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# White Paper: Design of a Parametric, Conceptual Design Environment for Building Information Modeling (BIM) Software Application

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**Abstract**

This case study addresses the design research methodologies behind the making of a parametric, conceptual modeling design environment in an existing Building Information Modeling (BIM) platform. The challenge was to build a fully associative and parametric 3D modeler where geometry is created, manipulated, and parameterized in a manner approachable by a larger audience of architects and designers. A team of interaction designers, user researchers, domain experts and software developers created these new tools in an effort to make the creation and rationalization of range of building forms accessible to a wide array of end users.

Specifically, this case study looks at design research methods used to understand user requirements about conceptual design workflows, and how the end result addressed these requirements. The case study also addresses the value of creating simplified user interfaces for user testing of architectural software applications. By simplifying the interface, the team was able to solicit specific feedback about new tools and

workflows without the overhead or pre-conceptions associated with using an existing software platform. Finally, the case study presents some of the successes and failures, the lessons learned from applying new design research and development methods, as well as the final results of the project.

### **Keywords**

Conceptual design, architecture, user research, scenarios, storyboards

### **ACM Classification Keywords**

Design

### **Introduction**

The design process in the Architecture, Engineering and Construction (AEC) is an intricate dance [1, 2] that involves multiple parties including owners, architects, builders, engineers, tenants, and the public at large. The design process is complex and often involves large, sometimes geographically distributed teams. Depending on the complexity and scale of the project, design teams work together for months or even years<sup>1</sup>. The work is usually divided into clearly defined phases [3, 4] that include pre-design, conceptual design,

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<sup>1</sup> For example, a user research visit to a large international office in Northern Europe revealed that several of its top designers worked on the façade of a single skyscraper for approximately two years. This lengthy process is not an isolated case. Our team found out that similar happened in many other firms specializing in complex, international large scale projects. The lengthy process is due to the fact that number of complex requirements and constraints needed to be met and resolved, including overall building form, sustainability regulations, client requests, city regulations, finances, material issues, etc., during different stages of the projects.

design development, construction documentation and construction administration.

A major portion of the conceptual design phase is dedicated to early geometry explorations and analysis, and design iterations. While much of this phase revolves around aesthetics and definition of the geometric form, designers also need the ability to analyze area, volume, materiality, and energy performance of the architectural form to better understand how the future building will perform. As designs become more geometrically complex, it becomes necessary to “rationalize”<sup>2</sup> the form by breaking down abstract geometric shapes into buildable components, to analyze the cost and constructability of the design. Once the conceptual design exploration is completed, design information needs to move downstream into the construction documentation phase of the project. In typical workflows, the conceptual model information loses fidelity as the model progresses into design development. Furthermore, maintaining a bi-directional relationship between the conceptual model and the more detailed construction model has been a thorny issue.

The software on top of which this parametric, conceptual design application was built is a Building Information Modeling (BIM) platform with an integrated database that provides bi-directional parametric associations between elements. The software also

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<sup>2</sup> To “rationalize” a surface or a form is a term used in conceptual design phases of architecture projects. To rationalize a surface means that a complex surfaces is broken down into buildable parts.

provides the ability to filter, schedule, quantify, and analyze elements in the model. Historically, the primary focus of this BIM application has been to create internally consistent and fully coordinated construction documentation. Conceptual modeling features were not available and users were using an array of different tools to create their conceptual model studies. The flow of information to and from a concept model into the BIM application was not seamless and often required custom scripts and convoluted, prescriptive work process. To address the earlier phases of design work, the design team built a working “proof-of-concept” prototype environment to test ideas, and then integrated this prototype environment into the BIM platform.

### Objectives and Goals

Usability testing and user feedback showed that form making and rationalization tools in the native BIM application were seen as insufficient for conceptual model studies [Good strong point to start.]. The overall objective of the “proof-of-concept” was to improve on the conceptual design workflows within a mature software application that has an extensive customer base and is primarily focused on later stages of design.

There were four project objectives:

1. Better understand the architects’ requirements in the conceptual design phases of architecture projects, specifically advanced form making and manipulation, form rationalization and exploration of design iterations. The design team focused their research on early adopters and visionaries. This research influenced the creation of requirements.

