

# Report on integrated practice

University  
and  
industry  
research  
in  
support  
of  
BIM

# 2

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Throughout the history of architecture, the essential building representation has been drawings. Innumerable books review how drawings and sketches are relied on in architects' thinking and creative work.<sup>1,2</sup> The replacement of drawings with a new base representation for design, communication, construction, and archiving of buildings is a revolutionary and epoch-making change, in both architecture and in the construction industry generally. This change alters the tools, the means of communication, and working processes.

The source of this transformation, building information modeling, is still a young technology, derived from parametric modeling in manufacturing, which itself is only 20 years old.<sup>3</sup> The new representation has many advantages, being integrated and internally consistent, but its most essential aspect is that it is machine readable. Computers can "read" the building description's geometry, topology, and properties; they can abstract, encode, process, and derive new information. The new representation also allows presentations to people that are much easier to comprehend and interpret than drawings, allowing enhanced communication, such as is web-based design reviews and walk-throughs. I will explore a few of implications of machine-readability here.

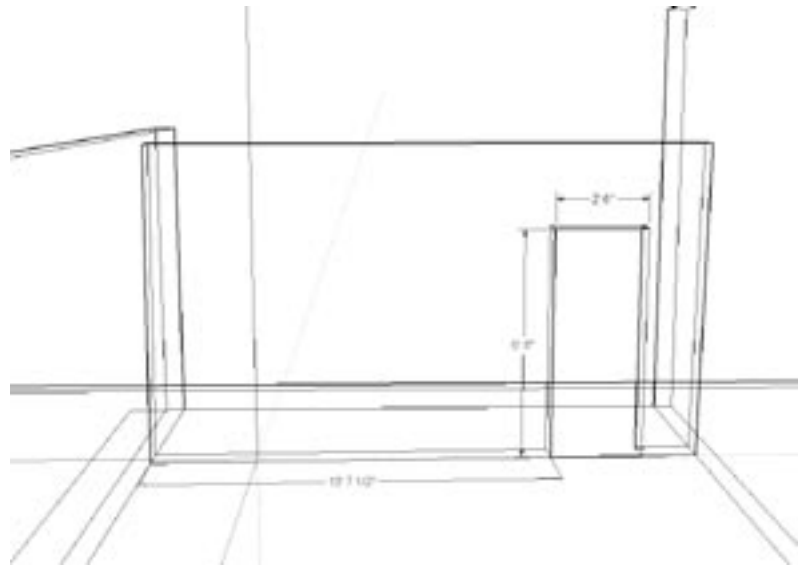
<sup>1</sup> Alberto Pérez-Gómez, *Architectural Representation and the Perspective Hinge* Cambridge, MA: MIT Press, 2000

<sup>2</sup> Donald Schon and G. Wiggins, "Kinds of seeing and their functions in designing", in *Design Studies* 13:2 (1992): 135–156

<sup>3</sup> J.J. Shah and M. Mantyla, *Parametric and Feature-based CAD/CAM: concepts, techniques, and applications* New York: John Wiley, 1995

An essential capability of all the BIM (Building Information Model) design tools is their support of parametric modeling; Revit®, ArchiCad®, Bentley Architecture, Digital Project®, and Vector-works® are all parametric modelers. Parametric modeling matured in the 1980s and '90s through intense industrial development and university research.<sup>3</sup> The basic idea is that 2D or 3D solid object shapes can be defined according to parameters, some of which are user-defined values and others relative to other shapes.

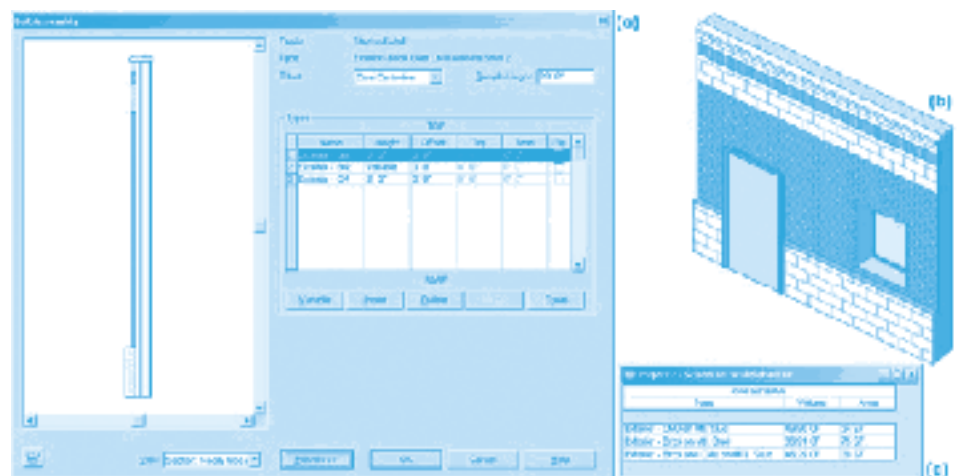
Because this is such a fundamental aspect of future research efforts, allow me to walk through the parametric definition of that most ubiquitous architectural object, a wall. Walls are of infinite variety of shape and construction. We begin with a generic wall, defined by its external shape, without construction details. It has a base plane, almost always defined as coplanar with the floor plane. Its top face may be a plane at a given height, defined by a fixed or relatively defined (possibly sloped) surface, or possibly by a set of adjacent object surfaces (for example, the bottom faces of a gable roof). The wall thickness is typically defined explicitly, based on a nominal value or on its type of construction. The two wall ends are defined through geometric construction, using a construction line parallel the wall and its possible intersection with abutting walls. This construction line has a start and an end point. The points may be fixed in x-y space of the plan or float. If floating, the end points may be defined by the intersections with designated intersecting walls. Some systems maintain the association between walls that abut and will automatically update abutting walls whenever a wall is moved.



