USE OF BUILDING INFORMATION MODELS IN SIMULATIONS

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ABSTRACT

The transition to Building Information Modeling (BIM) represents a substantial shift from existing business practices in the architecture, engineering, construction, and facility operations (AECO) arena. While the move from drafting to computer aided design (CAD) sought to automate an existing business practice, successful BIM virtually builds a structure first. Similar to the virtual prototypes in the manufacturing industry, now AECO designers and maintainers can use these virtual models for evaluating various courses of action for improved design and construction. This is especially true in the area of sustainability analysis for design factors such as day-lighting, climate control, and energy usage. This paper will address new emerging business processes stemming from BIM simulations.

1   INTRODUCTION

For many practitioners in the Architecture, Engineering, Constructions, Operations (AECO) industry, their view of Building Information Modeling is aligned with the next technological step following the move from manual drafting to CAD in the early 1980s. Historically, the AECO industry's efforts to implement and support better information flow between stakeholders with existing CAD systems have focused primarily upon format and output versus open information and workflows (i.e. a paper centric versus a process centric viewpoint). The transition to BIM is different than the move to CAD because CAD did not significantly alter business processes, but simply increased the speed at which centuries-old traditional tasks were completed through electronic means. This was comprised of digitizing a well-known 2D-based design and paper-centric project delivery system (Livingston 2007).

The move to Building Information Modeling (BIM) represents much more than the simple automation of an existing human-based operation. When accomplished correctly, BIM fulfills the promise of the inventors of CAD – virtually building the building before it is physically constructed.

Using this virtual model, simulations can be accomplished to determine the potential success or failure of various courses of action. There are a myriad of various simulations that can be accomplished through BIM or Virtual Design and Construction (VDC) and the number is growing every day. In all cases, these simulations' commonality is that they attempt to improve the design or delivery of the facility through the relative low cost of virtual means before the building is turned over to the customer. This paper will address several leading areas in BIM simulation today.

2   USE OF BIM IN SIMULATIONS

2.1   Sustainability

One of the primary opportunities for the NBIMS is that it was published 10 years after the formation of the United States Green Building Council (USGBC). While the USGBC was encouraging the construction of Leadership in Energy and Environmental Design (LEED) certified projects, the methods required for LEED building certification showed the increasing need for and importance of developing digital representation of the physical and functional characteristics of facilities in order to improve their design and document their performance. With each newly certified LEED Accredited Professional and the exponential growth in the number of LEED certified buildings since the turn of the 21st century, the need for reliable building data for simulating and analyzing sustainability features has become more pressing.

The new Autodesk Ecotect 2010 analysis software includes an expanded array of environmental analysis and simulation capabilities including shadows and reflections, shading design, solar analysis, photovoltaic array sizing and load matching, lighting design, right-to-light analysis for neighboring buildings, acoustic analysis, thermal analysis, and ventilation and air-flow. It relies on gbXML to import data from Revit Architecture, ArchiCAD, and Bentley Architecture. Figure 1 shows a variety of analyses using Ecotect. The Autodesk Green Building Studio web-based service comes bundled with Ecotect 2010 and can be used to evaluate multiple design alternatives for energy efficiency and carbon neutrality. Figure 2 shows the results output from Green Building Studio which includes summary information on building energy and resource use, carbon emissions, simulation assumptions, performance metrics, and costs that can be used to compare the energy costs of multiple building design scenarios at the conceptual design stage. The estimated energy and cost summary provides estimated information on annual energy cost; lifecycle energy costs (30 year); Annual energy consumption (electric and gas); Peak electric demand (kW); Lifecycle energy consumption (electric and gas); CO_2 emissions are based on the on-site fuel use and the fuel sources for the electricity in the region and an equivalency using an SUV (driven 15,000 miles/year) is also given to put the building's CO_2 emissions into perspective.

