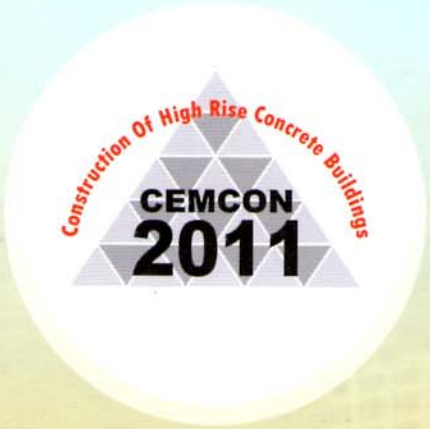
TECHNICAL VOLUME



An International Conference & Exhibition

CEMCON 2011

17-18 (Fri.-Sat.) June 2011

Hotel Sun - n - Sand
Bund Garden Road, Pune - 411 001.

Theme

Construction Of High Rise Concrete Buildings
(100 meters and above)

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Software Evolution- Changing the Way We Build Structures Today

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The author is a Senior Product Manager with Masters of Technology in Structural Engineering. He is involved in architecting and coding structural software for more than 16 years. He is one of the core developers of STAAD.Pro program and currently manages STAAD.foundation product. After graduating from Calcutta University, he joined Research Engineers as a software developer and since worked in different areas including graphics, user interface, database, analysis and design engine.

Back in 1994 — my final year in college — we were trying to finish the “multi storied building design” project. By my standards, it really was a herculean task. For the building design, we obviously had to do a frame analysis and the best method known to us was moment distribution and the most sophisticated electronic equipment we had was a scientific calculator.

As we started working on the project, we realized we were repeating the same methods and same calculations repetitively with simply different numbers. All 100 of us were following the same “proven and tested” method.

Fortunately we had one class called “Numerical methods and computer programming”, where we were taught the most common scientific programming language of that time called FORTRAN. Needless to say, I was very tempted to automate our repetitive manual calculations. To make a long story short (or a little shorter!), I ended up writing a very crude 2D frame analysis program. Back then we didn’t know terms like “case study” or “project management”, so we didn’t know how much time it saved (if at all !) or if there was any quality improvement. But it definitely helped us tremendously to verify our calculations, which in turn gave us confidence and helped to finish the project a little quicker.

That was my first baby step to enter into the bold world of engineering software. The goal was to automate and create efficient solutions for more accuracy, better coordination, collaboration and data management.

1. FEM for Structural analysis

Modern structural analysis software is based on a well known technique called the Finite Element Method (FEM). It is a numerical technique to solve partial differential equations as well as integral solutions. It originated from the need for solving complex elasticity and structural analysis problems in civil and aeronautical engineering. Its development can be traced back to the work by Richard Courant in 1943. He developed and utilized the method to obtain approximate solutions to vibration systems.

In 1963 Prof. Wilson and Prof. Clough at Berkley University developed a Symbolic Matrix Interpretive System (SMIS) for the purpose of teaching the static and dynamic analysis of structures. The purpose of this program was to bridge the gap between traditional hand calculation methods and matrix methods of structural analysis.

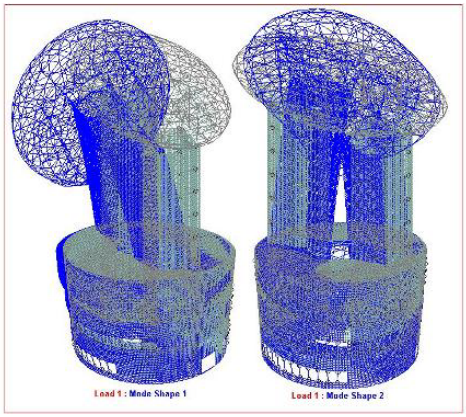
Prof. Wilson, in 1969, initiated the development of the general purpose static and dynamic Structural Analysis Program, SAP.