2. Translate these requirements into tangible designs and implementation specifications.
3. Develop a working research prototype that could be tested with a larger group of architects that shared similar design interests but were less proficient with crafting their own tools to iterate and improve on the designs.
4. Roll out subset of the developed prototypes in the existing BIM application, to augment the tool with workflows designed to support early conceptual design phases of projects.

The specific software goals of the project were to a) make 3D modeling robust and accessible to wide array of end users, b) drive geometry with parametric relationships, c) maintain a persistent relationship with the BIM model and d) create a single integrated design environment.

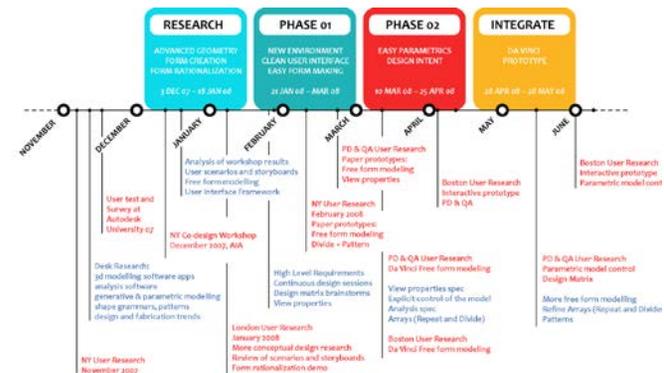


figure 1. Timeline and phases for the first 6 months of the project.

## Design Process

The time frame for the first part of the project was six months divided into four six-week stages (figure 1). Each stage had clearly set milestones and deliverables. The second six-month stage was dedicated to integration of a selected set of workflows into the native BIM application. The subsequent year of design and development was dedicated to further improving the designed workflows, and to further increasing the number of features in order to improve and close workflow gaps.

**The first project objective** was to better understand architects' needs in conceptual design phases of projects, specifically advanced form making and rationalization. The user research was initiated with 32 one-hour interviews with architects and engineers from six large and medium size architecture and engineering offices over a period of five days in November 2007. All interviewees were advanced users who worked on conceptual design phases of landmark projects [2]. Most of them frequently customized and developed their own software tools, and could be described to be working in a manner of "modernist transparency", a term coined by Sherry Turkle to describe users that gain access to the underlying mechanisms of a technology or a system to accomplish desired tasks [5, 6]. The goal of this focused research exercise was to ensure understanding of types of projects and conceptual design practices, to cluster types of tasks, identify terminology and collect information to develop personas. For example, while the design team started the interview process with the assumption that designers make a distinction between what is known in academia as generative and parametric design in their design process, a majority of interviewees stated that

they don't actively think about differences between the methods and fluently move from one into another.

Previous user research conducted within the company showed that architects often spend approximately 80% of their work day immersed within an architectural software 3D modeling environment. The sense of creative flow has been researched by Csikszentmihalyi who states that "[t]he experience of flow is critical to the designer's creativity. Self-consciousness disappears, sense of time becomes distorted" [7]. Non-encumbered use of software tools was identified as critical for supporting the designers' creative flow. The design team reviewed literature on architectural geometry [8] as well as BIM, Computer-Aided Design (CAD) and desktop publishing tools as well as gaming environments to better understand the nature of "creative flow" for range of different audiences.

GROUP B SCENARIO NAME THE WINDFARM & THE GOOSE TEAM MEMBERS

KEYWORDS  
SHIFT, MOVEMENT, CHANGE, LAYERS, ECOSYSTEM, ORGANISM

STEREOTYPICAL PERSON  
\*environmentalist  
developer  
\*designer

PROJECT S/M/L (OL)  
wind farm (mega farm)  
[visual issues, disruption of currents, noise, birds, electrical charge...]

ISSUES  
- factual data  
- dynamic analysis thru time  
- presentation of results