The Green Building Studio web service provides additional information required to help design a carbon neutral building and includes:

- **Carbon Neutral Potential -** summarizes the estimated CO_2 emissions for the building design and identify the options to help reduce them.
- **Electric Power Plant Sources -** summarizes the fuel sources for electricity generated in this region, which is information to be used in using renewable resources by an amount equal to the portion of the electricity that comes from fossil fuels in making the project carbon neutral by reducing electricity consumption or offsetting using renewables by an amount equal to the portion of the electricity that comes from fossil fuels.
- **Water Usage and Cost** – summarizes estimated water use in the building based on the number of people in the building as well as the building type
- **Photovoltaic Potential** - analyzes every exterior surface of the building, including roofs, walls, and windows, for their estimated potential to generate electricity using photovoltaics.
- **LEED Glazing Score** – calculates the percentage of regularly occupied floor area that has a Glazing Factor greater than 0.02. The score must be more than 75 percent to score LEED points and achieve full benefit from daylighting controls throughout the building.
- **Wind Energy Potential** - The estimated annual amount of electricity that can be generated from one 15-footdiameter wind turbine of conventional design.
- **Natural Ventilation Potential** - approximates the annual operating hours and energy required to mechanically cool and ventilate the building. It also estimates the annual number of hours that outdoor air could be used to naturally ventilate the building. Potential energy savings associated with not running the mechanical cooling and ventilation system during this period are projected, and finally, the net hours that cooling is required, even with natural ventilation, are estimated.
- **Building Summary** - Detailed statistics, assumptions, and information on building constructions are also provided. This information allows for an early assessment of code compliance and rough estimates of equipment sizing requirements for heating, cooling, and water heating, as well as window, wall, and floor area breakdowns.

The system also exports files various file formats including gbXML, VRML, DOE-2 and EnergyPlus for use in additional simulation analysis programs. The design alternative feature allows you to modify the base case assumptions and then run a simulation so that you can estimate the impact of these modifications on energy efficiency. This feature helps the user make significant design decisions more quickly.
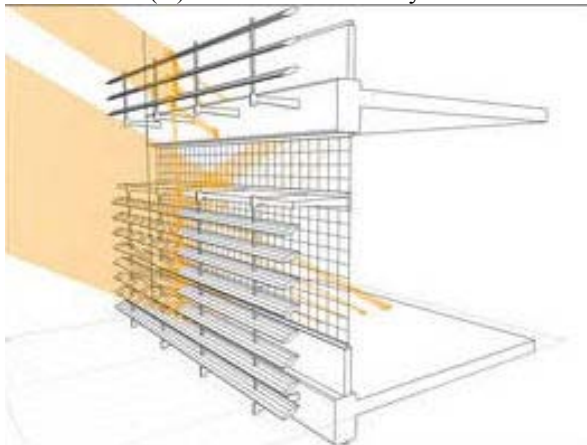
Other popular software packages with similar simulation capabilities in Graphisoft Ecodesigner, which is integrated with Graphisoft ArchiCAD and Virtual Environment by IES which has Plug-ins for Revit and SketchUp, and also imports gbXML files.
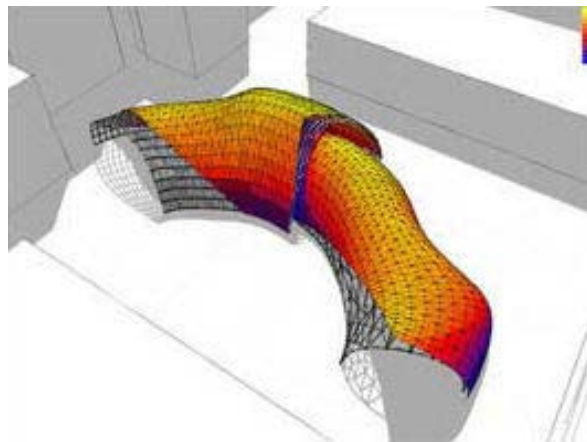
(A) Solar radiation Analysis
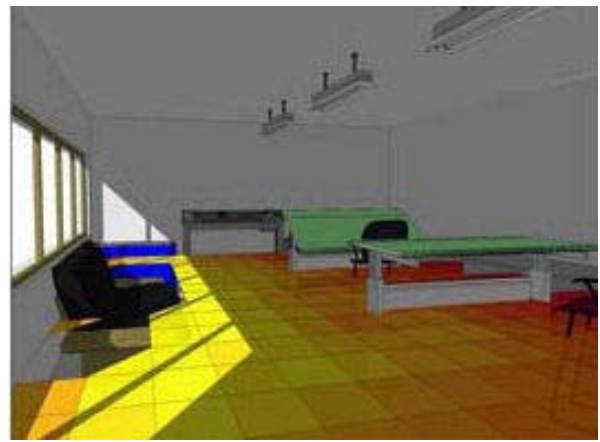
(B) Daylighting analysis

