A THOUSAND BIM

A rapid value-simulation approach to developing a BIM tool for supporting collaboration during schematic design

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Abstract. A typical architectural design project proceeds as collaboration among professionals who have different expertise, values and priorities. The collaboration is needed to make designs both rich yet feasible, but the professionally different ways of thinking can also be a block on the way of design development. This paper takes the example of the relationship between developers and architects, who tend to have different evaluation criteria, methods, and processes. A BIM-based tool, A Thousand BIM, is introduced as a means to quickly generate possible building typologies on a given project site, with computation of expected total values expressed in simple financial terms. Its aim is to help a group of heterogeneous professionals to communicate in the same language, articulate criteria and priorities in multiple perspectives, and share rapidly simulated evaluations of schematic design variations. The implemented evaluation process considers construction cost per square foot, land value, and sustainability as well as other soft design values such as views and accessibility. It can take various market data as inputs to cost calculation, and the weight to each of the design values is dynamically adjustable. A professional can explicitly set them, and share the criteria, priorities, and results of value simulations with others in an enhanced collaborative process.

Keywords. BIM; pro-forma; design collaboration; value simulation.

1. Backgrounds

There are many barriers that block collaboration among professionals in the building and design industries. A quintessential barrier may not be a physical or technological one; rather it may be epistemological (Turkle and Papert, 1990). The different ways of thinking that professionals have may make them reluctant to join
in design collaborations (Root et al., 1999; Holzer, 2009). During the design process, multi-disciplinary professionals may have different evaluation criteria, and understanding these differences is the key to a successful collaboration.

Architecture, engineering, and construction (A/E/C) industries have studied how to improve design collaborations for many years. Researchers developed virtual and physical platforms for a collaborative environment (Wang and Dunston, 2008; Rosenman et al., 2007). Improving communications by utilizing wireless and IT technology is accepted as an important factor in maintaining the quality of collaboration (Zurita et al., 2008). Providing shareable data format and online-storage is highlighted while building information modeling (BIM) technology is spreading widely (Cerovsek 2011; Azhar, 2011). Although professionals accept the significance of human aspects in collaborations, there are few studies on this subject (Arias et al., 2000; Xue et al., 2012; Singh et al., 2011).

Instead of understanding a value as an objective or universal measure, a human understands a value in relation to his profession, culture, or beliefs (Berger and Luckmann, 1967; Deleuze and Guattari, 1987; Fideler, 2000). Value is not measured; rather, it may be created in a thousand different ways by who measures it (Deleuze, 2006). In pondering a true value, it is more important to understand how humans create it than what the value is. A single design could be measured in various ways and have multiple values simultaneously. The value of a design can be fully understood only when multiple perspectives from various professionals are considered. Architects may evaluate a design from the balance between its forms and functions; developers may prioritize its financial values, such as net operating income or the land’s residual value; and end-users may consider the maintenance cost or the flexibility of space. In a conventional design project, it usually takes tremendous time to evaluate a design proposal through involvement of different professionals and form an aggregate judgement. Advanced building information modelling tools today present a new potential to alleviate this situation.

2. Extending BIM for Enhanced Collaboration

Use of BIM contributes to improved productivity of both the design and construction phases in many respects. BIM supports fast changes of design by providing parametric tools and component libraries. These tools reduce laborious reworking processes that are inevitable with conventional CAD tools. Likewise the use of intelligent, information-rich components in BIM makes it easy to check collisions of elements, construction errors, and any omissions in documents, and helps to identify many problems during the early design phase. Also, BIM’s cost calculation tool, such as material take-off, allows designers to develop a scheme with a financially reasonable strategy. These benefits of using BIM combined with
the simulation and evaluation of building performance such as energy consumption and structure promise to improve the return on investment (Shelden, 2009).

On the other hand, this large load and variety of information that BIM proceeds to rapidly build and process for a design project can become the source of problems for its human participants. For instance, the use of BIM anticipates that designers will include such considerations as fabrication methods, construction costs, and programmatic valuations from the early design phase. Controlling, keeping track of, and paying attention to each one of them throughout the development is a cognitive process different from a traditional one, where an initially sketched form is gradually elaborated with more information accumulated at each step of the way. The situation can become more difficult to comprehend when each of multiple professionals in a project simultaneously and independently generates project details, simulations, and evaluations from a different professional perspective. Producing a large amount of information does not always help unless there is a comprehensive way to grasp the totality of the project and to allow participants to understand and appreciate information across the professional boundaries.