The program was written in the FORTRAN language. In less than one year, Wilson and three students developed the first SAP program. It was freely distributed to all students and members of the profession and became the basic starting program for many different finite element projects and FEA software.

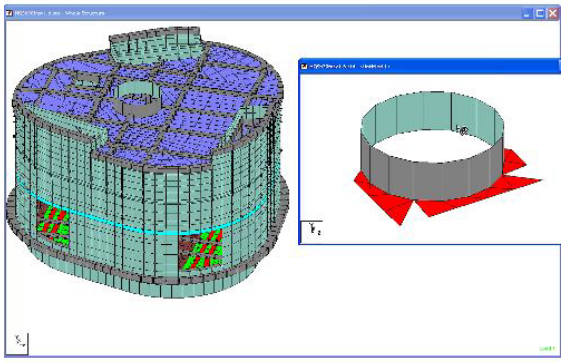
This program was modified many different times at different universities. The latest release of this program is CAL 91 and it is still used for teaching modern structural analysis.

In late 1970's, with the advancement of PC, STAAD became the first PC based structural design and analysis program. There are many structural engineering software programs commercially available today. Some are very generalized and used across the globe and some are very specific to local design codes, known as "local heroes". STAAD, SAP, ETABS, GT STRUDL are some of the commercially available structural software recognized and used globally. Where, SAP and STRUDL are known to solve very specific high end analysis, STAAD is more generic and popular for its simplicity, design engines and powerful graphics. There is barely any structural design being done today without any software. Clients and checkers demand software output and often mention which software to use. For more than 30 years, FEM has been in existence and there is nothing significant of anything to replace it as yet.

Below are some of the structures designed by STAAD.Pro.



Lithuanian Ethno-Cosmology Museum Lithuania



New Delhi Underground Metro Chamber, Mott MacDonald

Although the very basis of FEM remains the same after more than 30 years, the user base is now widely varied. With the evolution of the PC, virtually all mainstream structural software is developed and maintained on the PC platform. Going back to

1994, when I joined Research Engineers (the company then developing STAAD), computing was still expensive and less powerful as compared to computers in 2010. Even the slowest commercial PC of today is 10 times faster than the fastest PC in 1994. There were structural models that we ran back then for a whole night and in some cases for days, only to find out that the computer ran out of memory. Operating systems changed from 16 bit to 32 bit to 64 bit. Now we use laptops with 8GB memory and Terabytes of hard disk and even those could be extended.

But it is not only the computer raw power which made the programs better. Its matrix solving techniques like Skyline Solver or modern Conjugant Gradient Solver which make structural model run much faster. We have observed in some cases a better matrix solver can analyze the model as much as 1000 times faster.

The other important aspect of modern structural software is to use a physical modeling system rather than an analytical modeling system. Earlier, it was assumed that the user has good knowledge of the FEA method and they could interpret the software output easily. But as it is almost mandated now to use software to analyze structures, it's necessary for the software to understand the language of those engineers who are not FEM experts.

2. New Trend in Structural Software

All popular FEA software products are moving to physical modeling systems. Users from different industries demand solutions specific to their problem, not something very generic. That resulted in specialized software for building, plant, tower, bridge, etc. sectors. Most of these products are using FEA internally but the interface knows and talks the language of that specific industry.

The most popular building design software products are:

a) ETABS

b) RAM Structural System

ETABS is very analytically sophisticated and typically used for high end analysis. It recently received "top seismic product of the 20th century award". Many tall buildings/towers around the world are analyzed and designed using this software. Some landmark projects are

- Petronas Twin Towers (88 floors) in Malaysia
- Burj Dubai Towers (150+ stories) in UAE
- World Financial Center (101 floors) in Shanghai etc.
- Taipei 101 Tower (101 floors) in Taipei



But when it comes to the short (not so tall) building, RAM steals the show. It is the most popular software in the USA for designing small to medium size steel framing buildings. Released in 1990, it was also the first floor framing program.

Some of the landmark structures designed by RAM are the Las Vegas Convention Center, London's Credit Suisse building and Warsaw Trade Tower in Poland.

