay up to date.

The BIM Manager should always be versed in the latest technology being used by the industry. This does not necessarily mean they need to have a full-version copy of every software released to the market, but simply, that they are aware of it and can at least discuss and understand it. This may require educational seminars/webinars and research on the BIM Manager's part. Along with this, funding for software updates and subscriptions should be kept available so everything works properly.

6. Create your own resources.

As the firm implements the BIM and IPD methodologies, they should simultaneously keep a record of all the "do's" and "don'ts". When something new is discovered, record it for future use! As employees become more familiar with the software, have them create tutorials, walk-throughs, and a resource database for future reference. This may require a full time employee at the beginning of the implementation process, but will pay off in the long run.

(Hardin, 2009)

Software Explored:

Before research began, a short list of certain software was compiled that was to be highlighted and explored. This list was created by recommendations from Dr. Mahalingam and R.L. Engebretson.

The initial list of software included:

- i. e-Specs for Revit
- ii. Assemble Systems
- iii. Adobe 3D PDF viewers

Different software were discovered through the research that were then experimented with and explored to unveil their potential implications and uses. Arguably the most useful software that resulted from this include Autodesk BIM 360 Glue and Blue Beam Revu. The two software are completely different in their capabilities, but serve two completely different uses.

As the research went on, a list of desired functionalities was created to document the capabilities of the software for informative purposes. The list includes:

- i. Price – (short description)
- ii. Quantity Takeoff
- iii. Active Links
- iv. Excel Export
- v. Markups/Comments
- vi. Bi-directional Communication
- vii. Import models linked in Revit
- viii. Merge Models
- ix. Full Parameter Import
- x. Interactive 3D Model
- xi. Clash Detection
- xii. Model Variance Comparison
- xiii. Accessibility Control
- xiv. As-Built Drawings

A table highlighting the various functionalities of the examined software can be summarized in Figure 4 on page 20.

Assemble Systems:

To begin the research with Assemble Systems, numerous video tutorials were watched, how-to manuals and blog posts were read. Once a basic understanding of the software was acquired, a license of Assemble Systems was purchased for exploration. Time was spent experimenting and discovering Assemble's capabilities and shortcomings. An overview is found below:

Assemble Systems is an online model viewer that has the ability to import all project information and parameters - not just the "important" ones. It offers a streamlined, integrated method for instantly sharing and viewing project information. Every model produced within the process of designing and constructing a building can be placed into a single project and viewed by the entire team. This allows a firm to give instant access to a project's information to anybody who may want or need it - such as the client or building owner.

Assemble Systems does import all project parameters - even custom, shared parameters. The server also imports attached hyper-links as active links within the viewer, giving instant access to important information and documentation. However, only online web-URL's come in as active-links. Local file locations cannot be opened. Because of this capability, items such as Operations and Maintenance Manuals, product specifications, maintenance forms, and so on can be directly linked to the viewer as long as they are hosted online. This greatly increases the power of BIM modeling because the 3D model becomes more than a static visualization tool - it becomes dynamic. It does however lack the ability to hand the model and information over to the building owner because a license must be owned to have permanent access to the project information. Assemble Systems does allow exporting project information to a Microsoft Excel file that can be saved and shared.

Examining Figure 5 on page 21, one can see how Assemble Systems ties into the BIM process. Virtually all stakeholders in the project interact with the Assemble viewer or information. The Architects, Contractors, and Engineers create their associated BIM models and send them to the BIM Manager. The BIM Manager then takes the models, checks for conflicts, and uploads the models to Assemble Systems. Once this occurs, all the necessary stakeholders will be able to view all AEC models – complete with model parameters and information. From there, all stakeholders will be able to access necessary documents that have been linked to the models and cost estimates will be able to be made intermittently. Every time a design change affects the cost of the project in major way, the project teams will be made aware and have the ability to share this information with the building owner or client. This process will help coordinate the entire process from beginning to end.

Important Items to Note:

- Assemble does not include the ability to alter model geometries and quantities natively.

These must be done within Revit and re-published to Assemble. Assemble only allows alterations made to properties of objects and families. This ensures model security by only allowing the model's publisher to alter the geometries of the project.

- As of now, Assemble only allows altering information for Type Properties, and not Instance Properties.