(C) Shading analysis
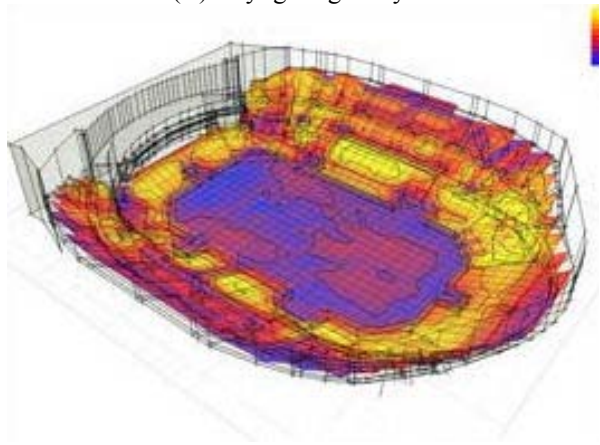
(D) Ventilation and Airflow Analysis

Figure 1: Different kinds of analysis performed by Autodesk Ecotect (Source: `<www.autodesk.com/revit>`)

2.2   VICO Virtual Construction (VC)

The Virtual Construction (VC) process involves building a building twice, once on the computer and once in the real world. It is a process by which a builder simulates a building before and during the actual construction process. VC relates time (4D) and cost (5D) to the underlying building model and allows the user to instantly relate a change to its impact on the project. It is ideally suited on projects with high cost and high risk and which can lead to high rewards for mitigating those costs and risks. Virtual construction is the natural extension of BIM superimposed with schedule and cost which when it is made accessible to all stakeholders thus fostering communication and cooperation. The BIM allows the project team to collaboratively examine and tweak the building to meet budget and completion goals. As such, VC is invaluable for budget-constrained projects, where deadlines are important and project success is critical. As shown in Figure 3, the project risk is reduced as the representation of project progresses from 2D to 3D to 4D (schedule) to 5D (cost).

VC is most applicable to projects of about $20 million and up, however, size is not as important as risk in the decision of whether to select VC or not. According to VICO (`<www.vicosoftware.com>`), through the use of VC on a hospital expansion project connecting three existing buildings with 102,000 sqf., the project team was able to eliminate 95% of the design clashes (700) and also reduced the project scheduled duration by 27% (42 weeks).

Autodesk

GREEN BUILDING STUDIO

about   demos   downloads   support

Logout   Your Projects   User Settings   Corporate Account

Energy & Carbon Results | US EPA ENERGY STAR | Water Usage | PV Analysis | LEED Daylight | Weather | 3D VRML View

File Downloads
- gbXML File
- VRML File
- DOE-2 File
- EnergyPlus File
- Weather File(binary)
- Weather File(CSV)