There are many published case studies for RAM. In one such study, RAM saved an estimated 1200-1800 hours of engineering time. The project was a $132 million, 12 story elliptical tower with an underground parking structure.

In another study, Anderson & Doig Structural Engineers saved $85,000.00 for a hospital project just by using RAM. It was a $50 million project for a medical institute in Sacramento, California.

Civic Center Office Building, Denver, Colorado, USA

Organization: Martin/Martin


Medical Institute, Sacramento, California, USA

Organization: Anderson & Doig Structural Engineers

2.1 FEA Software for Post Tension and RCC slab design

The most popular slab design software products are:

1) RAM Concept
2) ADAPT
3) SAFE

RAM Concept and ADAPT are two trusted sources when it comes to residential building and parking structure. Both the programs specialize in post tension slab design, but support reinforced concrete design, too. These are based on FEA and replace conventional strip methods to handle slabs of any shape and size.

SAFE is probably used more often for tall buildings as it is tightly integrated with ETABS and part of the same environment.

2.2 STAAD(X) (STAAD.Pro next generation)

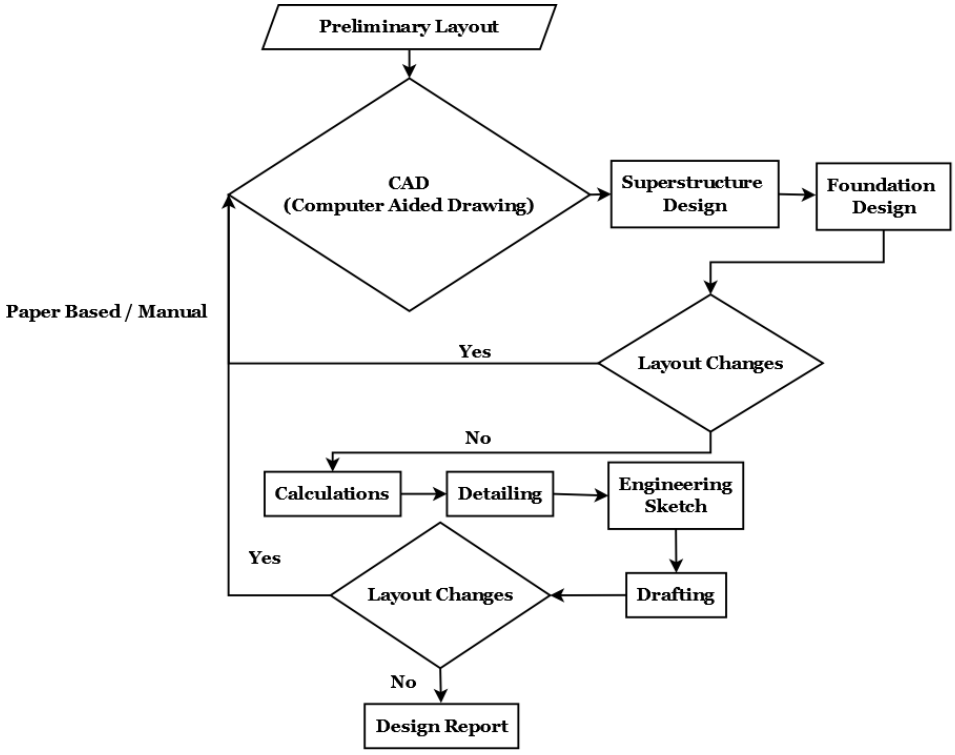
STAAD.Pro has been on the market for more than 13 years since its release in 1997. Bentley, who acquired Research Engineers in 2005, has been working for the last few years to bring the next generation of STAAD software. The project is called STAAD(X) and it promises a new paradigm in physical and parametric modeling. It also serves as the basis of many new and upcoming products such as STAAD(X).tower.

STAAD(X) provides physical objects like shear wall, slab, continuous beam and column, isolator etc. Program will manage all analytical connectivity internally and will flow through all segments of structural design. It can be used for simple static frame analysis to nonlinear dynamic analysis of very complex structures.

