Application of BIM in Structural Engineering

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ABSTRACT: *This paper explores how the use of Building Information Modeling (BIM) can be a beneficial platform for structural engineers. The current state of BIM is analyzed, giving a general overview on how architectural; engineering and construction firms are applying it on their projects. The interlinking of BIM with structural analysis softwares like ETABS, SAP2000 and Robot Structural Analysis is evaluated. Also, an independent structure is modelled in BIM and is analyzed and designed in Robot Structural Analysis software. Apart from it, the ease in redesigning and modifying the structure is discussed.*

Keywords -*BIM, Revit, Robot Structural Analysis, Structural Engineering,*

I.INTRODUCTION

The use of new methods and software is one of the most important tools that structural engineers are using nowadays to stay competitive. Engineers are constantly looking for new ways to improve and keep the pace on today's economy, reaching to new heights in the aspects like productivity, coordination and problem solving. Building Information Modelling (BIM) can potentially help with these important aspects. The core feature that BIM offers is the ability to integrate intelligent objects in the model. These intelligent objects contain all the data regarding a specific component, from geometric characteristics to the way they interact with other components, making the entire model full of information. [1]

Structural engineers can take advantage of BIM in different ways, as the model can be constantly updated with any changes in the design or general specifications, keeping all the data as accurate as possible. BIM transforms the way we handle and visualize components. It has grave impact on designing activities like, conceptual design and structural analysis. BIM ensures reduction in design and drafting errors and hence provides with lower designing cost and improved productivity. It also allows for better analysis of situations through simulation. The fact that the use of BIM lets one visualize the whole picture lets one identify potential design issues, and come up with new and creative ways to solve problems.[1]

This paper will focus on the state of building information modelling and its influence in structural engineering. The benefits that BIM represents for structural engineering in the areas of productivity, coordination and consistency of data, and visualization and simulation are also investigated, all this with the objective of obtaining a clear idea of the impact that BIM has in structural engineering.

A small independent room of size 4.5m X 4.5m is modelled in BIM. Using the interoperability of BIM and its compatible analysis software it is designed. Also, the enormous advantage BIM and RSA presents in the design and modification in design of any structure is studied and its advantages summarized.

II. LITERATURE REVIEW

Cesar Augusto Hunt[1] presented the benefits BIM can offer in structural engineering. Also, the importance of inter disciplinary coordination and the benefits arising out of it were discussed in detail.

M. Obergriesser1, A. Borrmann2[2] studied the impact of BIM on the construction industry. Multidisciplinary facet of BIM and its impact in Information Delivery Model was studied was evaluated by them.

Gary Wyaat[3] examined the role of the structural engineer in the BIM process and explains how the integrity of BIM model is maintained during the structural engineering process. Also, the benefits and advantages of BIM in structural engineering and the difference between the CAD centric and BIM centric drafting is discussed.

William F. Ikerd[4] evaluated the changing trends in the design industry. The time required by majority of structural engineers to completely transit to BIM was analysed by him. Also, a logical justification about why BIM is the next phase of evolution in the design industry is explained by the author.

REMARKS- In all the literature surveyed, the importance of BIM is underscored. BIM in combination with structural analysis have the potential to make the design and drafting process more efficient and less taxing.

III. BIM IN STRUCTURAL ENGINEERING

To understand how BIM applies to civil engineering, it is helpful to first take a look at the legacy 2-D drafting-centric design process. This process starts with preliminary design, moves to detailed design, and then on to construction documentation. Each step is completed before the next one begins, and collaboration is very limited. This process works well until the inevitable design change needs to be made, at which point time-consuming and error-prone manual drafting updates are required. As such, this process has inherent practical limitations.[5]

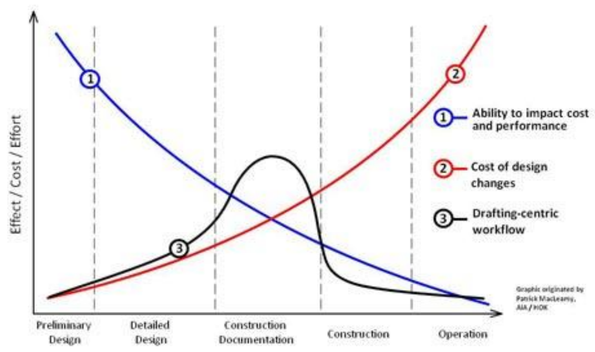


Figure 1. Level of effort required w.r.t time.
(Source: "What does BIM mean for civil engineers?" [5])