**Figure 1** Wall with fixed height and abutting tow end walls. If either of the end walls is moved, the center wall will change its dimensions.

Door or window placement is defined a given length down the wall from its start, and a given width, height, and in the case of windows, a base height. Doors and windows consist of two parts: the window or door itself, and the shape that is subtracted from the wall that is filled by the door or window. Both are located in the coordinate system of the wall, moving with it. An example with a door is shown in Figure 1. The internal structure of standard walls in BIM design tools are defined as a set

of layers, as shown in Figure 2. The wall consists of a structural core, such as concrete block, wood or metal studs, and various layers of sheet material on both sides. The layers are important for bills of material and assessing the wall's performance. Most BIM design tools have the ability to vary the construction layers within a wall, either horizontally, as in Figure 2, or by defining arbitrary polygonal regions of the wall to which a set of wall layers can be assigned.



**Figure 2** The new stacked wall type in Revit 7. **a** shows the wall defined with three subwalls, **b** shows an instance of the wall placed in a project, **c** shows the wall schedule for quantity takeoffs.

If a homebuilder wishes, he or she may gain cut material lists by automatically laying out the framing. This uses the wall as defined up to here and the framing layer as the context, adds framing details at the openings and end-connections, then frames in the rest. These procedures rely intimately on the rules and structure of the wall as defined by the BIM design tool.

A well-crafted parametric wall must also address a range of special conditions.

1. The doors and window locations must fall within the polygonal elevation of the wall. They typically give a warning or are not created if this condition fails.
2. The wall logically ends where its base plane extends beyond the floor plane with which it is associated.
3. Doors and windows cannot be arranged so that they overlap or be spaced less than a given distance apart.

It takes care to define a generic wall. It is not unusual for a class of building objects at the detail design stage to have 150 or more rules defining them.<sup>4</sup> It also explains why users sometimes encounter problems in unusual wall layout situations. Can walls be curved or lofted? Can they support detailing of the connection between heterogeneous materials within them? Answers to such questions vary for different BIM design software, based on the rules that are implemented within them.

All current BIM architectural design tools include parametric walls, some types of doors, and windows. They also typically include window walls, columns, stairways and ramps, residential roofing, open web steel joists, floors and ceilings, structural beams, braces, slabs, and footings. The list of predefined parametric objects provided in the

different BIM design tools varies. The BIM tool developers are in a race to fill out the most-used building systems. In response to inevitable limitations, each also provides a way to define new objects as well as modify existing ones. The complexity of this task varies. Some systems facilitate it with fairly easy-to-learn sketching and scripts, while others require programming capability.

In the near term, architectural firms need to have one or more persons capable of developing new parametric objects, if they expect to support a wide range of construction technologies. When you acquire a particular BIM design tool, you are also acquiring a set of abstract architectural objects that have a particular built-in behavior style. A website that tries to keep current on BIM design tools, the objects they support and the objects' behavior is <http://bim.arch.gatech.edu/>.

Because many building systems have no tools for detailing them, BIM design tools support the ability to create cut sections and draw in the detailing. The contents of drawn sections are not machine readable, but allow the selective use of BIM capabilities and reduce the computation requirements on workstation hardware.

With this introduction, some of the research issues associated with parametric modeling can be reviewed.

Building objects distinguish a BIM design tool from general parametric modeling systems, such as Inventor® or CATIA®. The parametric building objects encapsulate architectural knowledge and expertise. They are not defined singularly, but as systems, using other objects' rules in their own definition. Walls, doors, and windows are part of the space enclosure system, for example. At the detailed level, parametric models of building systems need to respond to applicable codes, support various levels of detailing, support varied analyses, and at the most detailed, support for fabrication. An important short term area of BIM research and development is the filling out the different building systems, defining the objects in those systems and their behavior.

The author's group has been involved in the specification of fabrication-level parametric design tools for precast concrete fabrication,<sup>4,5,6</sup> and now in the specification of an engineering product for cast-in-place concrete. Some other building systems also have parametric objects already defined for them. Fresh and waste water piping has been developed for process plant modeling tools<sup>7</sup> and can be used in architecture, and some landscape and sitework systems are available.<sup>8</sup> Some of the other building systems that will soon need to have parametric objects and assemblies include: custom curtainwall systems, electrical, emergency and alarm systems, fire sprinkler systems, steel trusses, sheet metal ductwork, mechanical system layout, wood paneling and other finish systems, hung ceiling systems, roofing and water sealant systems, and elevators and escalators. Some of these sets of parametric objects will be developed independently, while others will be associated with proprietary construction systems, for ceiling systems for example. Parametric design tools facilitate

<sup>4</sup> Rafael Sacks, C.M. Eastman, and G. Lee, "Parametric 3D Modeling in Building Construction with Examples from Precast Concrete," in *Automation in Construction* 13:3 (2004): 291–312

