

# User Innovation in Digital Design and Construction:

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Dialectical Relations between Standard BIM Tools and Specific User Requirements

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Submitted to the  
Department of Architecture  
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### Abstract

The use of Building Information Modeling (BIM) tools is increasing across the Architectural, Engineering and Construction (AEC) industry. This technology is being adopted in many different countries, in a wide range of types of projects, and by professionals from different disciplines. In other words, BIM tools are being applied in many different *contexts of use*. Consequently, the requirements of its users are becoming heterogeneous and this heterogeneity hinders the development of BIM tools that can satisfy all possible user requirements. Instead, tools are developed to satisfy more broad, general, and generic needs of the AEC industry.

The present thesis examines how BIM users are adapting the standard tools to satisfy their specific requirements. Utilizing the *user innovation* theory as the framework of analysis, the thesis examines whether and how BIM users are adapting the tools to respond to their requirements through *user innovation*. Studying eight specific BIM user innovation cases, from different *contexts of use*, the thesis presents and analyzes the processes underlying BIM user innovation, from the starting motivation, to the final distribution of the actual innovation. This analysis has two main objectives: first, to recognize whether there is *user innovation* in the case of BIM tools; and second, to understand how that innovation is developed. Finally, the thesis extracts patterns of innovation, and examines whether these user innovation cases fit the model described by the *user innovation* theory.



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Finally, I would like to express my deepest gratitude to my family: especially to my amazing husband Fernando, my partner in life and research – without his encouragement this whole MIT adventure would not have been possible; and to my mother Alexandra and my father Luis for all their long-distance love and support.

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## Table of Contents

<b>1</b>	<b>Introduction</b>	<b>14</b>
1.1	Problem Statement	15
1.2	Methodology	17
1.3	Research Questions	18
1.4	Significance of the Study / Contributions	18
<b>2</b>	<b>Gap Between Standard BIM Tools and Specific User Needs</b>	<b>20</b>
2.1	<b>BIM Definition</b>	<b>21</b>
2.2	<b>BIM Tools</b>	<b>22</b>
2.3	<b>Context of Use Problem</b>	<b>24</b>
2.3.1	<i>Context of use</i>	24
2.3.2	Diverse Locations	24
2.3.3	Diverse Projects	27
2.3.4	Diverse Disciplines	27
2.4	<b>The Importance of Adaptability in Digital Design Tools</b>	<b>29</b>
2.4.1	Adaptation and Innovation in BIM Tools	31
<b>3</b>	<b>User Innovation Theory and BIM</b>	<b>34</b>
3.1	<b>User Innovation Theory</b>	<b>35</b>
3.1.1	Types of Innovators	36
	Manufacturer-Innovators and User-Innovators	36
	Lead Users	36
3.1.2	Reasons Behind User Innovation Emergence	37
3.1.3	Support for User Innovation	38
	User Toolkits	38
	User Communities	39
3.1.4	Free Release of Innovations and Open-Source Initiatives	40
3.1.5	Social Creation of Meaning	41
3.2	<b>Application of User Innovation Theory to the Case of BIM</b>	<b>42</b>
3.2.1	Innovation Definition in the Context of BIM	42
3.2.2	The Process Behind BIM User Innovation	43
3.2.3	User Innovation Flow Diagram	44
3.2.4	Indirect Support for Innovation in BIM	46
3.3	<b>Case Study Methodology</b>	<b>47</b>
3.3.1	Sources of Evidence	47
3.3.2	Unit of Analysis	48
3.4	<b>Criteria For Case Selection</b>	<b>48</b>

<b>4</b>	<b>Cases</b>	<b>52</b>
4.1	Dynamo	54
4.2	Revit Python Shell	64
4.3	goBIM	72
4.4	MIT-CO Workshop	78
4.5	Free BIM Apps	86
4.6	SOM BIM Dashboard	94
4.7	HOK Curtain Wall Generator	104
4.8	ICABIM	112
<b>5</b>	<b>Conclusions</b>	<b>120</b>
5.1	Comparison of Cases	121
5.2	Findings	130
5.3	Conclusions	136
5.4	Future Steps	137
<b>6</b>	<b>References</b>	<b>138</b>
	List of Interviews	140
	Figures	142
	Bibliography	144