However, the Assemble Systems team is planning on a late November/early December update which will include this functionality.

- There is no automatic notification when an Assemble model version is updated.

In order to be alerted to the update, the publisher must manually alert you through e-mail, phone call, text, etc.

- As of now, Assemble is useful for 3D model viewing and not 2D graphic or sheet viewing.

However, in the November/December update, Assemble will be adding the ability to publish 2D graphics such as sheet views and schedules - greatly increasing its functionality as a dashboard option.

- Assemble does NOT import models that are linked within Revit.

BIM 360 Glue

Autodesk BIM 360 Glue is an online based model viewing and editing software with clash detection capabilities. It allows a user to merge numerous models into one cohesive model to view various clashes between different models. For example, a user can “Glue” (upload) an architectural model showing wall locations and layout, and merge that model with a structural model showing beams, columns, floors, and so on. If a column were to be clashing (intersecting) a wall or floor where it was not supposed to, BIM Glue notifies the user of the clash. This capability can save immense amounts of time and money by immediately recognizing clashing elements so they can be fixed as soon as possible - before construction begins.

As soon as a model owner updates and re-Glues a model to the cloud account, all team members viewing the model at the time of the upload are simultaneously alerted that the model has changed. BIM Glue then gives you the option to reload the current model so it is congruent with the newest version.

Another benefit of BIM Glue is that all information is stored in the cloud. This frees up valuable space on the native computer system, allowing for increased processing power. All information is also backed up within the cloud, eliminating the need to worry about computer crashes. It must be noted that BIM 360 Glue currently only supports Windows operating systems. There is an iPad mobile App however that allows users to view and markup the model as well as take measurements, view hyperlinks, and run their own clash report. One pitfall to BIM 360 Glue is the fact that it requires a stand-alone subscription plan apart from other Autodesk subscriptions and packages. BIM 360 Glue is not included in other Autodesk packages.

Important Items to Note:

- **BIM Glue can upload and read virtually any 3D file type.**

This gives you the ability to upload and view models created in various programs - which may be the case when working with certain consultants. Revit, Autocad, Navisworks, Sketchup, and even IFC files are all readable through BIM 360 Glue.

- **It allows for advanced project security and access by giving the project manager the ability to set permissions and security settings.**

This allows different users varying levels of access which will insure that the alteration of the model is limited to qualified individuals.

- **All previous versions of a model are automatically saved, allowing users to view the project history and progress.**

If an alteration to the model is unwanted, users can simply revert back to a previous version and continue to work on and update that model.

- **You can mark up a 2D view and then notify a user of the comment, but then that user must manually change the view in Revit themselves.**
- **It does not import Type parameters - only Instance parameters.**

However, I have contacted Autodesk support and I was informed that it should import all custom and shared parameters. This issue is currently being investigated.

SimpleBIM:

SimpleBIM is a powerful tool to help reduce file size by choosing what parameters and objects will be exported from the Revit model. The model exports as an IFC 3D model which is readable by numerous software such as Adobe PDF. This is useful in a few scenarios. If a model is being tested for energy efficiency, the model owner can specify to export only the parameters and object that would affect the energy usage of the building. This greatly reduces the file size and the time it takes to run the test because there are fewer pieces to the model. If the model is one cohesive model - already incorporating architectural, structural, mechanical, and plumbing systems - SimpleBIM gives the ability to specify only certain aspects of the project. If the structure of the building is being examined, then the owner of the model need only choose to export the structural elements of the model. Once again, this greatly reduces the file size; saving valuable time and effort.

SimpleBIM is not an all-encompassing dashboard option. It does not give the ability to create an initial Quantity Takeoff or estimation within the software itself. SimpleBIM, as it stands, does not allow applying markups and comments to the model because it is used to prepare a model for data exchange. Once the model is in IFC form, it can be loaded and viewed with an outside program such as Adobe Acrobat which allows markups and comments. SimpleBIM also does not offer a method of communicating with Revit itself. For example, you cannot change an object property within SimpleBIM and have that information automatically be uploaded back to Revit. As of now, SimpleBIM's main use would be as data exchange software because IFC files are readable by numerous programs.