Links
- Run List
- Design Alternatives
- Notes

Energy & Carbon Results
Annual Flexible End Use

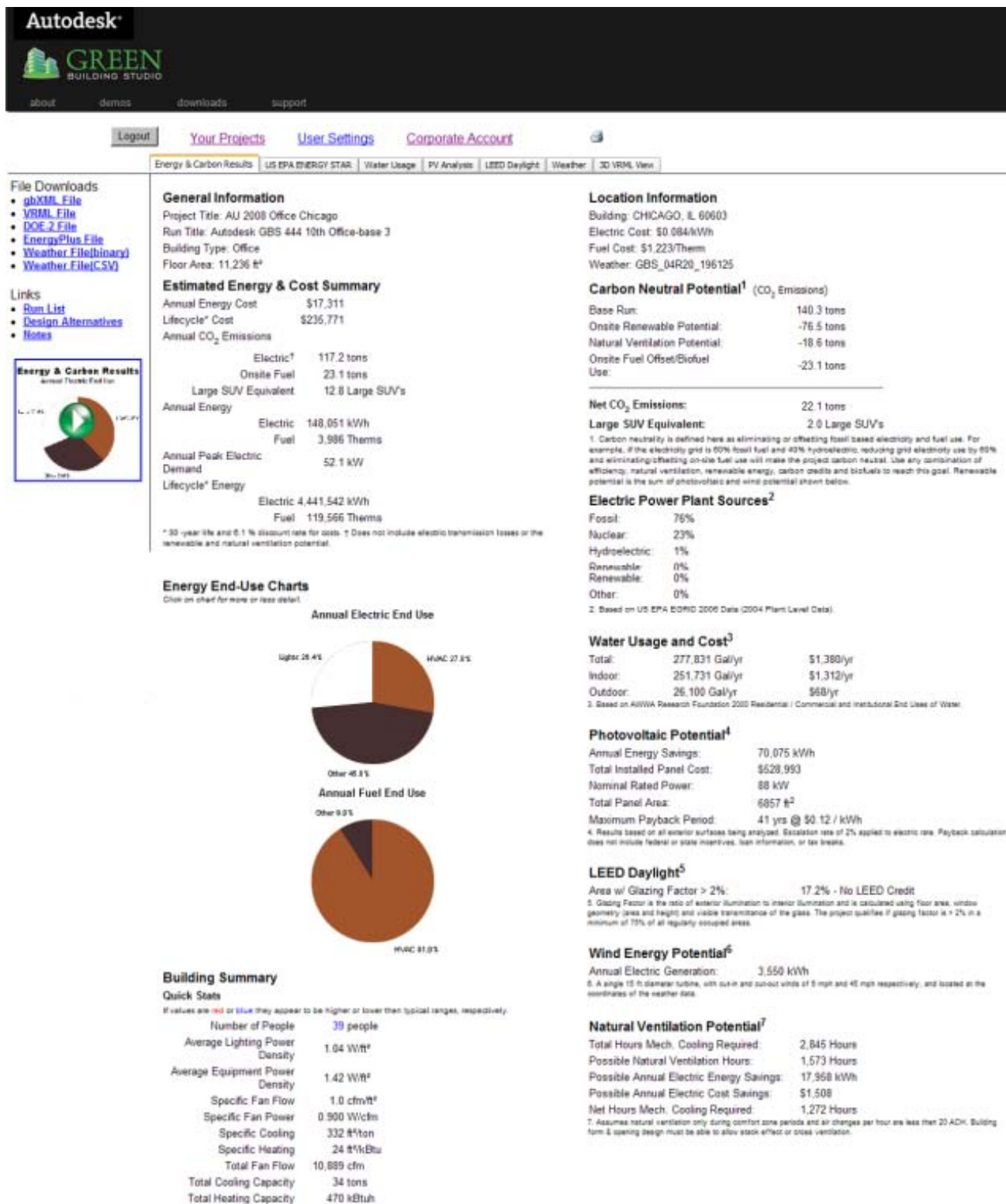**General Information**
Project Title: AU 2008 Office Chicago
Run Title: Autodesk GBS 444 10th Office-base 3
Building Type: Office
Floor Area: 11,236 ft²

Estimated Energy & Cost Summary

Annual Energy Cost	$17,311
Lifecycle* Cost	$235,771

Annual CO_2 Emissions

Electric†	117.2 tons
Onsite Fuel	23.1 tons
Large SUV Equivalent	12.8 Large SUV's

Annual Energy

Electric	148,051 kWh
Fuel	3,986 Therms

Annual Peak Electric Demand   52.1 kW

Lifecycle* Energy

Electric	4,441,542 kWh
Fuel	119,566 Therms

* 30-year life and 6.1 % discount rate for costs. † Does not include electric transmission losses or the renewable and natural ventilation potential.

Energy End-Use Charts
Click on chart for more or less detail.

Annual Electric End Use

Lights 26.4%   HVAC 27.8%   Other 45.8%

Annual Fuel End Use

Other 9.0%   HVAC 91.0%

Location Information
Building: CHICAGO, IL 60603
Electric Cost: $0.084/kWh
Fuel Cost: $1.223/Therm
Weather: GBS_04R20_196125

Carbon Neutral Potential[1] (CO_2 Emissions)

Base Run:	140.3 tons
Onsite Renewable Potential:	-76.5 tons
Natural Ventilation Potential:	-18.6 tons
Onsite Fuel Offset/Biofuel Use:	-23.1 tons

Net CO_2 Emissions:	22.1 tons
Large SUV Equivalent:	2.0 Large SUV's

1. Carbon neutrality is defined here as eliminating or offsetting fossil based electricity and fuel use. For example, if the electricity grid is 60% fossil fuel and 40% hydroelectric, reducing grid electricity use by 60% and eliminating/offsetting on-site fuel use will make the project carbon neutral. Use any combination of efficiency, natural ventilation, renewable energy, carbon credits and biofuels to reach this goal. Renewable potential is the sum of photovoltaic and wind potential shown below.