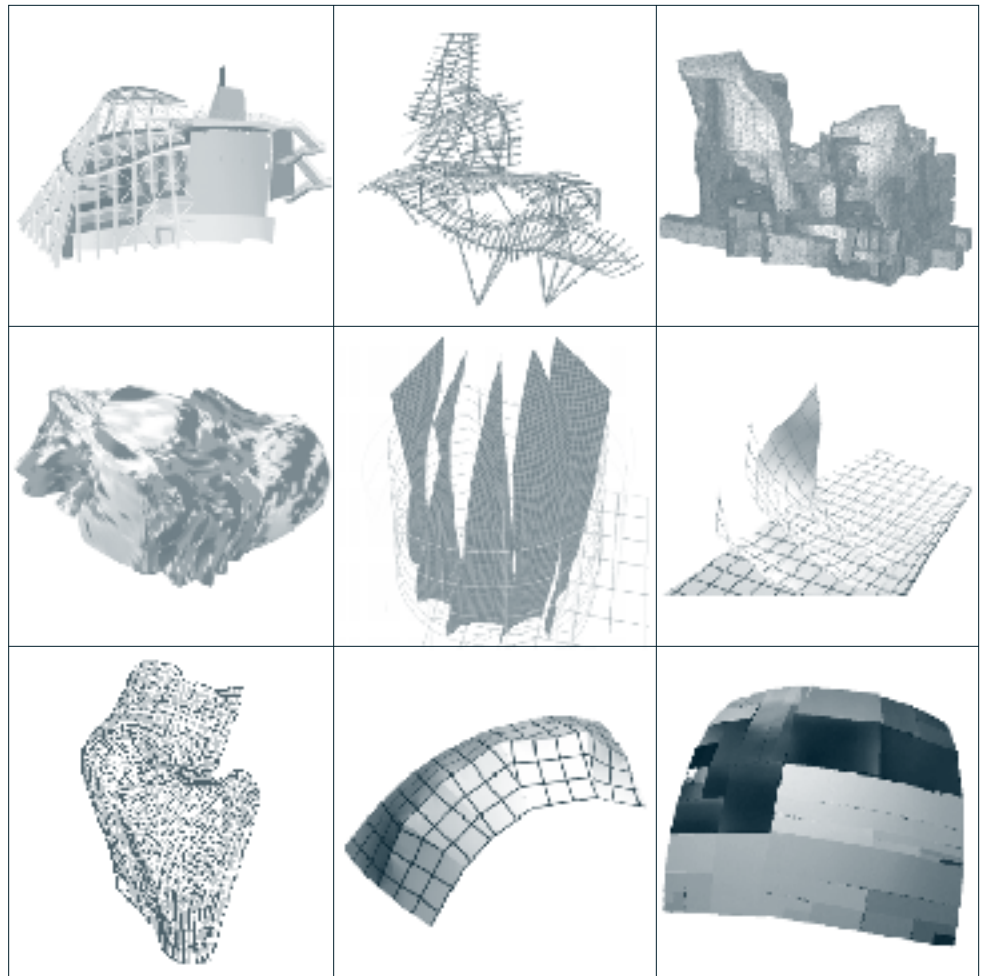
<sup>5</sup> C.M. Eastman, G. Lee, and R. Sacks, "Development of a knowledge-rich CAD system for the North American precast concrete industry," in K. Klinger, ed., Indianapolis, IN: *ACADIA 22* (2003): 208–215

<sup>6</sup> G. Lee, C.M. Eastman, R. Sacks, and R. Wessman, "Development of an intelligent 3D parametric modeling system for the North American precast concrete industry: Phase II," in *ISARC – 21st International Symposium on Automation and Robotics in Construction* Jeju, Korea; NIST, 2004, 700–705

<sup>7</sup> H. Edward Goldberg, "Today's Plant and Piping Programs: Options for P&ID and 3D plant design," in *Cadalogist*, December 1, 2002, available at <http://www.cadalogist.com/cadalogist/article/articleDetail.jsp?id=84331>, accessed March 31, 2006

the quick design and layout of these systems, and incorporate the basic “good practices” for proper detailing.

Each of these building systems will be implemented as an extension or “plug-in” to one of the BIM design tools, developed by the BIM tool software companies or by third parties. In either case, they will be developed for a single BIM design platform. Today, no way exists to develop such objects with built-in *create* and *edit* operations in an open or sharable manner. What is available is the ability to exchange fixed object geometry and attributes, without editing capabilities. As a result, architects and other purchasers of BIM design tools, are selecting a set of objects, for multiple building systems, that are exclusive in their capabilities to a single system. Teams wishing to work on multiple BIM platforms cannot exchange their designs in an editable format. A major long-term research objective will be the development of sharable parametric objects. Significant effort and some results have been made to achieve this goal, coming from mechanical parametric modeling, who have the same problem.<sup>9,10</sup>



**Figure 3** A few of the different types of shapes and skin covering methods investigated in the Ph.D. thesis of Dennis Sheldon.<sup>13</sup>

Investigations of building systems have been picked up with enthusiasm in the universities, not dealing with current construction practices, but rather for developing new methods of construction, inspired by work from the offices of Frank Gehry and Sir Norman Foster, among others. Explorations include skin and rib systems coming from shipbuilding and airplane fabrication, numerical control cutting of formwork for precast concrete, and the capabilities of developable surfaces (those that can be made of sheet material curved in one direction).<sup>11,12</sup>