3DA Systems:

3DA Systems offers a one-click PDF converter that plugs into Revit architecture. The exporter has the capability to reduce file sizes by up to 97%, which greatly increases its exchangeability by allowing uploading it to a cloud based server or even through e-mail. The software offers the ability to easily view, markup, and comment directly on the PDF itself. However, the problem with 3D PDFs is that they do not export any hyper links as active links. This is a major flaw in the software because it does not directly link online documents, manuals, and websites into one cohesive document. This limits 3D PDF's capability to be used as a universal dashboard for BIM modeling.

Important Items to Note:

- 3D PDF's would be the most useful if an office simply wanted to share the design with a client or outside stakeholder for viewing purposes. If the receiver of the PDF does not require the specifications, manuals, and other documents, then the 3D PDF would work perfectly as a simple, universal viewing platform.
- In order to export to Excel from the 3D PDF file itself, you must first export the information in a CSV file format. In order to export the model data directly from Revit to Excel, the [3DA Systems Metadata Exporter](#) must also be purchased. This will allow a one-click to Excel functionality within Revit itself.
- The mobile app for iOS systems does not include the capability to view model and object properties. It is simply a 3D model viewer with very limited functionality. This severely limits 3DA System's capability for use as a dashboard - even if it had active links.

Blue Beam:

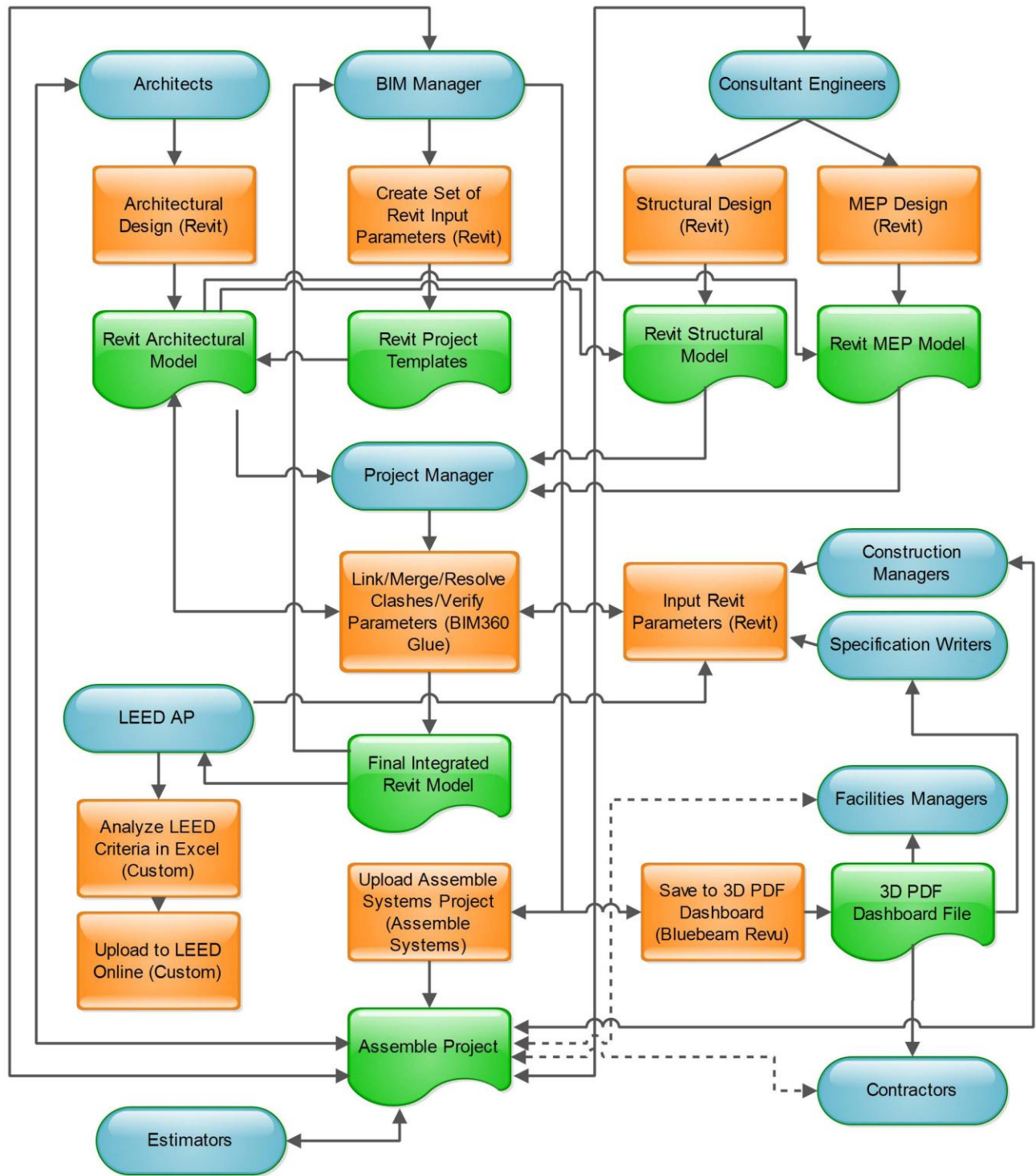
Revu Blue Beam is essentially an alternative PDF viewer to Adobe Acrobat with a few added perks. Blue Beam offers the creation of online Studio Projects and Sessions which are essentially private servers that allow posting various documents/PDFs for other members to view and markup. It is a central location for all files associated with a single project.