3. Current typical workflow in design offices

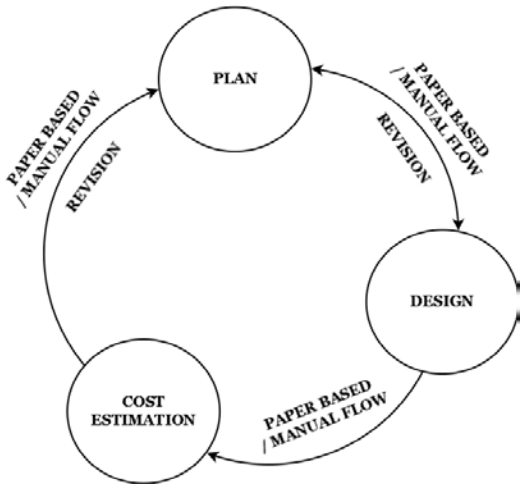
Not only structural analysis but every aspect of a structure is now digitized. For example, CAD software helps to create site drawings, architectural plan etc. Structural software is used to analyze the structure, design software is used to design beams, column, and slabs, detailing software is used to detail connection, and foundation software is used to design the foundation. But still, most of the software is very problem specific.

The process is very fragmented and often does not have the means for proper coordination. There are attempts being made today to integrate these discrete solutions to work as one environment. But still, all those individual software have their own assumptions, often the interface does not look the same and even the output formats are different.



3.1 What is wrong with the current process?

Probably there is nothing wrong with the current process if we do everything right in the first place and the project is very small and simple. But change is inevitable. So, the first issue with the current process is the change management. The current change management is manual and paper based. But both architects and engineers are using software. So, it would be nice if those changed data can be processed digitally so a change in one platform would update changes in other platform. Take a very simple case of residential building. If the client wants to make any change like removing a column (because its blocking views) then an architect needs to create a fresh set of drawings for engineers and needs to recalculate the bill of material. But in an integrated environment, a change in the floor plan should change the structural model and would revise the bill of material without much manual and paper based intervention.



If we extend that scope a little more to include electrical and plumbing, making a small change can affect all the processes and each design needs to be checked or potentially

revised. But with the integrated environment, it's possible for the architect to check the effect on plumbing layout or electrical layout very easily and quickly.

Now take the example of a medium to large size apartment complex tower where you may have swimming pools, gardens, a park, a library and a gymnasium. Different faces of the tower may have different views. The builder may want to create a web site where prospective buyers/clients can see the entire complex in real time 3D. With the help of a computer and available geospatial software, those data can be digitized and stored.

With the integrated solution, a prospective buyer will be able to check 2D data like a floor plan as well as a 3D view of the tower and even inside the apartment. They can click on a window and see the view from there. Clicking on a room can give you all information about that room. If a change occurs, those data are still integrated and all stake holders can review changes easily.

But it's not only about change management. The most important part of integration is communication. Proper communication saves time and money. All the stake holders remain informed. All project team members stay coordinated and can make informed decision which definitely contributes to a project's success.

4. Some statistics

According to NIST (US National Institute of Standards and Technology)-

1) Reusing information speeds project delivery time by up to 50%
2) Operations and Maintenance management speeds up by 14%
3) 30% of project costs are wasted due to poor communication between systems
4) 40% of engineering time is spent locating and validating engineering information.

Economist Magazine:

Economist magazine surveyed USA construction industry in the year 2000 and they concluded that $200 billon is wasted due to the mistakes and lack of coordination from $650 billon construction industry in USA.

5. BIM (Building Information Modeling)

Now we know and time demands that building design is not merely designing frames, slabs or footings. Now we need to make sure we design an "energy efficient building" or "green building". With the available and upcoming software and huge computing power, architects and engineers are exceedingly interested to innovate and optimize building design solutions. It brings us to today's buzzword: Building Information Management or, more commonly, BIM. Most infrastructure related software companies say they are BIM compliant or their software is a BIM tool. And it seems that every industry expert has something to write on the topic of BIM.