The graph in Figure 4 (above) maps the level of effort required over the life of a typical structural design project from preliminary design all the way through to construction and into operations. As the blue line indicates, the ability for the civil engineer to impact project cost and performance over the project lifecycle is at its maximum during preliminary design, but sharply decreases as the project progresses. The red line shows how the cost of making and executing design changes is low during preliminary design, but sharply increases during the project. Finally, the black line illustrates where civil engineers and designers expend the most effort and resources with a drafting-centric process—during the construction documentation phase[5].

The problem with this picture is that the peak of the effort (black line) coincides with a point in the project when the ability of the engineer to impact project performance is declining and the cost of making design changes is increasing. This gets to the heart of the limitations of a drafting-centric workflow. While it is theoretically possible to use this process to perform iterative design for optimizing project performance, realistically, very little of this is done. It is just too costly to make multiple design changes and evaluate impacts on project performance once the documentation is started. As a result, a drafting-centric process typically yields the first design that meets code, and not necessarily the optimal design[5].

The first step in the structural design process of a project following the traditional way is to interpret the architectural plans. This gives the structural engineer an idea of the design and set the foundation to create the analytical model that will be used in the structural engineering software to analyze the project according to the requirements, be it gravity, seismic, dynamic or wind. At the same time, usually drafters start the drawing part, creating a representation of the building and initiating the construction documents. This cause the creation of multiple drawings that contain the same information[5].

The fact that there are different models being worked on for the same project increases the efforts that need to be put in coordination, and opening the opportunity for errors. If there is a change that the structural engineer made to an element in the design, and that change is not updated by the drafter the documents become out of sync, affecting the validity of the design[5].

While using a building information model, both the physical, which contains the data used in the analysis applications, and analytical information, which is the model used in the structural analysis, are interconnected in the same place, allowing for its use not only in the structural analyses of the project, but also to produce the construction documents[5].

The structural members like beams, columns, that are part of the physical representation can be assigned load, material properties and other important information necessary to run the structural analysis. It also contains the geometric properties, strength of the materials, and boundary conditions of the structural members.

Structural analyses programs can then import all this information thanks to embedded tools and application programming interface (API). After the analysis process is finished, the model can be exported with the results, automatically updating all the information, and the documentation dependent from it. Analysis results such as the internal force of a structural member and the area of steel rebar can be stored into the model for future use.

This greatly reduces the time spent in detailing and drafting, since documents containing information like the geometric size of a structural member, the type and quantity of steel rebar, concrete, can be easily generated.

Contrast this legacy approach with one that is becoming a standard across the AEC industry—BIM. When compared to the traditional way to work, the benefits of using BIM in the structural design are obvious, especially when analyzing the workflow. This results in an intelligent 3-D model of the structure in which elements of the design are related to each other dynamically[5].

Time constrains usually dictate that structural design and construction documents production start parallel, so as the structural engineers begin their analyses, the structural drafters begin developing the documentation set (framing plans, bracing elevations, typical details).

The use of multiple models, models that are not coordinated with each other or the documentation, requires a manual effort to keep them and the documentation package synchronized, to the detriment of a firm's efficiency, quality, and flexibility. Whereas the use of building information model that drives analysis, coordination and documentation reduces these problems[5].

With BIM, referencing the architectural plans is still the first step. But instead of creating several models, there is just one model, a single integrated structural model that includes both a physical representation that drives documentation and coordination and an analytical representation used for multiples analyses[5].

In this way, BIM facilitates evaluation of many more design alternatives. As part of the design process, civil engineers can leverage the information model to conduct simulation and analysis to optimize the design for objectives such as constructability, sustainability, and structural safety. Finally, with a BIM process, design deliverables can be created directly from the information model. Deliverables include not only 2-D construction documentation, but also the model itself and all of the rich information it contains, which can be leveraged for quantity take off, construction sequencing, as-built comparisons, and even operations and maintenance[5].

The use of modeling, 3-D visualization, and analysis is nothing new for structural design professionals. The difference is that with traditional drafting-centric approaches, design, analysis, and documentation are disconnected processes. This makes evaluation of what-if scenarios inefficient and cost prohibitive[5].