- One of Blue Beams major selling points is the *unlimited storage space*. At Revu's most basic level, it can be used as Cloud storage for users to store and access files in the cloud – with an unlimited storage capacity.
- Blue Beam offering markups and comparing documents. Once a file has been altered or marked up, users can compare the two documents side-by-side, and Revu highlights what has been changed. This will help avoid missing certain markups and changes made to documents.
- Users can import 3D PDF's directly from Revit (or other publishing software), and these PDF's even include linked files as active-links that can be clicked on and viewed.
- Blue Beam allows users to set security protocols such as password protection, signature, etc.

Dashboard Option	Assemble Systems	BIM 360 Glue	SimpleBIM	3DA Systems	Revu Blue Beam*	Navisworks
Pricing	\$3,600/year	\$150/seat/month	(1-4)\$350/seat (5-9)\$170/seat	(PDF)\$179 (Metadata)\$149	Standard: \$179/seat CAD: \$239/seat eXtreme: \$299/seat	\$2,100 \$8,400
Quantity Takeoff	✓	✗	✗	✗	✗	✓
Active Links	✓	✓	✗	✗	✓	✓
Excel Export	✓	✗	✓	✓	✓	✓
Markups/Comments	✗	✓	✗	✓	✓	✗
Bi-directional Communication	✓	✓	✗	✗	✗	✓
Import Revit Linked Models	✗	✗	✓	✓	✓	✓
Merge Models	✗	✓	✗	✗	✗	✓
Full Parameter Import	✓	✗	✓	✓	✓	✓
Interactive 3D Model	✓	✓	✓	✓	✓	✓
Clash Detection	✗	✓	✗	✗	✗	✓
Model Variance Comparison	✓	✗	✗	✗		✓
Accessibility Control	✓	✓	✗	✓	✓	✓
As Built Drawings	✗	✓	✗	✓	✓	✓

Table 2 - Software Recap

As a part of the research, a list of necessary functionalities was compiled in order to give a method of analytically comparing the various software. This provided a convenient method of summarizing the functionalities.



R. L. Engebretson Co. BIM Process Integration Flowchart with Software for Processes

Prepared by: Ganapathy Mahalingam; 10/20/2013

Figure 5 – Integration Flowchart

Many individuals from varying professional backgrounds must collaborate and work together in order for a project to be successful. Figure 5 illustrates necessary models and information which must be shared and with who. It draws out necessary lines of communication throughout the design and construction process.

Reasoning and Conclusions:

Through the research, I have found that it is possible to link important documents (Operations manuals, maintenance forms, specifications, etc.) to a 3D model. One of the biggest challenges however is not simply linking the documents, but sharing the information with necessary stakeholders. For example, if the building owner expects a hand-over of the BIM model, they need a platform to actually view and access the information with. From what has been discovered, Blue Beam and 3D PDF's may be the answer. Blue Beam offers a piece of software that includes nearly all necessary functionality for use as a dashboard. Virtually the only functionality that Blue Beam lacks is clash detection. It offers a fully interactive 3D model - complete with all custom parameters - and all the hyper-link parameters are active-links. As Blue Beam is used more often and becomes more familiar, more functionalities continue to make themselves known. Its potentials keep growing.