5.1 What is BIM?

BIM is primarily a process to generate, analyze and manage building data during its life cycle. It typically consists of data like geometry, geospatial relationships, geographic information, quantities and properties of different building components.

As the middle name suggests (“I”), it is the flow of information. The data can be stored locally or can refer to a link. Data could be very technical or non-technical. It can contain images, text, video, graphics or any other form of information.

BIM solutions are primarily offered by Bentley Systems, AutoDesk Inc., Tekla and GraphiSoft. But BIM is a fairly new concept and evolving. Now the effort is largely to contain data and link different software through a common process.

In August 2004, NIST issued a report entitled "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry" which came to the conclusion that, as a conservative estimate, $15.8 billion is lost annually by the U.S. capital facilities industry resulting from inadequate interoperability due to "the highly fragmented nature of the industry, the industry’s continued paper based business practices, a lack of standardization, and inconsistent technology adoption among stakeholders".

So, it’s clear we need an integrated solution where paper based practice will be replaced by standardized digital information. With BIM, the industry is trying to achieve the following.

1. Enhanced 3D visualization with inter discipline object representation
2. Better coordination resulting in informed decisions
3. Reduced cost
4. Faster delivery
5. Efficient change management

5.2 BIM for life cycle management (tall building)

After completion of a project, BIM can be extended for building life cycle management. “Tall buildings are like a city on its own", as described by one of the World Trade Center (now destroyed by terrorist attack), designers. It can have its own fire fighters, security, medical office, food court, shopping places, parking structures etc. During the life cycle of a tall building, it might need many retrofit and renovation works, so a proper BIM system will help engineers and architects tremendously. It will help even firefighters to study the safety clearance.

5.2 Bentley’s BIM solution

Bentley strives to provide a BIM solution by integrating multi disciplines involved in a building’s life cycle management. Bentley is one of the largest providers of infrastructure software.

Bentley’s official website describes it best: “Bentley’s fully integrated multi-disciplinary software empowers architects, structural engineers, civil engineers, electrical engineers, mechanical engineers, energy assessors, site designers, and other professionals to design, analyze, construct, manage buildings of all types and scales. Each discipline-specific application provides an informed work environment to support the design and documentation process throughout all phases of the project lifecycle from conceptual design and construction documentation to coordination and construction”.

Bentley’s BIM solution can largely be categorized in four disciplines

1) Bentley Architecture
2) Structural Modeler
3) Bentley Building Mechanical Systems

4) Bentley Building Electrical Systems

Bentley Architecture:

Bentley Architecture is an advanced BIM application which virtually creates 3D prototypes of buildings and provides seamless integration among design, engineering, analysis, construction, and operations for the entire lifecycle of facilities.

Structural Modeler:

Structural Modeler (formerly known as "Bentley Structural") is another BIM solution which empowers structural engineers and designers to create structural systems for buildings and industrial plants in steel and concrete with unlimited possibilities.

Bentley Building Mechanical Systems:

Bentley Building Mechanical Systems is another BIM application that empowers mechanical engineers to create air-handling and plumbing systems for high rise buildings.

Bentley Building Electrical Systems:

Bentley Building Electrical Systems streamlines the design and modeling process for a variety of electrical subsystems, such as lighting, power, fire detection, security, communications, and other building subsystems. A comprehensive range of dedicated tools facilitate automated symbol placement, raceway design, cable and circuit routing, schedule generation and more, supporting a variety of international, country-specific, and user-defined standards.