**Figure 3**, from the Ph.D. thesis of Dennis Sheldon, illustrates some examples of the kind of fabrication methods being explored. Individuals and firms are developing parametric models of such assemblies, allowing them to be edited and integrated with standard building elements. Particular issues involve decomposing freeform shapes into developable surfaces that can be fabricated.<sup>13</sup> Another is the exploration of procedures supporting design-for-fabrication rules that allow designers to know while they are designing that their forms can be

<sup>11</sup> Daniel Shodak, M. Bechthold, K. Griggs, K.M. Kao, and M. Steinberg, *Digital Design and Manufacturing: CAD/CAM Applications in Architecture and Design* New York: John Wiley, 2005

<sup>12</sup> Philip Beesely, N. Chang, S. Williamson, eds., *Fabrication: Examining the Digital Practice of Architecture*, Proceedings 2004 ACADIA Conference, University of Waterloo, Ontario

<sup>13</sup> Dennis R. Sheldon, *Digital Surface Representation and the Constructibility of Gehry's Architecture* Cambridge, MA: MIT, 2002

<sup>8</sup> See <http://www.cadinfo.net/scripts/software-products.cfm?cat=Digital+Terrain+Modelling> accessed March 31, 2006

<sup>9</sup> Guk-Heon Choi, Duhwan Mun, and Soonhung Han, “Exchange of CAD Part Models Based on the Macro-Parametric Approach,” in *International Journal of CAD/CAM* 2: 1(2002): 13–21

<sup>10</sup> Guy Pierra, J.C. Potier, P. Girard, “Design and Exchange of Parametric Models for Parts Library” in *Proceedings of the 27th International Symposium on Advanced Transportation Applications, ISATA '94, Aachen, Germany* (October 31–November 4, 1994): 397–404

fabricated.<sup>14</sup> A growing number of projects around the world exhibit the results.<sup>15</sup> There are not enough students with good parametric modeling skills available today; those with such skills are being quickly hired by major firms.

In the longer term, the limitations of the current generation of built-in building objects will be eliminated, either within design firms or university research groups. They will offer plug-ins for lofted curtainwall design systems, building skin and rib definition and editing tools, for lofted interior wall systems, and other systems. The implication is that families of parametric objects will support particular styles of design. In the 1980s the work of Stiny and others on shape grammars<sup>16</sup> suggested the possibility of developing design tools that captured and allowed generation on new buildings incorporating a particular style. The objects and behavior of BIM design tools realize this capability. Just as computer animation groups develop avatars with movement and gesture styles, so will architectural software houses develop BIM modeling extensions supporting design styles.

<sup>14</sup> Eduardo Lyon, "Design for Manufacturing in Architecture Mapping in Between Curved Surfaces Design and Fabrication," in *The Proceedings of eCAADe 2005 Conference*, Lisbon, Portugal (September 2005)

<sup>15</sup> James Glymph, D. Shelden, C. Ceccato, J. Mussela, and H. Schober, "A parametric strategy for free-form glass structures using quadrilateral planar facets," in *Automation in Construction* 13 (2004): 187–202

<sup>16</sup> Terry Knight, *Transformations in Design* Cambridge: Cambridge University Press, 1994

Up to this point I have dealt only with embedding of design knowledge into the physical systems of a building. But, this is more the expertise of the construction engineer than the architect.

Storing predefined spatial arrangements is done every day in the design of office layouts. Standard practice in interior office architecture is to identify different types of workstations associated with different job classifications, such as different grades of administrative assistants, managers, accountants, etc. For each job classification, needs analysis is used to derive a standard workstation configuration, defined as a block or template. The configuration components are then mapped to specific products. The workstations are laid out in alternative compositions, sometimes based on extensive analysis of workflows and social issues and provide the basis for ordering the office equipment.<sup>17</sup> This process has become relatively fast and error-proof.

Parametric modeling BIM design tools allow great expansion on the interior architecture workstation concept. They have been actively recognized for having these capabilities by franchises, who adapt a standard design of parts of or whole buildings to variable contexts. As reported in an Autodesk 2004 press release: "CASCO, a full-service architecture/engineering firm serving major national and international retail clients, including Bed Bath & Beyond, Toys 'R Us, Circuit City, and PETsMart, uses both Revit and Buzzsaw for design of store prototypes and their rapid adaptation for multi-state roll-outs." This is a classic use of parametric modeling. CASCO and the other franchises develop standard design families, not as a fixed layout, but rather as a set of elements and compositional rules. The family immediately adapts to

different contextual settings, but guarantees that the design is complete and satisfies required rules and relations.

Such capabilities also open up the possibility for design firms or sophisticated users to develop parametric models of different space uses that have a level of refinement, analyses, and detailing that are not possible within standard design practice. There is already active discussion for the development of such parametric objects for Emergency Room (ER) layout, intensive care wards, and operating suites in hospital design. Similar discussions have been held for federal courtroom design. This use of parametric modeling is a classic example of "knowledge capture" in software, allowing the combined expertise of individuals to be integrated and encapsulated into a design tool. This approach to developing corporate expertise has already become important in aerospace and high-end manufacturing.<sup>18</sup> I expect it to also be significant in architecture, and will be a continuing research activity to the field.