Electric Power Plant Sources[2]

Fossil:	76%
Nuclear:	23%
Hydroelectric:	1%
Renewable:	0%
Renewable:	0%
Other:	0%

2. Based on US EPA EGRID 2006 Data (2004 Plant Level Data).

Water Usage and Cost[3]

Total:	277,831 Gal/yr	$1,380/yr
Indoor:	251,731 Gal/yr	$1,312/yr
Outdoor:	26,100 Gal/yr	$68/yr

3. Based on AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

Photovoltaic Potential[4]

Annual Energy Savings:	70,075 kWh
Total Installed Panel Cost:	$528,993
Nominal Rated Power:	88 kW
Total Panel Area:	6857 ft²
Maximum Payback Period:	41 yrs @ $0.12 / kWh

4. Results based on all exterior surfaces being analyzed. Escalation rate of 2% applied to electric rate. Payback calculation does not include federal or state incentives, loan information, or tax breaks.

LEED Daylight[5]

Area w/ Glazing Factor > 2%:   17.2% - No LEED Credit

5. Glazing Factor is the ratio of exterior illumination to interior illumination and is calculated using floor area, window geometry (area and height) and visible transmittance of the glass. The project qualifies if glazing factor is > 2% in a minimum of 75% of all regularly occupied areas.

Wind Energy Potential[6]

Annual Electric Generation: 3,550 kWh

6. A single 15 ft diameter turbine, with cut-in and cut-out winds of 5 mph and 45 mph respectively, and located at the coordinates of the weather data.

Natural Ventilation Potential[7]

Total Hours Mech. Cooling Required:	2,845 Hours
Possible Natural Ventilation Hours:	1,573 Hours
Possible Annual Electric Energy Savings:	17,968 kWh
Possible Annual Electric Cost Savings:	$1,508
Net Hours Mech. Cooling Required:	1,272 Hours

7. Assumes natural ventilation only during comfort zone periods and air changes per hour are less than 20 ACH. Building form & opening design must be able to allow stack effect or cross ventilation.

Building Summary

Quick Stats
If values are red or blue they appear to be higher or lower than typical ranges, respectively.

Number of People	39 people
Average Lighting Power Density	1.04 W/ft²
Average Equipment Power Density	1.42 W/ft²
Specific Fan Flow	1.0 cfm/ft²
Specific Fan Power	0.900 W/cfm
Specific Cooling	332 ft²/ton
Specific Heating	24 ft²/kBtu
Total Fan Flow	10,889 cfm
Total Cooling Capacity	34 tons
Total Heating Capacity	470 kBtuh

Figure 2: Autodesk Green Building Studio Summary Output (Source: <http://www.autodesk.com/revit>)
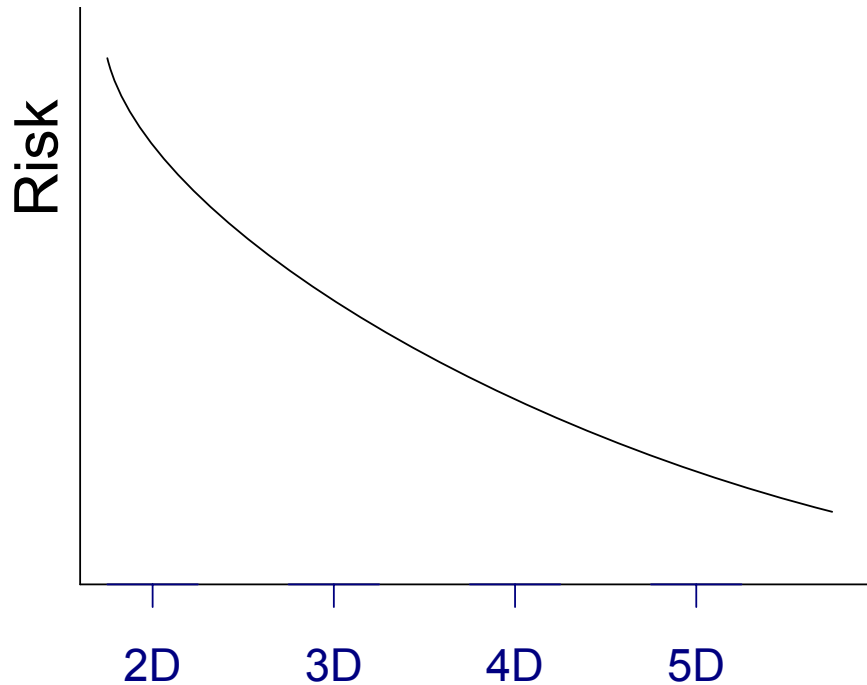
Figure 3: Decrease in project risk with the increase in model details