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## Figures

01. Preliminary User Innovation Flow Diagram for BIM.	45
02. Dynamo: User Innovation Flow Diagram.	54
03. Dynamo's User Interface.	56
04. Revit Python Shell: User Innovation Flow Diagram.	64
05. Form Creation with Revit Python Shell.	66
06. goBIM: User Innovation Flow Diagram.	72
07. goBIM screenshot.	74
08. goBIM screenshot.	74
09. goBIM screenshot in an iPhone.	74
10. MIT-CO Workshop: User Innovation Flow Diagram.	78
11. User interface flow chart of the object Interaction Query tool (oiQ). A context awareness tool that allows assessing complex interactions between model elements, designed by the student team composed by the author and Moa Carlsson.	80
12. oiQ's uses virtual volumes to find complex interaction between model elements.	80
13. oiQ's conflict visualization.	80
14. Free BIM Apps: User Innovation Flow Diagram.	86
15. Case Apps screenshot.	88
16. AEC-Apps screenshot.	88
17. Autodesk Exchange Apps screenshot.	89
18. Revit Application Store screenshot.	89
19. SOM BIM Dashboard: User Innovation Flow Diagram.	94
20. SOM Wall Evaluation done with information harvested through the Dashboard.	96
21. SOM Revit Best Practices and Guidelines.	97
22. SOM Revit Best Practices and Guidelines.	97
23. HOK Curtain Wall Generator: User Innovation Flow Diagram.	104
24. Top left: HOK Curtain Wall Generator: User interface.	106
25. Top right: KMCMC facades.	106
26. Bottom left: Detail of KMCMC facade.	106
27. Bottom right: KMCMC project by HOK.	106
28. ICABIM: User Innovation Flow Diagram.	112
29. Evaluation of one specific innovation already developed by ICABIM.	114
30. Innovation explanation (taken from the AU presentation).	114
31. Innovation's return of investment (taken from the AU presentation).	114
32. User Innovation Flow Diagrams of the eight cases studied.	126
33. Preliminary User Innovation Flow Diagram for BIM.	128
34. Final User Innovation Flow Diagram for BIM: the result of adding the eight cases' diagrams.	129





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## List of Abbreviations

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**ADN:**

Autodesk Developer Network

**AEC:**

Architecture, Engineering,  
and Construction

**AIA:**

American Institute of  
Architects

**API:**

Application Programming  
Interface

**AU:**

Autodesk University

**BIM:**

Building Information  
Model(ing)

**DCG:**

Design and Computation  
Group

**GSA:**

General Services  
Administration

**IFC:**

Industry Foundation Class

**QA/QC:**

Quality Assurance / Quality  
Control

**RPS:**

Revit Python Shell

**SDK:**

Software Development Kit

**SOM:**

Skidmore, Owings, and  
Merrill

**VDC:**

Virtual Design and  
Construction

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# Introduction

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## 1.1 Problem Statement

The use of Building Information Modeling (BIM) tools is increasing across the architectural, engineering, and construction (AEC) industry. Different industry surveys indicate that BIM tools are being adopted in many different countries, for a wide range of types of projects, and by professionals from different disciplines<sup>1</sup>. In other words, BIM tools are being applied in many different *contexts of use*.<sup>2</sup>

Among BIM tools' distinctive qualities is their ability to generate information models that contain not only data regarding the three-dimensional form of a building, but also regarding its materials, components, structure, and cost – all facts that are highly dependent on the *context of use* of the tool. As one of the key aspects of BIM tools is their ability to generate models that contain specific information about the project, and as the projects that are being designed and managed using these tools become more diverse in terms of location, type of project, and discipline, the requirements of the users grow more heterogeneous. For instance, as the tools are being introduced in many different countries, the conditions to which projects are subject – such as materials, building codes, construction systems, and liability structures -- change. In addition, as BIM tools are applied in different types of projects – health care, residential, educational, commercial, and governmental – that vary widely in size and requirements, their designs have to accommodate different types of programmatic conditions, structures, MEP systems, code compliance, etc. Finally, the wide range of types of firms that are using the tools – designers, engineers, builders, MEP specialists – have different tasks, requirements, and workflows to fulfill with the applications.

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<sup>1</sup> Surveys conducted across the AEC industry in the US indicate that architects, contractors, engineers and owners using BIM have grown from a 28% in 2007, to a 49% in 2009. Similar surveys conducted in United Kingdom, France, and Germany indicate that, by 2010, 36% of the participants had adopted BIM. McGraw-Hill Construction Smart Market Report, The business value of BIM in Europe, (2010): 4. McGraw-Hill Construction. «The Business Value of BIM, Getting Building Information Modeling to the Bottom Line.» SmartMarket Report, 2009, 52.

<sup>2</sup> The International Organization for Standardization (ISO) defines “*Context of use*” in ISO norm number 9241-100:2010 as the “users, tasks, equipment (hardware, software and materials), and the physical and social environments in which a product is used”. Maguire refers to the *Context of use* concept, stating that: “When a product (or system) is developed, it will be used within a particular context. It will be used by a user population with certain characteristics. The user will have certain goals and wish to perform various tasks. The product will also be used within a certain range of technical, physical and social or organizational environments that may affect its use.” Maguire, Martin. "Context of use Within Usability Activities." International Journal of Human-Computer Studies 55, no. 4 (October 2001): 453-483.