<sup>17</sup> Francis Duffy, P. Hannay, eds., *The Changing Workplace*, London: Phaidon Press, 1997

<sup>18</sup> Satyandra K. Gupta, W.C. Regli, and D.S. Nau, "Integrating DFM with CAD through design critiquing," in *Concurrent Engineering: Research and Applications* 2, 1994

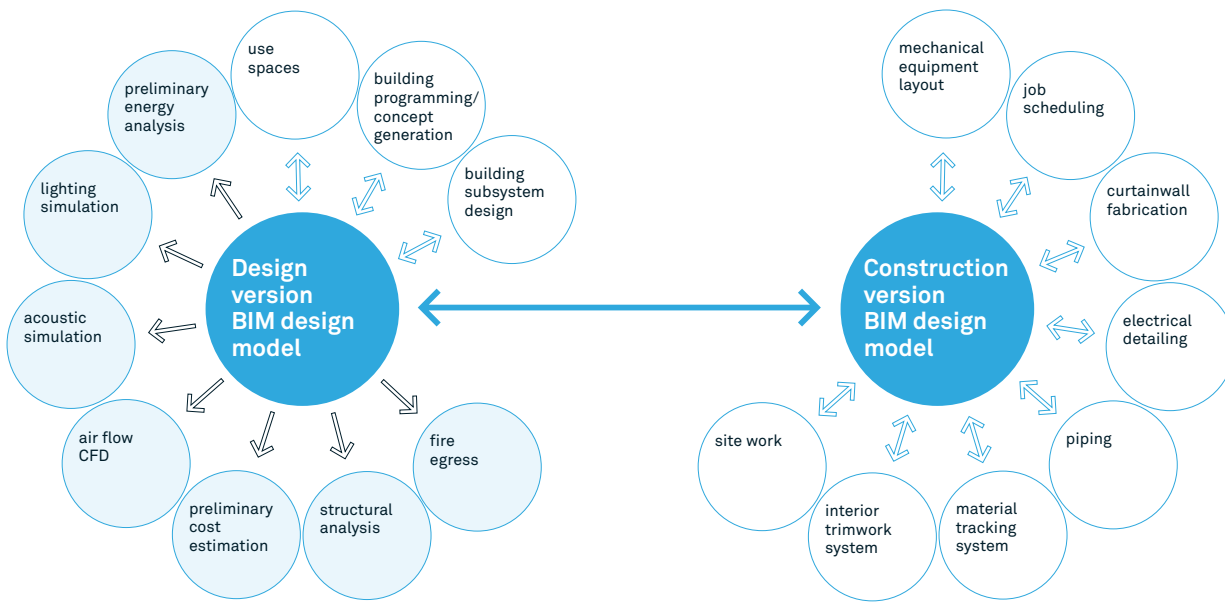
An important result of modeling all the construction systems in a building is that coordination among the different building trades becomes much simpler than it is currently. Many building systems are laid out only approximately in drawings and are finalized later, on site during construction. This requires all trades to inspect the on-site layout because the drawings are unreliable, and usually also to fabricate on site the components to be installed. 3D models of all subsystems changes this situation. Subcontractors can define 3D models of their subsystem knowing the layout of the others, then check them, via web-coordination, as they proceed. Not only can subcontractors plan effectively and determine all system elements needed, they can also prefabricate many of the parts into assemblies, taking advantage of automation that can be carried out in shops but not on-site. On-site work is then much quicker, with greater quality control. Mechanical systems have been found to be fabricated and installed with large savings as a result of 3D modeling and component prefabrication and assembly.<sup>19</sup> The goal is to fix the design before construction, which has been identified as a requirement of Design-for-Manufacturing.<sup>20</sup> The broader implication is that the current productivity gap between construction and manufacturing can be greatly reduced.

<sup>19</sup> T. Sawyer, "Soaring into the Virtual World – Build It First Digitally," in *Engineering News Record*, (October 10, 2005)

<sup>20</sup> Stephen Fox, L. Marsh and G. Cockerham, "Design for manufacture: a strategy for successful application to buildings," *Construction Management and Economics* 19 (2001): 493–502

Component-based construction may lead to new forms of signature design. I will not be surprised to see "signature" component designs for kitchens and bathrooms "the Julia Child Kitchen," the "Brittany Spears Necessarium", the George Lucas Home Theater, or other high-end consumer spaces. These may be made of fixed size or defined with parametrically varying external interfaces. This suggests future research on the development of connections and joints that support increasingly complex forms of prefabrication.

The benefits of building information modeling begin with a machine readable integrated 3D model of a building project. Machine readability means that the design or construction information may be extracted or interfaced with many other applications. A few of these are shown in [Figure 4](#).



**Figure 4** Some of the applications that can be supported by interoperability using BIM technology. Applications that allow creating and editing the design are denoted with a large blue circle, those that support detailing or editing within white circles, while analysis applications that are generally one-way flows are shown in light blue circles.

The potential to use analysis applications not as an occasional check after design, but to rely on multiple analyses and simulations throughout to inform design becomes practical. This also applies to cost estimation and scheduling. The ability to assess a design, both quantitatively and qualitatively, at a level and comprehensiveness impractical today, and to open the door to a broad range of new analyses and assessment tools. This is not to suggest that analyses will become the drivers of design, any more than cheapness and speed are today. It rather means that the level of expertise and competence embedded in the design can be at a much higher level than is currently practical.