VICO Control is a location based virtual construction system that allows the creation of compressed schedules which allow the user to determine progress by comparing actual productivity to the project schedule. Many BIM models are not able to store information beyond what the building looks like and as such do not allow the user to store info on the construction process. VICO Control allows integrated construction of the whole project and allows the user to link duration and cost information directly to the model. Accordingly the user can instantly see the impact of changes in scope and schedule on the entire project. It links the building model to estimating and scheduling information going from 3D to 5D and allows the user to add additional parameters to each and every element in the BIM. Thus, the user can attach a recipe describing the means and methods of construction to a particular piece of geometry. Such a system allows the user, for example, to determine the concrete, steel, formwork and labor associated with the column shown in Figure 4, in order to produce an estimate and schedule for that component. A building then becomes an accumulation of all its components (Figure 5) and its construction schedule becomes a combination of the schedule for each of its components (Figure 6). Simulation of such a building with different components will allow for design and value engineering improvements for the project.

Another form of simulation involves generating virtual mockups (Figure 7) of a building, e.g. determining the size and shape of metal panels that cover an intricate structural steel substructure or generating shop drawings for interior finishes. In closing, a project may be represented in several parallel models created by the designer, contractor and the subcontractor respectively. The architect is interested in design coordination, the contractor is interested in cost and schedule simulation, the subcontractor is interested in fabrication of building components, the owner is interested in the as-built model. If the contractor works with the designer at beginning the may be able to use the designer's model instead of creating their own. Sometimes the contractor is interested in building their own BIM in order to (1) learn project, (2) to generate cost and schedule and (3) to perform a quality assurance on the project This decision is based on project type and team preferences.
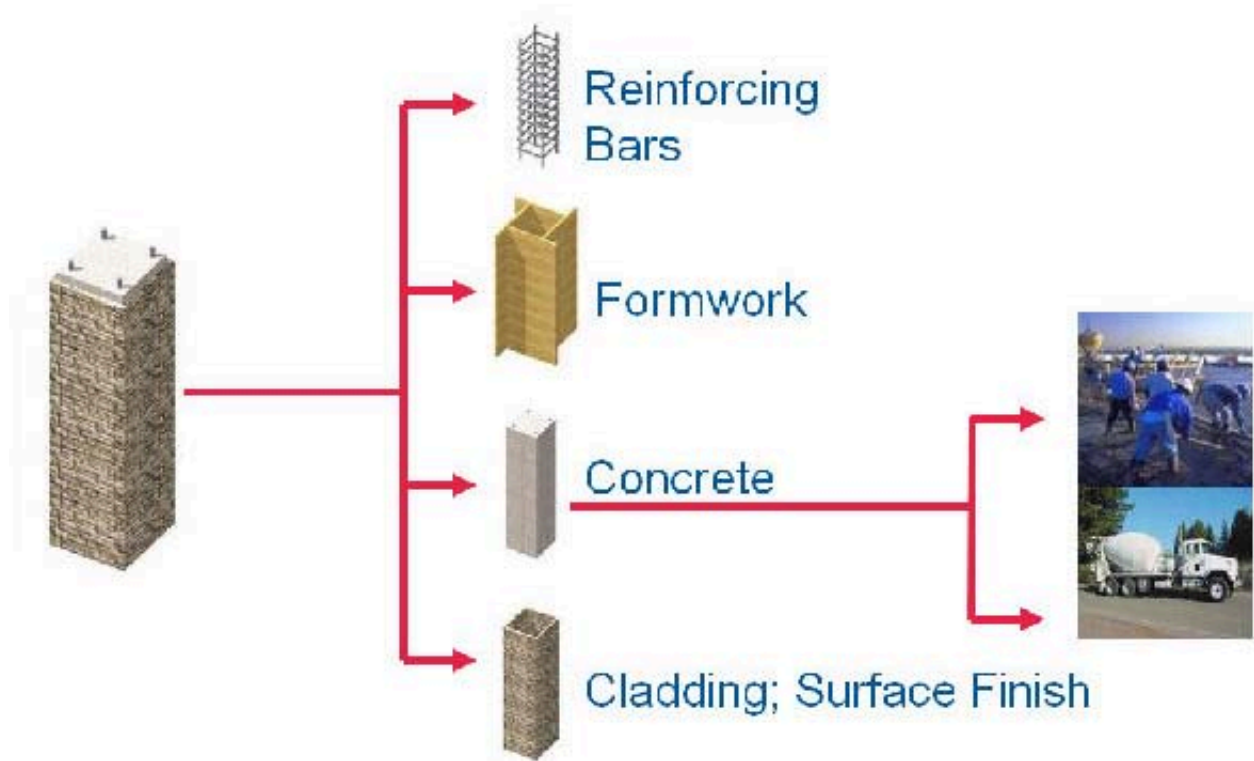
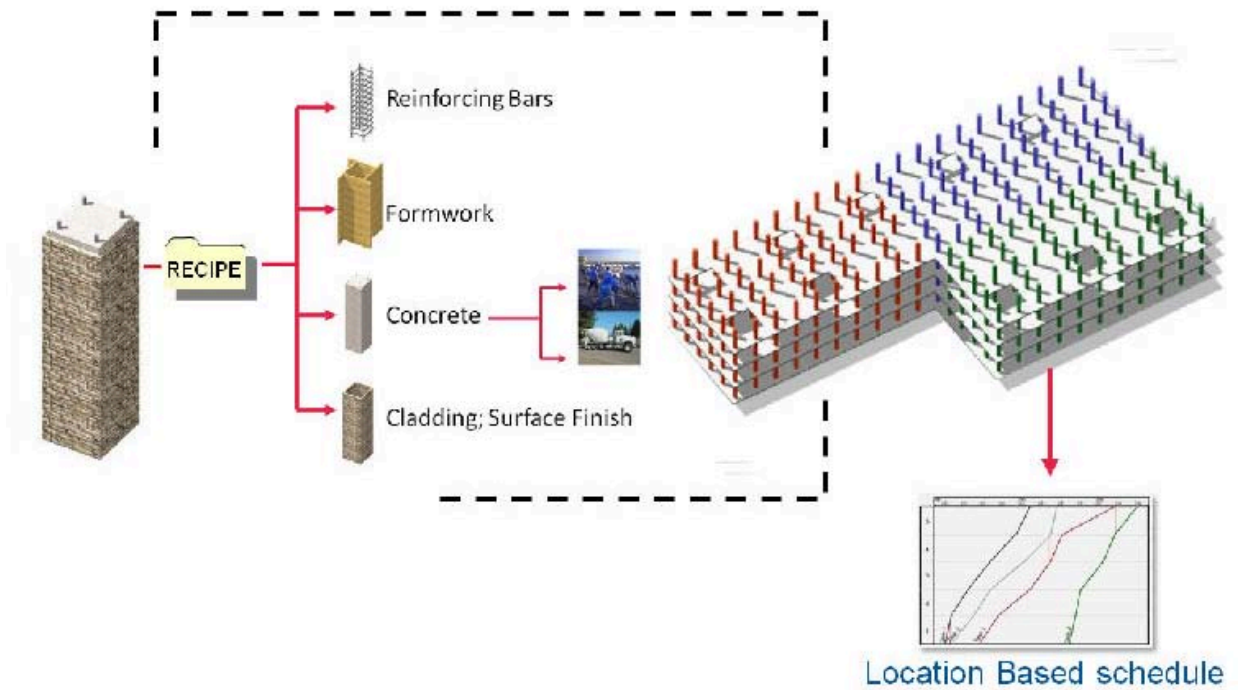Figure 4: Building component recipe, methods and resources for (Source: VICO Software)