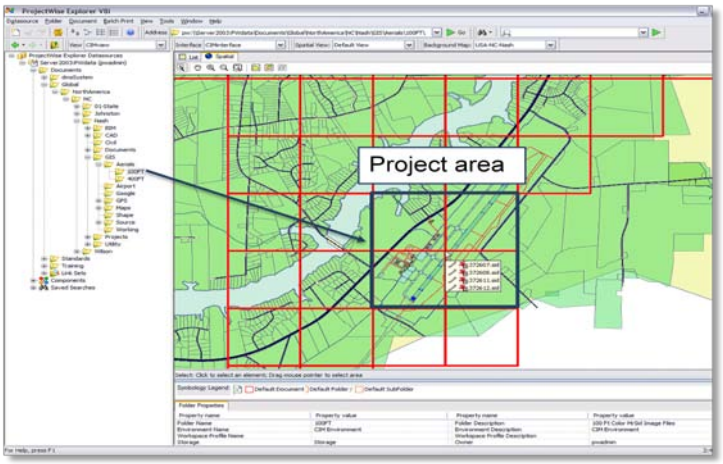
ProjectWise:

In addition to the above mentioned standard BIM tools, Bentley offers another solution called "ProjectWise" which can be used by almost anyone involved in a building project. Bentley BIM software relies upon a federated database concept. Instead of depending on a single model file or database, it draws from a collection of different models and information sources created by the different people involved in a project. ProjectWise supports hundreds of Microsoft Office, CAD and BIM file formats. It offers a project collaboration environment. No two players are necessarily editing the same database, but the system brings all the pieces together for collaboration. Once the model is there, it can be reviewed in a collaborative environment. They may work on different aspects of the project, for many different companies, and could even be in different cities or countries. ProjectWise is optimized for real-time collaboration across distributed teams and can be deployed in a local office or online as a hosted managed solution.

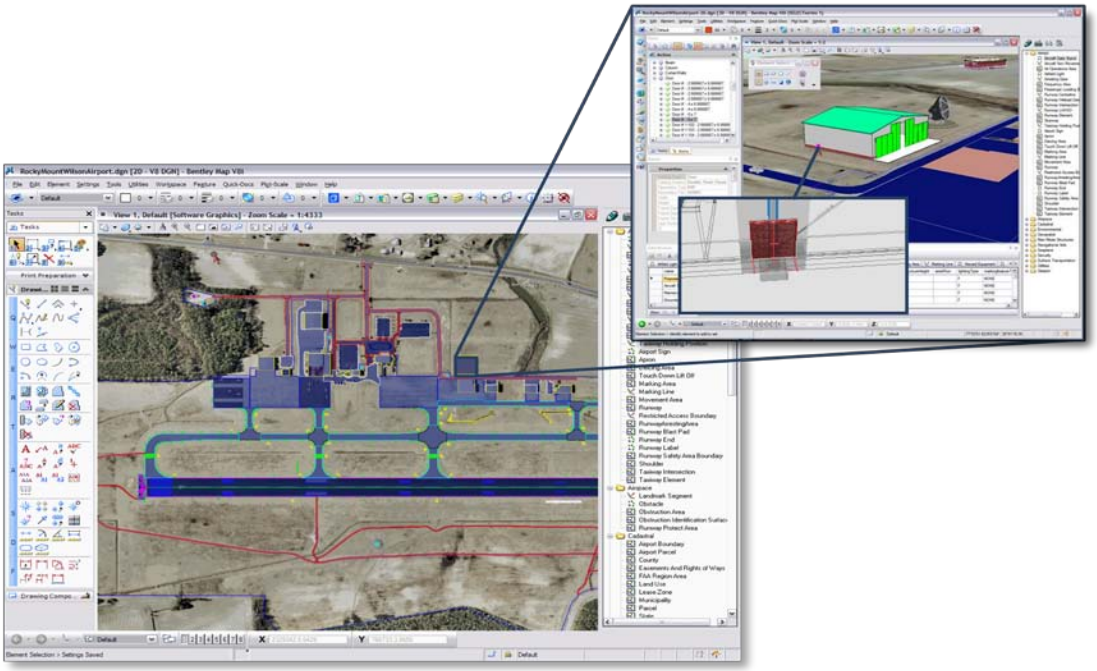
Bentley Map & ProjectWise Connector:

Bentley Map facilitates geospatial data integration within the enterprise and extends the value of all types of spatial information. Since Bentley Map is tightly integrated with MicroStation, it allows the simultaneous manipulation of raster and vector data with CAD accuracy. A seamless interoperability environment makes it easy to work with commonly used spatial data formats. It can be implemented with any two-tier database connection supported by MicroStation, a two-tier connection to Oracle Spatial or a three-tier connection to Oracle Spatial or ArcGIS using a ProjectWise Connector.