Data exchanges between two applications can be carried out in several ways, using direct, proprietary links between specific BIM design tools; and using public data exchange formats. Direct links use middle-ware software interfacing standards, such as ODBC or COM, or proprietary interfaces, such as ArchiCad's GDL or Bentley's MDL, which make portions

of the building model accessible for application development. The public level interface involves using an open-standard building model, of which the IFC (Industry Foundation Classes)<sup>21</sup> or CIS/2 for steel<sup>22</sup> are the principle options. Software companies quite reasonably prefer to provide exchanges to specific other companies, because they can support them easier, and it keeps customers from using competitor's applications. On the other hand, users like to "mix-and-match" applications to provide functionality beyond what can be offered by any single software vendor. Interoperability is critical for projects involving large teams, because gaining interoperability of the different systems used by the team is easier than moving all team firms to a single platform. The public sector also wishes to avoid a proprietary solution that gives any one software platform a monopoly. Thus the IFC data model is likely to become a true international standard for data exchange and integration within the building construction industries.

<sup>21</sup> Thomas Liebich, ed., *Industry Foundation Classes IFC2x Edition 2 Model Implementation Guide Version 1.6* (2003)

<sup>22</sup> Andrew Crowley and A. Watson, *CIMsteel Integration Standards, Release Two*, 5 Volumes, [Implementation Guide], Steel Construction Institute and Leeds University, 2000

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The Industry Foundation Classes (IFC) is an international, public-domain standard managed by the International Alliance for Interoperability (IAI), made up of a consortium of industry firms worldwide.<sup>23</sup> The IFC uses the technology of ISO-STEP 10303,<sup>24</sup> the international product modeling standard used in manufacturing and defense industries.

The STEP technology uses a product modeling schema language called EXPRESS, and a set of standard libraries, called Integrated Resources. The IFC is an object-based extensible data schema defined in EXPRESS for the definition of buildings and their components.<sup>25</sup> It provides both a set of data models with which to exchange data, and a set of abstract constructs to extend the current capabilities. IFC undergoes progressive development over time, adding information to support specific workflows. A listing of current projects is maintained on the International IFC website.<sup>26</sup>

IFC defines a neutral data format comprised of a set of data objects. BIM applications selectively define a subset of data objects they want to receive (import) or pass to others (export) for a specified task, for translation to/from the application's native data structure. Most typically, data is exchanged in IFC using a text file format that is part of STEP, called a Part-21 file. The result is a more sophisticated DXF-type of exchange between two applications. XML is another optional IFC exchange format. In the same way that exporting a DXF file to another application that then may modify the data and send it back, the resulting read back data just adds to the existing data, duplicating the exchanged data. More intelligent methods are required to support collaborative data exchange. IFC data carries IDs, called GUIDs (Globally Unique Identifiers) that are unique nametags that

can be used by applications to track versions of data and manage updates and merges, regardless of the application or user that generated the data. However, the use of GUIDs means that each IFC application must be able to carry the GUIDs it receives from other applications when it imports data, then export the GUID with the data it is associated with. Such behavior is required of IFC-compliant applications. However, it is not always implemented.

<sup>23</sup> See <http://www.iai-international.org/index.html> accessed March 31, 2006

<sup>24</sup> See [http://www.tc184-sc4.org/SC4\\_Open/SC4\\_Work\\_Products\\_Documents/STEP\\_\(10303\)/](http://www.tc184-sc4.org/SC4_Open/SC4_Work_Products_Documents/STEP_(10303)/) accessed March 31, 2006

<sup>25</sup> C.M. Eastman, *Building Product Models*, Boca Raton, FL: CRC Press, 1999

<sup>26</sup> See <http://www.iai-international.org/Projects/ExtensionProjects.html> accessed March 31, 2006

Production use of IFC has begun with file level exchange, but very soon IFC will need to be supported by a building model repository – a database. An IFC repository can carry the accumulated design information generated by multiple applications, maintaining the data's various geometrical, material, and performance relationships. There is intense development to realize effective tools for such building model repositories, dealing with easy-to-use interfaces, change management, interface tools, among others.<sup>27, 28, 29, 30</sup>

This work is needed for the potential benefits of building model repositories to be realized.

<sup>27</sup> See <http://www.epmtech.jotne.com/products/edmserver.html> accessed March 31, 2006

<sup>28</sup> Seok-Joon You, D. Yang, and C.M. Eastman, "Relational DB Implementation of STEP based product model, CIB T6S7 Information technology in construction," CIB International Congress, Toronto, W78 (May 5–7, 2004)

<sup>29</sup> Q.Z. Yang, "IFC-compliant design information modeling and sharing," in *ITcon Information Technology in Construction*, Vol. 8 (2003): 1–14; see <http://www.itcon.org/2003/1> accessed March 31, 2006

<sup>30</sup> See <http://www.blis-project.org/~sable/> accessed March 31, 2006

<sup>31</sup> See <http://www.iai.no/idm/index.html> accessed March 31, 2006

<sup>32</sup> Facilities Information Council, *Charter for the National Building Information Model (BIM) Standard*, National Institute of Building Sciences (December 15, 2005)

Effective data exchange supports a work process needed to accomplish some task. Embedded in the work process is one or a series of interrelated data exchanges dealing with specific types of information content. A very simple example involving only two applications is shown in Figure 5. It diagrams a typical roundtrip flow between an analysis application and a BIM design application. It begins with the extraction of needed data from the BIM design tool to the analysis application. The importing analysis adds to the dataset environmental conditions, needed object properties (for that type of analysis), loading conditions and test assumptions, and other information not carried by the BIM design tool. The analysis is executed and the results reviewed and possibly changed, allowing multiple iterative analysis runs, exploring how to achieve better results. Eventually, the results are passed back to the originating application, with possible modifications to the design, and the analysis results showing the performance of the most recent design. It involves at least two exchanges with the BIM design tool. Often, it is desired to retain the intermediate trial runs for later review.