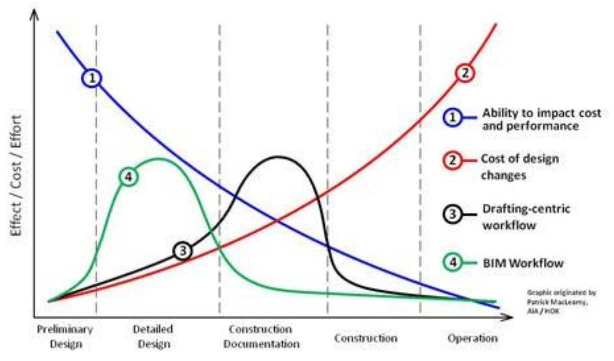


Figure 2. Level of effort required w.r.t time in BIM.
(Source: "What does BIM mean for civil engineers?" [5])

As the green line in Figure 2 (above) demonstrates, by dynamically connecting design, analysis, and documentation in a BIM workflow, most of the effort in a structural design project is shifted back into the detailed design phase when the ability to impact project performance is high and the cost of making design changes is low. This allows engineers to spend more time evaluating what-if scenarios to optimize the design and less time generating construction documentation. With this in mind, consider how adopting a BIM process translates into real benefits for structural design[5].

IV. 4D STRUCTURAL INFORMATION MODEL

A 4D structural information model is a building information model that is complemented not only with the structural information of the project, but also takes under consideration the time, enriching all the basic information that is already part of the model. Among the important points that are included into the new model are information like reinforcement details, loading conditions, load types, schedules, construction activities, resources, amount of steel, concrete and others[6].

The characteristics of structures under construction are very peculiar. Usually material properties change over time and loading conditions can vary depending on the stage and type of activities that undergo. This is why the structural analysis during constructions has a lot to do with the loading conditions, and the resistance of the elements in question.

New 3D modeling tools are allowing structural engineers and designers to create models for documentation and coordination. As a result, more and more structural engineering firms are embracing this new methodology. BIM software is based on the object oriented programming, in which instances of structural members are assembled to create a building structure. Each member possesses the information and functionality that fully defines it (a beam element has is material and sectional properties) as well as its purpose within the structure (horizontal member on X level, spanning between columns Y and Z) [8].

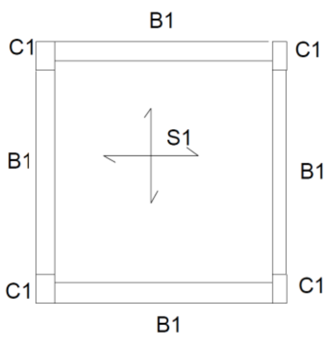
BIM based structural design tools help engineers optimize their structural design, to compare and contrast various approaches to sustainable designs with associated lifecycle costing, and when a concept is approved, it provides the foundation for construction sequencing and field operations. Fabrication and construction can be done error-free, and the effort required for checking drawing declines drastically[7].

V. CASE STUDY

To understand how the connectivity of BIM software and structural analysis software works, it is important to introduce the concept of physical and analytical representation of structure. The physical model is a true model of the structure of a project, and the analytical model transfers all the information needed by the structural engineer. Using a building information model, both the physical and the analytical representations of the structure remain interconnected, facilitating the process of transferring information and keeping the integrity of the model.

The plan of a room is given below. Beams and Columns are designed manually and by RSA and the results obtained by both the methods are compared.

f ck=20N/mm2 , fy=250N/mm2 , Live Load =3.0 kN/m, Floor Finish, width of masonry wall =230mm, Cc=20mm. The beam and column are manually designed.



A lot of companies have invested in this developing technology. Autodesk Revit is the market leader in this segment. Autodesk Revit provides direct link with many of the prevailing analysis and design softwares like, Staad Pro, SAP2000, ETABS and Autodesk's own Robot Structural Analysis (RSA) among a few. RSA is completely compatible with Autodesk Revit, and allows seamless interaction between the BIM model and structural model.

In the first step, an architectural model for a small room of size 4m X 4m is developed in Revit. Revit directly allows the user to create walls and assign attributes to it, like its exterior texture, etc. The model contains all the information from wall placement to door and window positions.