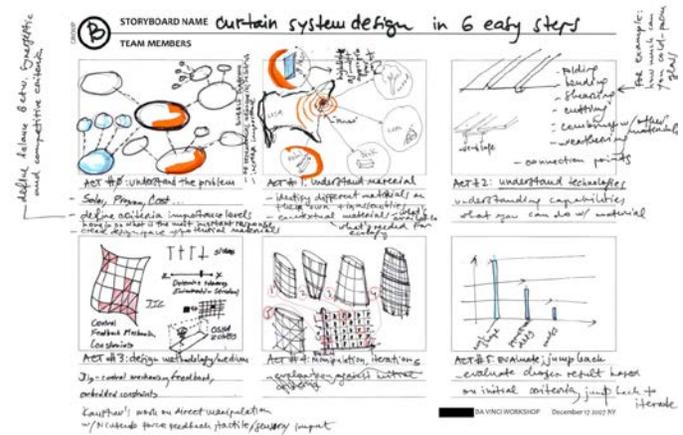
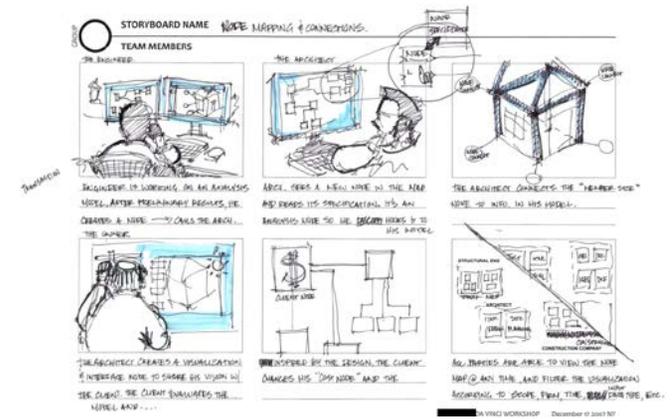
SCENARIO  
A newly proposed giant wind farm off the coast of Maine is in the migration path of the monarch geese, creating a windfall of concerns from environmentalists. The designers need to present evidence that the new development will not impose threat to the migrating geese and the ecosystem at large. They use an array of analysis methods to study issues such as flight patterns, altitude, landing locations, view, overall climate conditions, etc.

figure 2. A sample scenario written by workshop participants.

The next activity aimed at “unpacking” and better understanding conceptual design workflow was a day-long workshop with 20 architects. Many were previously interviewed and chosen not only because their work was at the cutting edge of their profession (e.g., sustainability, computation, fabrication, tool customization, etc), but also because they articulated problems in a way that provided guidance for the design team. The participants completed structured tasks and, together with the Autodesk design team, wrote scenarios (figure 2) and illustrated storyboards (figures 3 and 4) that described desired conceptual design workflows, either entirely new or typical for their daily practice. One of the participants referred to the early conceptual design phases of projects by making an analogy with jazz improvisation:

*In terms of designing software, how about being able to take a theme and be a little more free with it, the same way a jazz musician would take a theme and improvise with it.*

While this process is fairly standard in the human-computer interaction community [see 8, for example], the application of this process was an uncharted area in software design for the AEC industry.



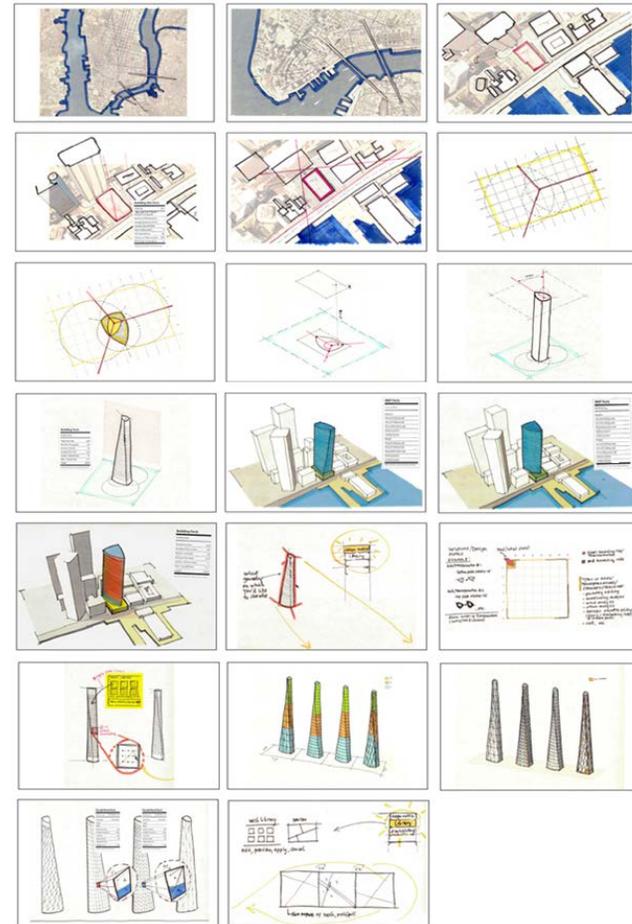
figures 3 and 4. Sample storyboards created by workshop participants.