The identification of workflows for specific types of analyses, along with the contents of such flows, using the IFC data model as a base, is a major line of work being undertaken in Europe, as they seek to move IFC-based models into widespread use. The Building Smart initiative by Norway proposes to develop and use the Information Delivery Manual process, using IFC Views.<sup>31</sup> This approach is also being considered by the U.S. National BIM Standard initiative, led by the Federal Infrastructure Council.<sup>32</sup> Currently, analysis interfaces for structural analysis have been developed for a number of BIM design tools. However, for other analyses, such as energy, cost estimation, lighting, air flow, and

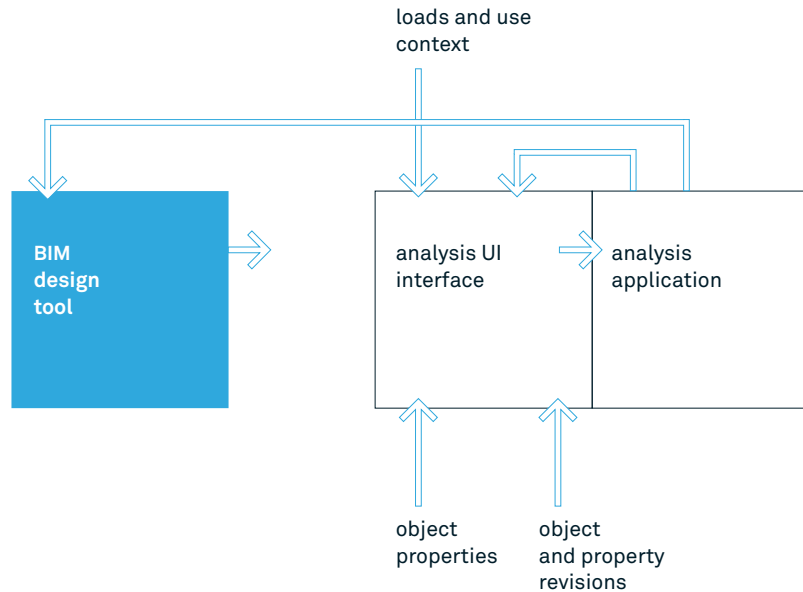


Figure 5 Typical workflow for the roundtrip between a BIM design tool and an analysis application.

mechanical equipment simulation, much more work is required to make the workflows effective. The development of Views (or similar construct with a well specified workflow process and set of IFC data) will engage researchers for the next few years, making the exchange capabilities with BIM tools truly production quality.

The IFC building model works, and after 10 years is receiving broad acceptance as the only publicly accessible non-proprietary building model standard world-wide. However, it is complex to use and is open for multiple interpretations of use. It is not inherently reliable. While it provides means to capture any type of data, it also provides multiple ways to define data. Thus two legal IFC implementations may not write and read a meaningful dataset, requiring side agreements and conventions of “best use.” IFC Views will greatly reduce this problem, but not eliminate it. Humans avoid such ambiguity issues in conversation, acknowledging that people may use the same word in different ways, or that different words mean the same thing. They infer how the other person is using his or her terms, and adjust the vocabulary

accordingly. This path is being followed in the Semantic Web, which uses inference and ontologies to identify information equivalences in web data. This approach is expected to eventually lead to a new generation of IFC-like models in a decade or so.<sup>33, 34</sup> It is expected to eventually lead to robust plug-and-play integration and automatic interfacing of applications.

<sup>33</sup> Peter Katranuschkov, R. Scherer and Z. Turk, “Intelligent services and tools for concurrent engineering: An approach towards the next generation of collaboration platforms,” in *ITcon Information Technology in Construction*, Vol. 6 [Special Issue Information and Communication Technology Advances in the European Construction Industry] (2001): 111–128; see <http://www.itcon.org/2001/9> accessed March 31, 2006

<sup>34</sup> C. Lima, T El-Diraby, and J. Stephens, “Ontology-based optimisation of knowledge management in e-Construction,” *ITcon Information Technology in Construction*, Vol. 10 (2005): 305–327; see <http://www.itcon.org/2005/21> accessed March 31, 2006

### 3.4/ New analyses and simulations to inform designing

The availability of a standard representation for building models in IFC format will facilitate the development of a very broad range of new assessment and simulation software to inform designing. A partial listing of research papers presented at the 2005 Building Futures Council Conference on the Future of the Construction Industry provide one indication of new application directions. Students from Stanford outlined development of a sophisticated pedestrian simulation modeler;<sup>35</sup> Hans Verheij developed an on-line negotiating and planning tool to work out contractual arrangements among worldwide partners;<sup>36</sup> Tanyel Turkaslan outlined an embedded building commissioning model using IFC;<sup>37</sup> and Elif Yagmur described an interactive cost estimating and scheduling system for use in preliminary design.<sup>38</sup>

<sup>35</sup> X. Pan, C.S. Han, K. Dauber, K. Law, "Human and Social behavior in Computational Modeling and Analysis of Egress," in Proceedings, *BFC Conference on the Future of the AEC Industry*, Building Futures Council, Las Vegas, NV (March 16–17, 2005): 189–204

<sup>36</sup> Hans Verheij, "Collaborative Planning of AEC Projects and Partnerships," in Proceedings, *BFC Conference*: 167–177

<sup>37</sup> Tanyel Turkaslan and O. Akin, "Computational Support for Building Evaluation: Embedded Commissioning Model," in Proceedings, *BFC Conference*: 178–188