Figure 5: Location based schedule and 5D model (Source: VICO Software)
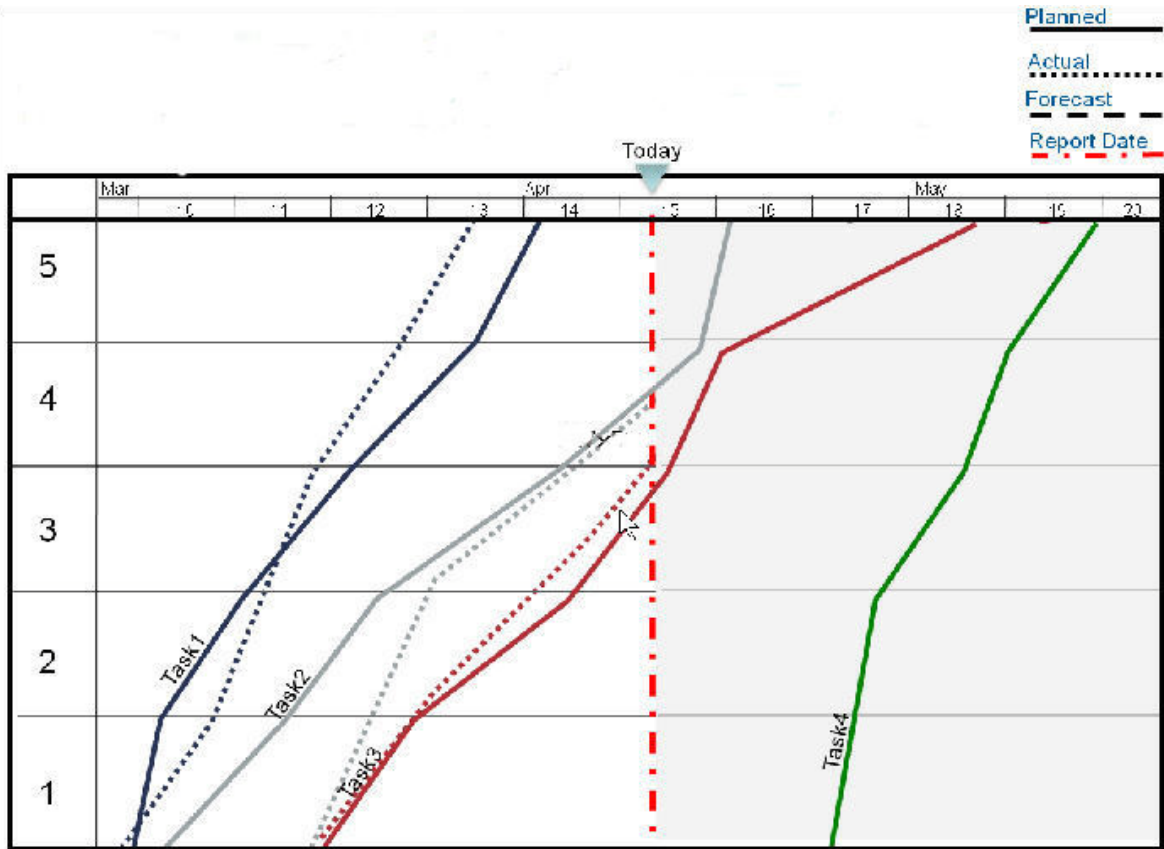
Figure 6: Location based schedule (Source: VICO Software)

(A) Physical mockup   (B) Three views of virtual mockup

Figure 7: Location based schedule (Source: VICO Software)

3   CONCLUSIONS

Simulations using BIM allow designers, builders and facility operators to explore and refine design, construction and maintenance options by changing design, construction and operation parameters. For these reasons, it is expected that there will be a very large increase in simulations using BIM over the next decade. Building a BIM once and analyzing it a multitude of times for a variety of purposes increases the ROI on the modeling cost and encourages many more entities to generate BIMs. The increased societal concerns with sustainability issues has increased the demand for simulations to determine the environmental impact of design decisions. Likewise the increased complexity of buildings has resulted in greater demand for modeling and simulations to help in selecting the means and methods of construction.

REFERENCES

Autodesk <http://www.autodesk.com/revit>
Livingston, H. (2007). "National Standards Evolve Slowly: While the National CAD Standard plugs along and plugs in, the National BIM Standards Project gains momentum." *Cadalyst*, Copyrighted August 16, 2007, <http://aec.cadalyst.com/aec/article/articleDetail.jsp?ts=100107020144&id=449711> (October 1, 2007).
Vico Software (<http://www.vicosoftware.com>)

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