**The second objective** was to translate requirements gathered in interviews and the workshop into tangible designs and implementation specifications. Creation of personas and detailed storyboards (figure 5) is a typical next phase for interaction designers. These activities anchor the work and enable drafting high level user requirements. The below images illustrate the process from getting initial building program and site information, to definition of constraints and relationships, early conceptual form explorations, and design iterations. Creating a conceptual modeling tool that is approachable by a larger audience required addressing all these issues.

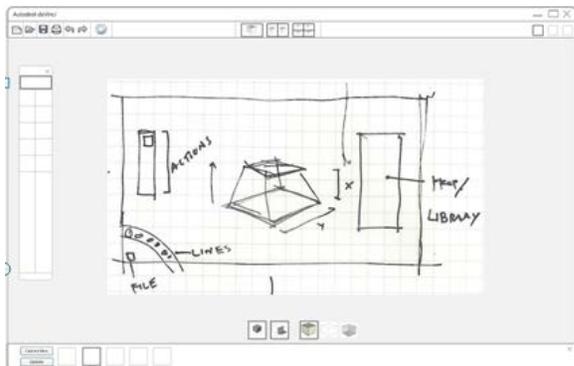
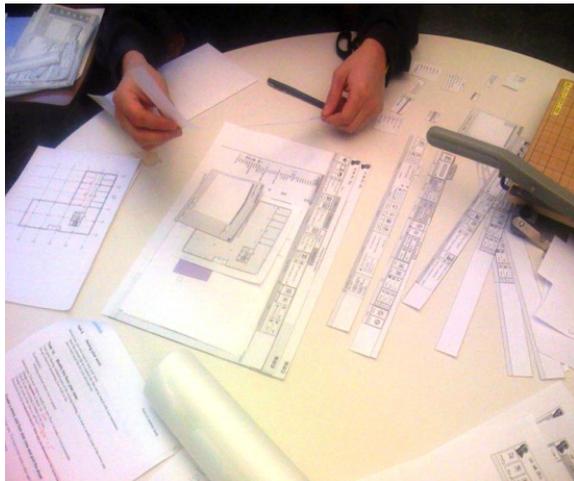
**The third objective** was to develop a working prototype that could be tested with end users. The team worked collaboratively with end-users to create low-fidelity, paper prototypes (figures 6 and 7). While paper prototypes presentations were an effective way to test early design ideas, the paper representations quickly reach a ceiling due to the high level of in-canvas interactive nature of 3d modeling software.

The development of high-fidelity (working-code) interactive prototypes in turn presented different challenges:

- 1) Reaching to a larger audience for the purposes of user testing and iterating on the interactions and the workflows meant that number of target users had knowledge of other existing conceptual design tools and expected similar tools and interactions in the high fidelity interactive prototype [1].



**figure 5.** A storyboard for a skyscraper located in a dense urban context.



figures 6 and 7. Early paper prototyping.

- 2) Not all users had experience working in the existing platform. A parallel project during the release addressed overall redesign of the user interface at which point it was accounted that the existing platform has over 800 commands (figure 8).

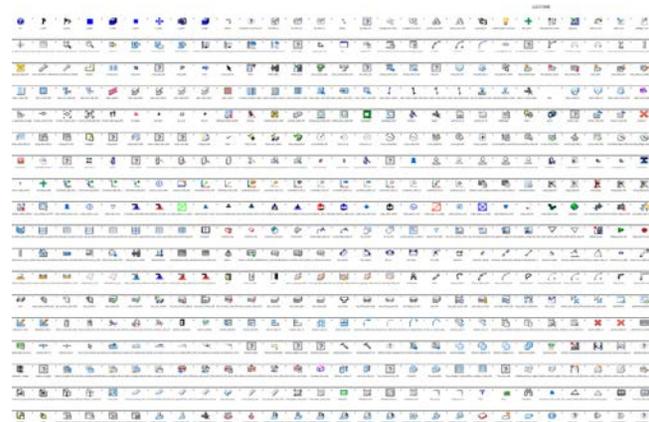


figure 8. A subset of commands in the existing platform.