This paper introduces a tool that is intended to enhance collaboration among a group of heterogeneous professionals by helping them to communicate in the same language, articulate criteria and priorities from multiple perspectives, and share simulated evaluations of schematic design variations. The proposed tool, A Thousand BIM, takes advantage of the versatile power of BIM, and extends it to accommodate epistemological pluralism and cross-disciplinary interactions. The tool quickly computes and generates possible building typologies on a given project site with visualization of expected total values in financial terms. For instance, it automates the process of computing a pro-forma financial statement for architects and developers during the design process, and helps them to quickly decide whether a proposed project is worth investigating.

3. Implementation of A Thousand BIM

The system is composed of four modules: data feeder, form generator, analysis visualizer, and financial evaluator. The overall workflow follows Mitchell’s (1977) genetic algorithm in architectural design, which is composed of form generation, evaluation, and selection.

The first module (the data feeder in Figure 1) imports an XML document with basic project information such as location, construction cost per square foot, site, climate, energy cost, urban context, and market statistics, which become the basis for calculating the land’s residual value and net operating income. The data can be obtained by collecting information manually or purchasing a service from real-estate market data providers.
Then a user makes selections from basic typologies of plan such as Cube-shaped, L-shaped, I-shaped, and O-shaped ones, and specifies gross floor area, maximum building height, and land-to-building ratio. The form generator (module 2 in Figure 1) produces variations of buildings that satisfy the required architectural program as well as their mutated forms that are random combinations of two plan typologies (Figure 2). Then the building form is subdivided into small space units called rooms.

The key component of this system is the analysis visualizer (module 3 in Figure 1). For each room, the tool computes the weighted score of each design value such as view, accessibility, sustainability, ceiling height, daylight, temperature, ventilation, parking proximity, and loading convenience, and adds them up. It then shows the pattern of aggregated room values distributed over the whole building. This process accounts for rooms with good view that many hotels near tourist attractions would charge higher, and rooms with easy access and sustainable features that clients of laboratories are willing to pay additional to rent. Accordingly, the tool assigns those desirable rooms with suitable functions while interpreting other rooms as space for circulation and services.

This module implements an artificial neural network algorithm inspired by the self-organizing map (Kohonen, 1990). It is a computational model of biological
neural networks composed of an input layer, intermediate layers, and an output layer. The input layer accepts initial data and passes them to implicit intermediate layers. Their initial values are manipulated there, reconstructed into new values, and summed up to become the total value of an output node (Figure 3).

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\text{WeightedScore}_{\text{DesignParameter}} = \text{NormalizedScore}_{\text{DesignParameter}} \times \text{InputWeight}_{\text{DesignParameter}}
\]
At the beginning, each score of design values such as views and accessibility is calculated through a simple algorithm that utilizes the distance between a room’s location and surrounding urban elements such as nearby buildings and landmarks (Figure 4). Resulting scores are stored as metadata attached to the room and become the input of a neural network algorithm. The process then goes through two intermediate layers of computation. In its first layer, attribute scores are normalized and multiplied by corresponding input weight specified by a user. Then in the second layer, the results are summed up to be the value of a room.

Finally, in the financial evaluator in Figure 1, these room-values of a building are summed and added to the land’s residual value. This total value represents a design judgement expressed in financial terms, and is the result of a single epoch of one professional’s value simulation. The simulation process can be repeated by the same person as well as by different professionals in a collaborative project. The criteria and priorities adjusted for repeated simulations are transparent and accessible to all participants to share, open up one professional’s judgement process to others, and let the participants see possibilities beyond what is usually excluded by their own professional cultures. Various professionals gain opportunities to learn each other.

Figure 4. Results of space analysis and their visualized patterns for individual design values (sustainability, accessibility, landmark, day lighting, view), as well as for their weighted sets (wet-lab, dry-lab, mixed-use lab). A grayscale value corresponds to the fitness level of a room for an attribute. The dark gray area is where the room fits well for a selected attribute.
4. Application Example

To illustrate the potentials and limitations of the tool, a comparative study with an existing building project is conducted. The selected project is a 278,000-square-foot research laboratory. One of its main design strategies is energy optimization using a varying facade design that balances solar heat gain in winter and shading in summer while preserving views. Another is the central void space that supports retail units on the ground and works as a center of collaborative activities (Figure 5, left).

Using the same site and context as the existing building, three simulations for a simple box form (building typology for the Cube-shaped) with differently weighted sets of design values for a dry-lab, wet-lab, and mixed-use lab were conducted. A dry-lab, such as a computer lab and office space, usually requires high-level parameters for design values of view and daylight. A wet-lab, such as a chemical lab, has relatively high operation cost and material traffic, and requires high-level parameters for the design values of sustainability, loading convenience, temperature and ventilation. Parameters for a mixed-use lab are set between these two laboratory settings.