Here are some of the examples on spatial integration.



Spatial Integration of Imagery and GIS



- Geospatially Align BIM Hangar to Site
- Analyze Design Interferences
- Validate Preliminary Cost Estimate

5.2.1 Intra discipline solutions

Although BIM is evolving to connect and flow information among multi disciplines, there is a huge disconnect even among intra discipline solutions. Coming back to Structural software, we know STAAD.Pro is the world's leading structural analysis software. But a structural solution is more than the analysis. It must include design of its components, detailing and construction drawings.

Bentley's Structural Software

1) Structural Modeler
2) STAAD.Pro / RAM Structural System

3) STAAD.foundation
4) RAM Concept
5) RAM Connection

These programs are mostly integrated through import/export functionalities. But for any two products there will be a unique integration which is difficult to maintain and very time consuming to develop.

Import/export may hit a big road block in the case of software from different vendors. Different vendors may not agree to publish their native format and that will be the end of integration.

For example for a steel structure one architect/builder may want to use following:

1) Revit for building modeling
2) STAAD.Pro for analysis
3) Tekla/ProSteel for connection detailing

This brings us to our next topic called ISM (Integrated Structural Modeler) which is currently being developed and promoted by the Bentley Structural team.

5.2.2 ISM

ISM is a unique concept where a common repository is created which can hold common data types shared by different applications across different vendors. It essentially creates a generic definition of different structural components. For example, a curve member can be created to define both straight and curved beams with certain flags and parameters.

A curve can be created with three points or two points and radius of curvature. So, for straight beam if we don't define third point, it essentially becomes a straight beam.

A member can just be rectangular or may have different shapes like wide flange, double angle, channel etc. or it can even be a joist, girder, castellated beam etc. Structural analysis software may just need to know only cross section properties and material to analyze that component but detailing software need to know the exact size and proper placement for connection detailing.

<u>The workflow (a practical scenario)</u>

1) Model the basic 3D structure in Revit
2) Integrate with ISM
3) Import ISM model into STAAD.Pro (a combined analysis and design software)
4) Analyze structure in STAAD.Pro
5) Export results from STAAD.Pro to STAAD.foundation for foundation design
6) Size all structural component using section database or vendor specified catalog
7) Save STAAD.Pro model to ISM
8) Import ISM model into Tekla
9) Perform connection detailing
10) Produce shop drawings
11) Save model in ISM

12) Open the model back in Revit

13) Repeat the process if necessary without losing any information and data integrity

5.2.3 Generative Component (GC)

There is another aspect of structural design which is optimization and innovation which brings us to our next topic called “Conceptual Design”.

An artist can conceptualize a complex shape but at this stage there is no commercially available tool to create a complex non-standard geometric model easily. But there is a growing trend for architects and builders to build something very complex and very unique.

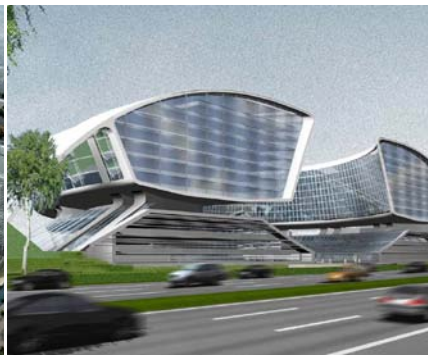
One of the key groups leading this innovation is “Smart Geometry Group”. It’s sponsored by Bentley Systems and the key product displayed in “Smart Geometry Conference” is Bentley’s “Generative Components”.