Motivated by these findings, the team created a prototype with a simplified user interface (figure 9). The reductive exercise began by turning off all tools, creating a clean canvas and then identifying typical tasks (for example, create a specific form and then modify it) in the existing version of the software. The goal was to isolate tools / commands needed to complete tasks and add them to a palette which the team called the "life raft" (figure 10). The clear canvas provided a place to test new conceptual design features. Once a newly designed feature was implemented, the team first tested with in-house domain experts, further refined the designs, and then tested in architectural offices. For the six months of the project, the team conducted 52 usability evaluations in 11 architecture offices. Most were individual, one hour sessions with clearly defined tasks. User feedback from each usability session was used to redesign features and fix issues for the next usability session.

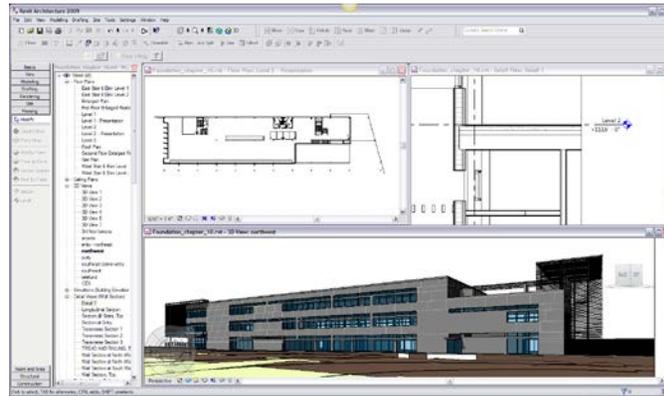


figure 9. Existing user interface.

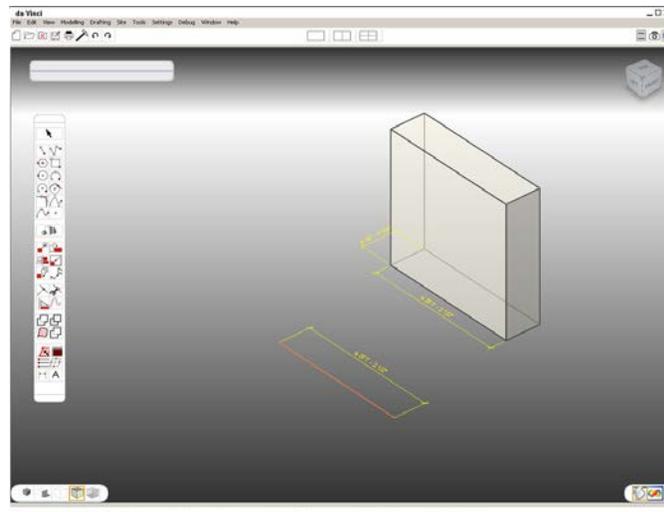


figure 10: Simplified user interface used as a test bed and to add new features.

3) A group of 30 polled architects that were not necessarily involved in early conceptual phases of design projects or worked on projects with “demanding” geometry were all familiar with the term “extrusion”, however approximately 75% were not familiar with any other modeling terminology such as sweep, loft, revolve etc. yet all CAD applications have separate tools for these operations. The findings inspired the team to simplify the creation of forms by merging different form-making operations (extrude, revolve, sweep, blend, loft) into a single “Create Form” operation. The software interprets the inputs and in cases where there may be more than one possible outcome, it pre-computes all options and presents image thumbnails. For example, if the selected input is a circle, and if the “Create Form” button is activated, the outputs can be a sphere or a cylinder (figure 11).

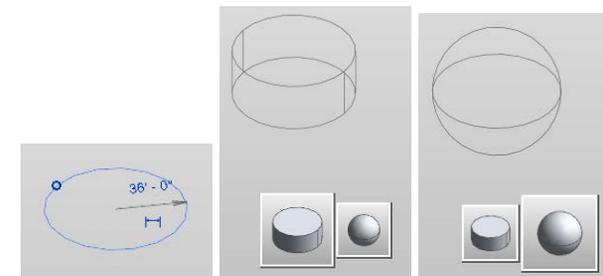
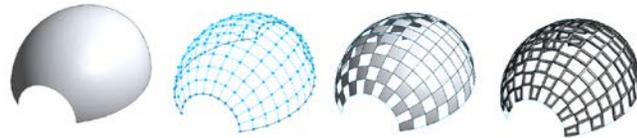


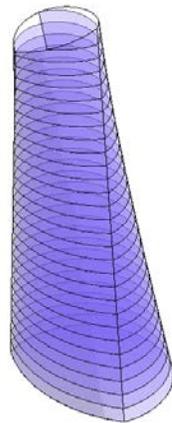
figure 11. Creating form: multiple outputs are available from a single input.