<sup>38</sup> Elif Yagmur and C.M. Eastman, "Automated Construction Scheduling & Cost Estimation for Designers," in Proceedings, *BFC Conference*: 27–40

### 3.5/ Design assessment tools

Another similar line of new applications will be design assessment tools. The most important type of design assessment tool is building code checking. The availability of a standard-format, machine-readable description of any building opens the door to put code checking on-line and make it web-accessible. Major efforts have been initiated by the Singapore Government to provide such services, under the name CORENET.<sup>39</sup> Recently, similar efforts have been initiated by the Norwegian government<sup>40</sup> and also by Denmark.<sup>41</sup>

In the broader picture, much design information is not mandatory, but rather defined as "best practice" or knowledge-learned. Architectural firms and school libraries are filled with building type and construction type guidebooks. The information model for the use of these books is that they are read by an individual, who will then figure out how to apply the knowledge to a design project. While this assimilation approach has positive aspects, many times the goal is not creativity, but rather direction-giving. Design guides or programs are given for most projects by the client. In the next decade, I expect to see mass re-structuring of design guides from a book-based information source, only usable by people, to a computer and person-based technology, allowing partial and interactive implementation.

<sup>39</sup> See <http://www.corenet.gov.sg/> accessed March 31, 2006

<sup>40</sup> See [http://www.iai.no/nor\\_iai\\_projects.htm](http://www.iai.no/nor_iai_projects.htm) accessed March 31, 2006

<sup>41</sup> See <http://www.detdigitalebyggeri.dk/english/0/10> accessed March 31, 2006

There are several major issues associated with building assessment, whether it be for codes or other purposes:

- Current efforts at code checking and other assessment tools are based on ad hoc computational procedures of such issues as circulation distances, area calculations based on specific definitions, head clearances, and circulation space widths. Without the careful development of robust algorithms, these computations will inevitably fail in some cases. We need carefully developed libraries of building geometry algorithms to implement such work.
- Both the analysis applications and design assessment tools that will use BIM require an expanded definition of building object properties and functional definitions based on building classification system. In the US, these are Uniformat® and Masterformat®. It is unclear at this time if these building classification systems are robust enough to support this new layer of usage.
- Assessment requires some mixture of explicit definition of conditions in the building model and inferring other aspects through computation. The balance of these two means of information generation must be worked out for various classes of issues, which become paradigms for other assessments dealing with similar building properties.

Each of these issues outlines areas of much needed research.

Until this time, architecture as a field has not had or supported its own knowledge-generation and research base. CAD systems, materials, and testing methods have been adopted from other fields. Even the current development of BIM was adapted from mechanical parametric modeling systems. The unique contribution of building parametric objects—walls, floors, ceilings, doors, windows, stairs, and now more complex elements such as building skins, structural systems, precast and cast-in-place concrete, the layout of mechanical and electrical systems—provide a core base of architectural knowledge. The extension of objects to include building space types—hospital ER and ICUs, and laboratories—capture uniquely architectural knowledge. The definition and behavior of these base objects, more so than their implementation, are an important kernel of architectural knowledge that should be controlled by the profession, not by software companies.

Architecture's emphasis on qualitative knowledge resulted in non-involvement in the first generation of design science, which was based on quantification and applied physics. We are now embarking on a second generation of design science that will address the qualitative aspects of design. This presents to the architecture profession the opportunity to develop a knowledge and research base, not unlike other professions. I have focused on relatively short-term issues, where IT infrastructure development has or should be undertaken by university research centers. The research I propose here supports the transition to building information modeling. Together, architectural firms and university research centers can develop strong bonds that advance the knowledge and capabilities supporting design and construction.







## Report on integrated practice

### 0 Preface

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### Introduction

Norman Strong FAIA  
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### Architectural education and practice on the verge

Daniel S. Friedman FAIA  
School of Architecture, University of Illinois  
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### 1 Change or perish

Thom Mayne FAIA  
Morphosis, Santa Monica, CA

### 2 University and industry research in support of BIM

Chuck Eastman  
Georgia Institute of Technology

### 3 Changing business models

James O. Jonassen FAIA MRAIC  
NBBJ, Seattle, WA

### 4 Roadmap for integration

Laura Lesniewski AIA and Eddy Krygiel AIA  
with Bob Berkebile FAIA  
BNIM Architects, Kansas City, MO

### 5 Suggestions for an integrative education

Renée Cheng AIA  
University of Minnesota

### 6 The Twenty-first century practitioner

Kimon G. Onuma AIA  
Onuma & Associates, Tokyo and Pasadena, CA

### 7 Applications in engineering

Joseph Burns PE SE FAIA  
Thornton-Tomasetti Group, Chicago, IL

### 8 Technology, process, improvement, and culture change

Jim Bedrick FAIA  
Webcor Builders, San Mateo, CA  
Tony Rinella, Associate AIA  
Anshen+Allen Architects, San Francisco, CA

### 9 International developments

Ian Howell  
Newforma, Inc., Manchester, NH

### 10 Information for the facility life cycle

Kristine K. Fallon FAIA  
Kristine Fallon Associates, Inc., Chicago IL  
Steven R. Hagan FAIA  
U.S. General Services Administration, Washington, D.C.

### 11 Construction industry perspectives: a conversation (DVD)

Norman Strong FAIA  
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David Mortenson and Greg Knutson,  
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