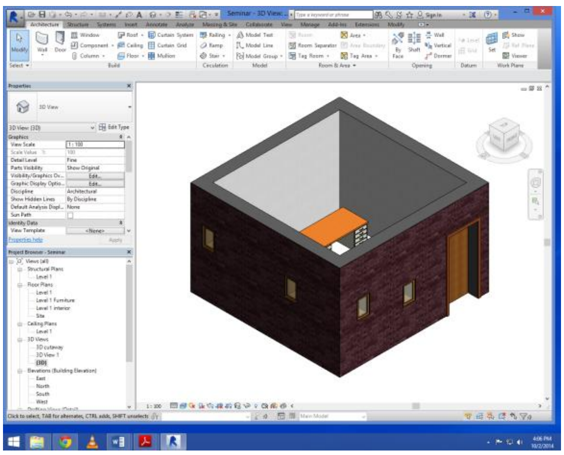


Figure 3: Modelling in Revit Architecture

After the architectural model is developed, column positions are fixed and columns of tentative dimensions are placed directly in the model. These column families are imported into Revit Structure.

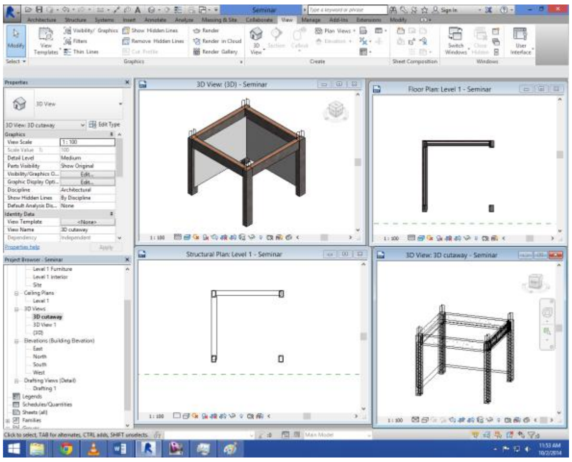


Figure 4: Modelling in Revit Structure

Once the modelling part is finished, using Revit Extensions the model is exported to RSA. The exporting mechanism is designed such that only structural components are exported and visualized in the RSA software.

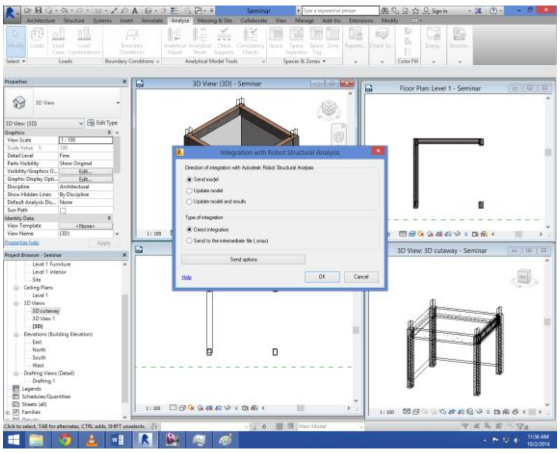


Figure 5: Revit Structure and RSA link 1

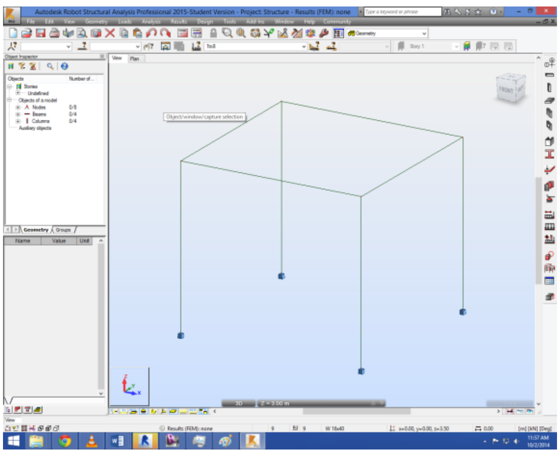


Figure 6: Revit Structure and RSA link 2

The structural model once imported into RSA is assigned fixed support as end conditions. On completion of the geometry of the structure, the frame is assigned a self weight and an UDL of 7kN/m throughout the span length on all 4 spans. And the command for performing the calculations are given. The SFD and BMD for this frame for the given loading conditions are obtained.

Design command is given to the software. It automatically designed the RCC members of the frame and calculated the area of steel required.