The comparative study shows coincidence between the actual building design and a simulation result with the dry-lab design value setting. As shown in the right image of Figure 5, the tool identifies the locations suitable for lab spaces near the building perimeters and at its high floors (the dark gray areas in Figure 5). It also identifies the ground floor and the central area of the building as the supporting area, including the common space and circulation (the light gray areas in Figure 5). In comparison, the existing building has a retail space on the ground floor, atrium in the center, and laboratory and office space on building perimeters. Thus the simulation indicates that the designers considered their main target clients as dry-lab users such as large IT companies and start-ups, as other buildings do near this building site. In contrast, if we use the wet-lab design value setting, the tool

![Figure 5. The sectional diagram of the existing research lab (left) and the pattern analysis of a Cube-shaped form with design value setting for dry-lab (right). This building in Cambridge, Massachusetts, was designed by CO Architects of Los Angeles and constructed in 2009.](image-url)
identifies the appropriate locations of the laboratory space on low floors and in the central space of the building, and all other supporting areas on high floors and near building perimeters (Figure 6, right). Or the use of the design value setting for a mixed-use lab would result differently in a cluster of wet-lab spaces on the first two floors, dry-lab space distributed on high floors near the south facade and nearby landmarks, and the retail and circulation space relocated around the building perimeters, as shown in the left image of Figure 6.

If the architect and the developer had used this tool during the early design stage, they could have quickly compared the suitable room layouts and their total financial values for those three alternative settings, dry-lab, wet-lab or mixed-use lab. Weights of some of those design values, such as view may be further fine-tuned to reflect each professional’s perspective in the successive iterations of value simulation. Other possible applications include comparisons between different building typologies on the same site, or even comparisons between projects at different candidate locations.

5. Conclusion

A Thousand BIM generates various building typologies and computes their values expressed in financial terms that are based on user-selected and –weighed evaluation parameters. This process of value simulation requires heavy information processing. The combined use of efficient computational algorithms and the framework of the robust BIM environment have demonstrated a potential to deliver a practical solution with sufficiently rapid execution.

This tool is intended to promote collaborations among multi-disciplinary professionals who have different expertise, values, and priorities. For instance, typical design collaboration between an architect and a developer entails a sequential process in which the developer gets a chance to evaluate design feasibility only after a spatial design is proposed by the architect. The architect then may update the initial design after the developer gives feedbacks. Throughout, the process and
rationale of one professional tends to stay opaque to the other professional, cognitive barriers may engender reluctance of participants, and a respect for difference may give way to suspicion.

The proposed tool is expected to combine such design/evaluation iterations into a more integrated and rapid concurrent process. Using the tool allows any participant of a project to explore options for varied architectural forms and programs, and access the results of value simulation with rapid feedback. The criteria and priorities in the evaluation process are transparent and accessible for all participants of a team. This lets participants open up the professional processes to others, and see possibilities of judgement beyond the usual bounds of their own professional cultures. This kind of tool also should be helpful for an individual designer to keep a grip on the valuation of evolving design that goes through countless changes and elaborations from an initial schematic state.

The study presented here has been fashioned so as to set up a laboratory test, and several future extensions are immediately identified. This implementation is confined to the use of a limited, fixed number of kinds of design values such as land value, sustainability, view and accessibility. Since architectural design projects typically deploy a variety of other controlling design values such as openness, privacy, security, maintenance, construction duration, and many more, development of a flexible, open-ended system is worth exploring to allow professionals in order to add and compute with a contingent set of diverse design values. Algorithmic development for computing each of those is a challenge. Also, additional end-user studies are necessary to illuminate how such a tool actually is exploited by professionals other than architects and developers, and affects on their collaboration. This leads to research on identifying effective interfaces, monitoring end-user experience, and measuring end-user performance. While the current tool is calibrated to a building design for commercial property with spatial units such as hotel, office, rental lab, and apartments, consideration of other types such as institutional buildings and houses is critical in understanding the potentials and the limitations of this approach.

In summary, the main contributions of this study include: 1) introduction of a novel platform tool that lets each participant explicitly set criteria and priorities of a design project, automates generation of schematic design variations, and performs value simulation as feedback to the participant, and 2) demonstration of implementing efficient computational algorithms for the typological design generation and the value simulation process in the context of architectural design.

Combined, they form a strategy for enhanced collaborations among different professionals in a multi-disciplinary design project. Time-consuming, reluctant, and opaque multi-stage collaboration can be transformed into a rapidly shared, transparent, and concurrent process of willing participants.
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