This heterogeneous nature of user needs hinders the development of BIM tools that can satisfy all possible user requirements. Instead, tools are developed to satisfy broader general and generic needs of the AEC industry. This gap between standard tools – or products – and specific user needs is not exclusive to BIM tools or the AEC industry, and has been extensively studied by innovation scholars. Some of their studies recognize the key role that users play when tools or products available to them do not satisfy their specific requirements. *User innovation* theories indicate the existence of an *information asymmetry* between users and producers of products, tools, or technologies. In other words, producers tend to have a good knowledge of the general needs of their market, while users tend to have very particular needs<sup>3</sup>. The highly heterogeneous nature of these needs makes it hard for producers to have knowledge of, and to properly respond to, all those needs. Therefore, users take the role of developing new solutions or adapting the existing ones to satisfy their needs, engaging in *user innovation*<sup>4</sup>.

In the same way described by *user innovation* theories, in the case of BIM tools, the need for bridging the gap between standard tools and user needs – generated by the *information asymmetry* – fosters opportunities for innovation. BIM users are developing new processes, plug-ins, and digital components in order to adapt the tools to their needs, generating a dialectical relation between standard technologies and user-specific requirements. These bottom-up innovations help technologies better serve users, and may prevent the promotion of standardization by one-size-fits-all tools.

The present thesis studies the case of BIM tools to understand how architects and other BIM users are adapting the standard tools to satisfy their highly heterogeneous needs. Applying *user innovation* theories to BIM, the thesis intends to explore whether and how BIM users are adapting the tools to respond to local, project, or user-specific requirements through *user innovation*.

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<sup>3</sup> Eric Von Hippel, *Democratizing Innovation* (Cambridge: MIT Press, 2005), 8.

<sup>4</sup> Professor Eric Von Hippel defines user innovation as the development or refinement of products carried out by user firms or individual consumers, rather than the products' supplier. Eric Von Hippel, *Lead Users: A Source of Novel Product Concepts*, *Management Science* 32, no 7 (Jul., 1986): 791.

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## 1.2 Methodology

The thesis is structured as a descriptive case study. In the context of this research, a case is understood as the process underlying the development of a BIM user innovation, from the starting point of the need that the user intends to solve, to the current stage of development and distribution of the actual innovation. From sources such as literature, professionals, members of academia, vendors, and information communities, cases from different countries and types of firms will be collected. These cases will be analyzed in order to understand:

- the specific characteristics of the user/developer;
- the user need that motivated the innovation;
- the process, and the resources devoted to the development of the innovation;
- the resulting innovation and its application in its *context of use*;
- the process of distribution of the tool (in the cases where it exists); and finally,
- whether the innovation has solved the user need or changed the use of the original BIM tool.

This analysis has two main objectives: first, to recognize when there is *user innovation* in the case of BIM tools' adaptation, and second, to understand how that innovation proceeds. Identifying the different elements – motivation, resources, distribution options, etc. – involved in the user innovation processes of the cases studied, the thesis intends to extract patterns of innovation and determine whether these user innovation cases fit the model described by *user innovation* theories.

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### 1.3 Research Questions

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#### Main Question

Are BIM users adapting standard tools to respond to local, project, or user-specific requirements through user innovation? How is the user innovation process developed?

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#### Secondary Question

- Are BIM tools flexible enough to allow users to adapt them to their needs?
- Are the adaptations and innovations a result of problems that users intend to solve or part of exploratory processes?
- Are the problems or questions that the innovations intend to address peculiar to a specific case or general in the AEC industry?
- What patterns and lessons can be extracted from the innovation experiences of BIM users?
- Do the cases of user Innovation in BIM fit the original model described by the user Innovation theory?

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### 1.4 Significance of the Study / Contributions

The gap between standard tools and user-specific requirements in the context of design is not only characteristic of BIM tools. Referring to the relation between information technologies and creative practices, William Mitchell et al. (2003) wrote that “software tools encode numerous assumptions about the making of art and design—precisely the sorts of presuppositions that truly creative practitioners will want to challenge. And the more software tools emphasize ease of use or familiar metaphors, the more they must depend on restrictive assumptions in order to do so.” The authors asserted the need for these technologies to be flexible enough to allow user adaptation and innovation. “Such tools [...] must be objects of critical reflection; they must be open to adjustment and tweaking, they must support unintended and

subversive uses—not just anticipated ones.”<sup>5</sup>

The present thesis researches how the implicit assumptions and restrictions that BIM tools encode can be overcome by architects and contractors through adaptation and innovation. The study intends to identify whether the technology is flexible enough to allow users to reflect critically on the tools and use them in the way they intend to, rather than being forced to adapt their work to them.