The most useful software to consider using would be Autodesk 360 Glue, Assemble Systems, and Blue Beam Revu. None of the software is inherently better than the other - they all serve different purposes. Assemble allows for more technical and numeric operations compared to 360 Glue's emphasis on visualization and clash detection. Blue Beam Revu offers a seamless and fluent solution to communication and collaboration within an office, and with outside stakeholders. If interoperability issues inherent with IFC files were eventually solved, SimpleBIM would be an extremely powerful tool for all AEC practices. This is because SimpleBIM offers the ability to easily trim a model to include only necessary parameters and objects, and IFC files can be read by a wide range of software.

BIM requires that all teams involved in the design and construction of a project are versed in BIM software and actively use it. What makes BIM so powerful is its coordination and collaboration abilities. As the saying goes, "a chain is only as strong as its weakest link". If a portion of the project team is not involved in the BIM process and practices, it will make no difference if the rest of the team uses BIM

because the lacking team members will hold the entire process back. In effect, it would create a bottleneck for the entire project. The potentials of BIM modeling and Integrated Project Delivery continue to impact the AEC industries on a daily basis. The future of the design and construction industry is bright, and as more firms continue to adopt the new way of thinking, the AEC industries will increasingly thrive.

Implications for Practice and Advancement of Future Research

There is no doubt that BIM Cloud integration has the capability to exponentially increase the efficiency of the Architectural profession. By implementing BIM, firms have the ability to communicate with project members, consultants, and clients anytime, anywhere. If a conflict or problem arises during the design and construction process, it can be acknowledged and dealt with virtually instantly.

Anywhere there is an Internet connection; team members will have the ability to review project details and models - continuously staying up to date on project information. This not only helps during the design and construction processes, but also allows for facility management throughout the building's life cycle. If a piece of equipment breaks down, the building owner can instantly view the Operations and Maintenance Manuals to attempt to fix the problem. If not, all the equipment's associated documentation can be viewed including manufacturer information, warranty information, and so on.

In order for BIM modeling to truly reach its full potential, rethinking the design and construction delivery process may be necessary. As of now, Integrated Project Delivery is the best delivery method for use with BIM modeling. This is because IPD was created with BIM in mind. IPD brings all project teams on board sooner in the process - keeping everybody informed and up to date. IPD does however require more time spent on the front end of the project because that is when a majority of the coordination occurs. Because of this, project fee structures may have to be revised to fit the new

process. Increased time up front means more fees at the beginning; less time on the back end means smaller fees as construction wraps up.

Research Limitations

The Graduate Research Assistanship used for this project had a few limitations.

1. Communication was restricted to the speed of sending, receiving, and responding to emails because I was not working within R. L. Engebretson Co.'s office (RLE). This slowed the process at times because certain actions required permission or clarification before proceeding. Although it did hinder the process at times, the delay was often minimal – limited to a few hours at the most.

2. During the process, I downloaded many trial versions of products. However, trial versions often times do not function exactly the same as the full, licensed version. This led to the possibility of not getting a full picture of certain software. The trial versions also only have a 30-day length associated with them. Because of this, it was required that the software were re-downloaded with new credentials. This set the research back a few steps because projects had to be set up again, along with all the attached information.

3. Because I was not working on an actual, in progress project with RLE, it was difficult to fully understand the functionality and benefits of each software. RLE did provide a sample, previous project that they have completed to offer insight into how their office sets up and views models. A hypothetical scenario was created using this information, but an actual client and their needs were not included. It

would be interesting to actually implement the software into the firm's business operations to examine the ease or difficulty associated with using the software on a day-to-day basis.

4. Because BIM is still in its infancy, the working knowledge of various software capabilities is limited.

Once more firms begin to utilize and learn BIM on their own, more information will become available.

5. Time was the ultimate factor in the research – as is often the case. Although there was ample time to explore the software to gain a working knowledge of how each piece operates on its own, it was difficult to gain a comprehensive understanding of the software. If additional time was given, actually implementing the software into RLE's business practice would be extremely interesting and informative.

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