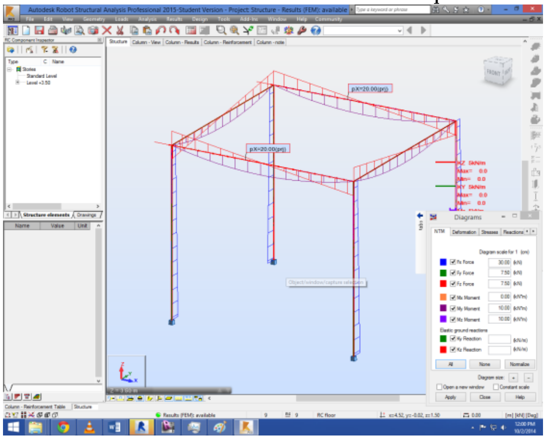


Figure 7: Analysis in RSA

Once the designing of the structure is done, the model is sent back and merged with the BIM model and any clashes if present were detected using Autodesk Navisworks. At this juncture the software provides us with detailed structural drawings and amount of steel required to proceed with construction.

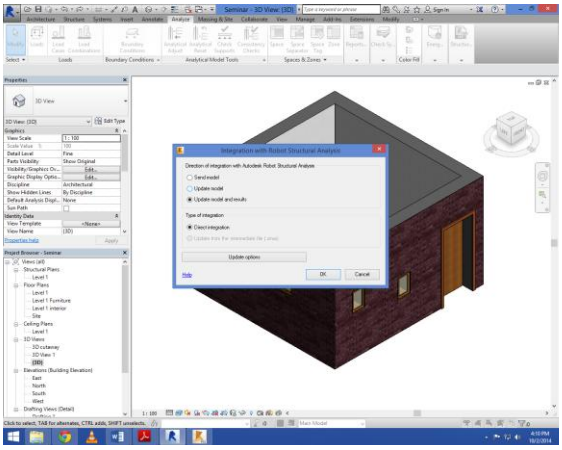


Figure 8: Revit Structure and RSA link 3

In conventional method, modifications would require redesigning of the whole structure and preparing the structural drawings again. The case where area of steel needs to be reduced was considered. Accordingly, the diameter of the stirrup bars is reduced and the spacing between them is decided to be increased. This is achieved using the structural detailing tool found in Revit Extensions.