If the inputs are two lines, three outputs are possible: a surface and two revolving surfaces as in the image below (figure 12). This feature





**figure 14.** Form rationalization: from surface, to surface divided with UVs, patterned surface and surface with applied panel components.



Mass Floor Schedule			Mass Floor Schedule		
Level	Floor Area	Floor Volume	Level	Floor Area	Floor Volume
Level 1	12232 SF	143309.48 CF	Level 16	6646 SF	69426.83 CF
Level 2	11869 SF	139741.88 CF	Level 18	6628 SF	68717.33 CF
Level 3	11124 SF	130304.18 CF	Level 17	6529 SF	68219.38 CF
Level 4	10996 SF	124876.42 CF	Level 16	6646 SF	68929.71 CF
Level 5	10886 SF	119388.89 CF	Level 18	4760 SF	58958.88 CF
Level 6	9693 SF	112366.87 CF	Level 20	4632 SF	52881.88 CF
Level 7	9118 SF	106662.85 CF	Level 21	4581 SF	56322.81 CF
Level 8	8868 SF	101284.83 CF	Level 22	4609 SF	49375.82 CF
Level 9	8228 SF	96088.88 CF	Level 23	3883 SF	48824.88 CF
Level 10	7787 SF	91159.82 CF	Level 24	3715 SF	45685.17 CF
Level 11	7392 SF	86359.84 CF	Level 26	3666 SF	41788.24 CF
Level 12	7084 SF	81831.83 CF	Level 28	3412 SF	40176.18 CF
Level 13	6834 SF	77473.83 CF	Level 47	3387 SF	38776.47 CF
Level 14	6281 SF	73744.33 CF	Level 48	3179 SF	34898.98 CF
			Level 49	3143 SF	34624.66 CF
					189243 SF

**figure 15.** A massing form loaded into a project and sliced by levels in order to perform area and volume analysis.

**The fourth and final objective** of the project was to create a single, integrated conceptual design environment while maintaining a persistent relationship with the BIM model (figure 15). Geometry created in the conceptual design environment could be loaded into any Revit project file, and used to perform floor area

analysis, host walls, floors, and roofs, and be rendered (figure 16). The conceptual model could be edited in the conceptual design environment, and then re-loaded back into the project. Associated elements such as walls, floors, and roofs could then be re-synced to the conceptual form. There was no need to re-model elements every time the base conceptual mass form changes.



**figure 16.** A sample conceptual model of a skyscraper in an urban context made by CASE Architects.

### Conclusions and Future Work

The prototype addressed an unmet need in the existing version of the software – tools for early, conceptual design phases of projects – and demonstrated the need for a software company to employ a wide array of user-

centered methods to better understand user needs in this area.

By stripping down the user interface and creating a new graphical representation (overall user interface layout, icons, view navigation, etc.) different from the current version of the software, the team was able to elicit an unbiased reaction from users who did not perceive that they were working in the existing application. That resulted in a creation of an entirely new look and feel of the user interface: a simplified design environment that supported users in focusing on the tasks at hand.

Developing a clean-slate, proof-of-concept graphical user interface (GUI) environment allowed the designers the flexibility to work in an unconstrained manner, unencumbered by the UI from the native BIM application. The new interface did not resemble any existing tools, allowed the team to focus on new designs, and get unbiased feedback from test subjects. De-coupling the code base from the existing UI allowed software developers to build internal functionality, while interaction designers could test and iterate on new designs. The result was new interaction designs that could then be "switched on" in the context of the larger platform.

The subsequent year of design and development was dedicated to improvement of the features and overall workflows from the first release, and design of new features in order to improve and close workflow gaps.

The new conceptual design environment, including the new form creation and rationalization tools, are now part of a mainstream BIM platform and are being used in production on architectural and engineering projects.

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