Generative Component (GC) is built on top of Bentley’s Microstation product (a competitor of AutoCAD, the most widely used CAD software). The key ingredient of GC is parametric-relational modeling. It’s all about smart geometry where basic geometric elements like arcs, lines, surface, solids etc. can be integrated, manipulated, transformed or rotated to produce very complex geometric model.

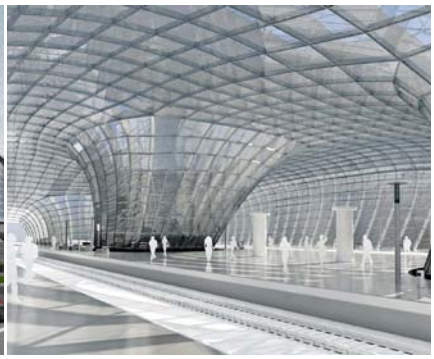
GC is parametric, so by changing basic element properties, many different shapes or prototypes can be generated to review.

Here are some models conceptualized by Generative Components to create some stunning structures we can imagine.

The Lagoons



Bothe Richter Teherani Moscow



Benjamin Schneider-TU-Wein.

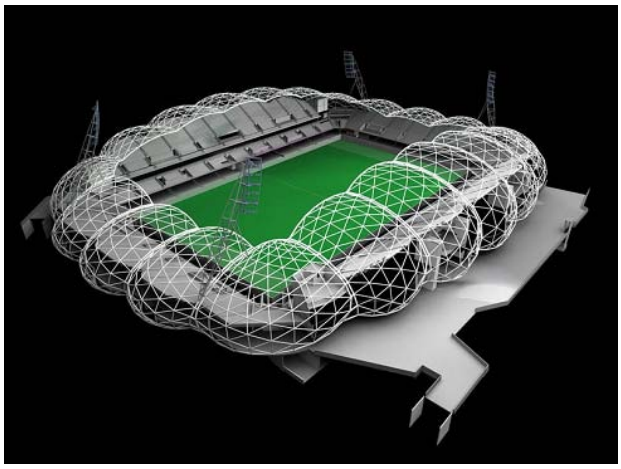
6. A Case Study (Melbourne Rectangular Stadium, Arup)

Melbourne Rectangular Stadium, designed by *Arup* was nominated for “2008 BE Awards of Excellence”. This new stadium will host 31,000 soccer or rugby fans. Its bio-frame, light weight steel structure was a cutting-edge design.

The project team wanted to optimize the design by different geometric configurations as well as to cope with any changes to the roof geometry during the design process. Arup selected GC because of its ability to test alternative geometric configurations. Using GC, Arup created a centerline model of wireframe which was then used by structural engineers to analyze the structure. The final structural model was exported to Structural Modeler for final member sizes.

Commenting on the project, John Legge-Wilkinson, CAD leader for the project, said.[1] “Realizing a geometric solution for the stadium roof structure was a critical design

element of the project. GC gave us the ability to create and rationalize the roof geometry to eliminate errors that occur when manual modelling methods are used. Moreover, GC allowed us to quickly regenerate different geometric configurations, which were used for optimization studies. In total, we regenerated and exported 24 different geometrical configurations using the GC model. These studies would not have been feasible without the ability of GC to quickly regenerate the different geometric configurations and export the data to analysis. The result was an efficient and cost-effective final design."



7. Next Generation

With GC in sight, I would place it at the top of my builder's workflow. I would like to conceptualize with GC, use ISM for structural workflow, BIM to collaborate with other disciplines, and use ProjectWise Integration server for geospatial information.

With ever increasing computing power and innovative software, it may be possible in the near future when I shall be able to choose my house/apartment somewhere in India and will collaborate with a builder and engineers for customization. I shall be able to click to view floor plan or explore an inside, 3D view of building in real time, all while sitting somewhere in California.

[1] http://www.bentley.com/pl-PL/Corporate/News/News+Archive/2009/Quarter+1/arup.htm