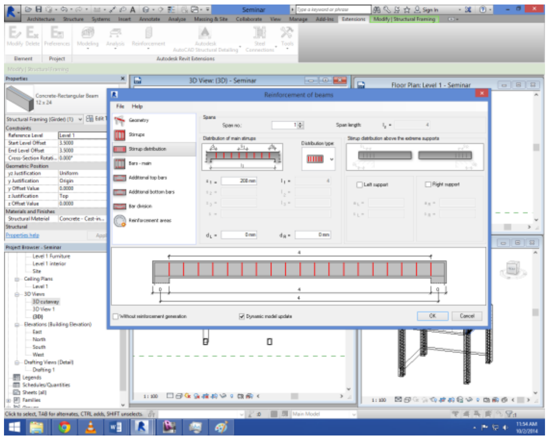


Figure 9: Modifications in Beam

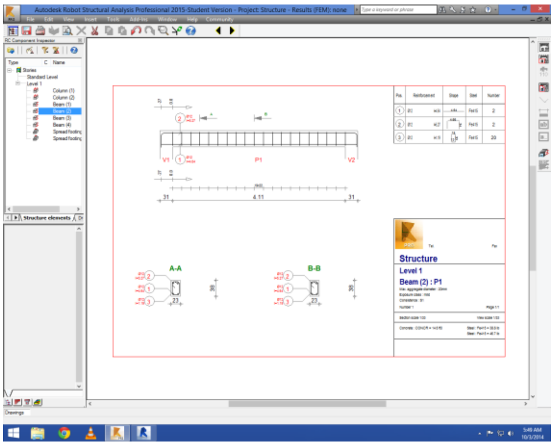


Figure 10 : Structural Drawing of Beam

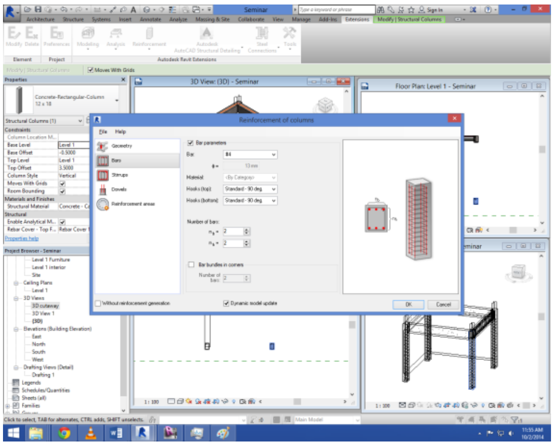


Figure 11: Modifications in column

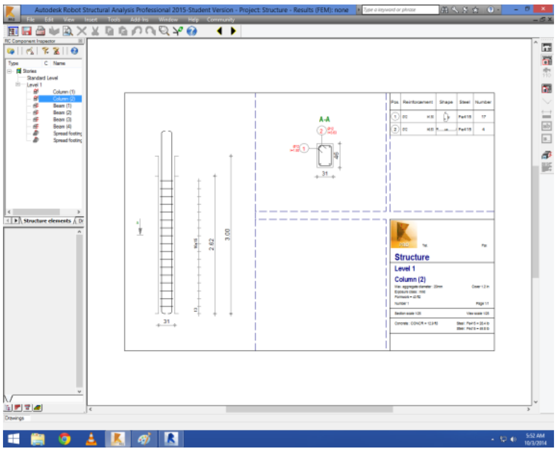


Figure 12: Structural Drawing of Column

VI. ADVANTAGES OF BIM

Building information models let structural engineers design, visualize, simulate, analyze, document, and build projects more efficiently, accurately, and competitively. Among the most important benefits of BIM for structural engineer are productivity, coordination and consistency of data, and improved visualization and simulation of problems and situations[1].

From the engineering point of view, the most important contribution from BIM is the increase in productivity, especially when producing in construction documents. In most structural engineering firms, especially large scale ones; it is common to work with teams that are in different geographical locations. In fact, it is expected that team workers can help with different projects according to the needs of the firm in that moment[1].

New technologies like cloud servers make this entire process much easier. Being able to have all the information in an online hard drive, where everyone working on a project can access it and modify it does wonders when there's a significant distance between workers. When this concept is applied to BIM, and it's naturally data rich database, it greatly benefits communication and productivity[1].

The production of the construction documents in 2D is the most labor intensive part of structural engineering. This is a process that is done completely automated when using a building information model. Important sections like reinforcement detailing, numbering and rebar schedules are automatically generated, saving a lot of time and effort. Figure 5 shows the value that architectural and engineering firms put on BIM according to the project phase. 53% of the firms that participated on the McGraw Hill Construction report list construction documentation as one of the top phases where BIM is valuable, only behind the design phase. This shows a clear indication of the benefits that the architectural and engineering firms are getting form BIM[1].

Revising the structural drawings of any structure is one of the most taxing job for a structural engineer. The primary design of any structure needs to be revised for various reasons. Sometimes, the architect feels the column is tarnishing the beauty of his design, many times the owner suddenly changes his mind and changes his preference about the usage of the building. In such cases, redesigning and redrawing the structural details can be an extremely unpleasant and repetitive task. BIM identifies the stirrups and other steel components for what they are and allows the user to change them accordingly. Once modelling is completed and a component is placed, resizing and redesigning it is extremely easy and in reality just a click away[9].

Good coordination in a project is essential to get the most out of BIM. A single building information model is used for both the analysis and the documentation phases, contributing to better coordination between the structural analysis results and the overall design, increasing consistency throughout the entire project[1].

Structural engineers can easily spend more time coordinating a project than performing the structural analysis. With the use of BIM, the time spent in coordination is reduced, allowing structural engineers to focus all their efforts in solving problems, instead of having to constantly be checking for errors or coordinating changes made[7].

BIM can also be implemented to come up with new and creative solutions to problems. The engineers can easily isolate and filter any area or element of especial interest from the structure, and are able to visualize it in 3D.This provides great project insight, enhancing its understanding and facilitating the process of solving problems and coming up with ideas[7].

Optimize outcomes by exploring design alternatives more easily and cost effectively during conceptual design. Once the future design parameters are known, a BIM process can aid in the creation of alternatives that address them while helping to identify the most economical and time efficient approach to a construction[7].
Also, since BIM identifies components instead of lines, it has the power to calculate and estimate the amount of materials used. It can very comfortably estimate the number of doors and windows, volume of brick work, weight and diameter of steel required, etc. This exhaustive list can then be correlated with the price per item to realize the total cost of the project and its components. The above data can also be exported to an excel sheet for further utilization[7].

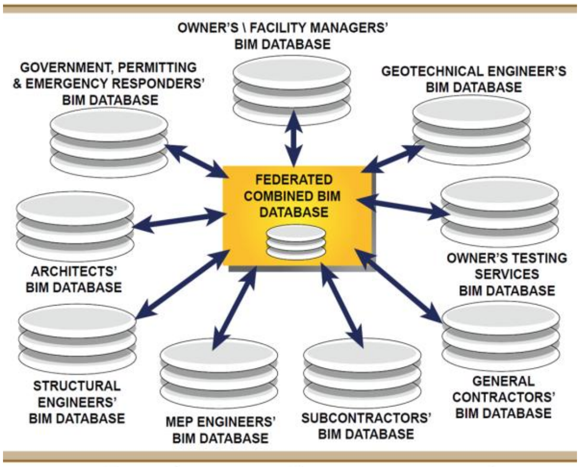


Figure 12: Federated Combined BIM Database (Source : The importance of BIM in structural engineering[7])

VII. CONCLUSION

The benefits of using building information modeling are evident, especially when analyzing the way that this methodology enhances the structural design workflow. Engineers are realizing the power of BIM for more efficient and intelligent design, and most firms using BIM are reporting strong favor for this technology[1].

The increase in productivity is a significant benefit that BIM provides in structural engineering. Construction documents are generated completely automatic when using a building information model, significantly reducing the time required for detailing. It also reduces the need to make extensive checks, helping prevent errors in the documentation that can affect the construction[1].

Using the building information model not only enables the production of construction documents, but it also serves as a base to present the results from the structural analysis and design in an easy sharable way, keeping all the information regarding the analysis, design and documentation of a structural project in one place. A single building information model is used for both the analysis and the documentation phases, contributing to better coordination between the structural analysis results and the overall design, increasing consistency throughout the entire project. The improved coordination can also be seen in better interoperability between team members' software's, allowing architects, structural and MEP engineers to manage a project more effectively.

The ability to create simulations and check different structural scenarios greatly help with analyzing a structure and taking decisions. This provides great project insight, enhancing its understanding and facilitating the process of solving problems and coming up with ideas. These visualizations can be used to present ideas in a more clear way, simplifying the process of explaining complex situations and helping teams communicate more adequately.

The ability to retrieve all the information related to a structure is particularly helpful at the time of disasters and natural calamities. Also, this holistic approach is well suited to help perform retrofitting and making some changes post construction safely.

REFERENCES

1. The Benefits of Using Building Information Modeling in Structural Engineering, Cesar Augusto Hunt, 8-1-2013.
2. Infrastructural BIM standards – Development of an Information Delivery Manual for the geotechnical infrastructural design and analysis process, M. Obergriesser & A. Borrmann, eWork and eBusiness in Architecture, Engineering and Construction – Gudnason & Scherer (Eds),© 2012 Taylor & Francis Group, London, ISBN 978-0-415-62128-1
3. "Maintaining BIM integrity in structural engineering office", Gary Wyat.
4. "The importance of BIM in structural engineering", William F Ikerd, Structure Magzine, October 2008, Page 40.
5. What does BIM mean for Civil Engineers, Adam Strafaci, October 2008.(http://cenews.com/article/6098/what_does_bim_mean_for_civil_engineers)
6. http://en.wikipedia.org/wiki/4D_BIM
7. The power of BIM for structural engineering, Autodesk 2012, @2007Autodesk.inc, Robobat.
8. BIM in Academia, Alexandra Pollock, Skidmore, Owings & Merrill LLP New York, NY, 2009.
9. Autodesk Revit 2015
10. http://knowledge.autodesk.com/support/revit-products/learn-explore#?sort=score
11. Autodesk Robot Structural Analysis 2015.
12. http://knowledge.autodesk.com/support/robot-structural-analysis-products/learn-explore#?sort=score
13. Autodesk Revit Extensions 2015.
14. Autodesk Naviswoks.