The thesis contributions will be:

- Understanding the relation between local context / user needs, existing tools’ limitations, resources available to those users, and the resulting innovations.
- Understanding how architects and other construction-related professionals are adapting digital tools to respond to local requirements and cultural and economic factors.
- Extracting general lessons about how BIM users innovate that could be utilized by other BIM users as guidelines for innovating in less advanced contexts.
- Understanding whether BIM tools are flexible enough to allow adaptation to local AEC contexts and how they could be made more flexible.
- Identifying whether there are recurrent similar innovation initiatives that could be adopted by the standard tools by absorbing them or by allowing more customization of the tools in a certain area.

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<sup>5</sup> William Mitchell, Alan Inouye, and Marjory Blumenthal, eds. *Beyond Productivity: Information, Technology, Innovation and Creativity*. Committee on Information Technology and Creativity, Computer Science and Telecommunications Board, Division on Engineering and Physical Sciences, National Research Council of the National Academies., (Washington, D.C.: National Academies Press, 2003), 4.

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**Gap Between  
Standard BIM  
Tools and Specific  
User Needs**

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# 2



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## 2.1 BIM Definition

There are currently several definitions of Building Information Modeling (BIM). Whereas some of them emphasize its methods, others highlight its deliverables. The definitions, in general, vary according to the use that the defining individual or institution makes of BIM. The General Services Administration (GSA), for example, defines it as:

[T]he development and use of a multi-faceted computer software data model to not only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design.<sup>1</sup>

Van Nederveen, Beheshti, and Gielingh, in their 2010 article, define BIM as:

[A] model of information about a building (or building project) that comprises complete and sufficient information to support all lifecycle processes, and which can be interpreted directly by computer applications. It comprises information about properties such as function, shape, material and processes for the building life cycle.<sup>2</sup>

In a 2009 article, BIM expert Chuck Eastman defined BIM as:

[T]he representation of building information in a computer-readable form. [...] Instead of drawings that are only interpretable by people (even though computer generated), the heart of BIM is that the computer can interpret the building model, in terms of its 3D form, its spatial organization, materials, parts and structure.<sup>3</sup>

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**1** U.S. General Services Administration, (GSA), *GSA Building Information Modeling Guide Series: 01 - Overview*, Version 0.6 (Washington, DC: GSA, 2007), 3.

**2** Sander Van Nederveen, Reza Beheshti, and Wim Gielingh, "Modeling Concepts for BIM," *Handbook of research on building information modeling and construction informatics: concepts and technologies* (Hershey, PA: Information Science Reference, 2010), 2.

**3** Chuck Eastman, "What is BIM?" *Architectural Transformations via BIM, A + U: Architecture and Urbanism*, Special Issue, August (2009): 16.

In the same article, Eastman also mentions the parametric capability of a tool as a foundational aspect of a BIM authoring tool. Finally, the National Building Information Model Standard Project Committee (NBIMS) defines BIM as:

[A d]igital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward.<sup>4</sup>

Although these definitions vary in terms of the use of BIM, two concepts are always present: the ability of the model to contain information in addition to the three-dimensional form of a building and the machine-readability of this information. For the scope of the present study, we will understand BIM as the digital representation of a building that contains not only its three-dimensional form, but also information about its materials, components, structure, cost, and spatial organization. The term *BIM tools* will be used to refer to the applications that can create or manage such a type of representation.

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## 2.2 BIM Tools

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There is no standard list of requirements or conditions to qualify a tool as BIM in the surveyed literature. Laisierin, for instance, proposes to consider the ability to produce IFC format files – International Foundation Class, the open file format for BIM tools – sufficient, but not mandatory, to consider a tool as BIM.<sup>5</sup> In the *BIM Handbook*, Eastman et al. name four conditions to help distinguish a BIM-capable tool. These conditions are: 1) the ability to contain not only three-dimensional form, but also information that can be used for “data integration and design analysis”; 2) the ability to organize objects in the model parametrically; 3) the fact that the model is not composed of separate two-dimensional files; and finally, 4) the reliable coordination of the model’s dimensions,

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<sup>4</sup> National Institute of Building Sciences, *National BIM Standard Version 1 - Part 1: Overview, Principles, and Methodologies (2007)*, 21. [http://www.wbdg.org/pdfs/NBIMSv1\\_p1.pdf](http://www.wbdg.org/pdfs/NBIMSv1_p1.pdf)

<sup>5</sup> Jerry Laisierin, foreword to *BIM handbook : a guide to building information modeling for owners, managers, designers, engineers, and contractors*, by Chuck Eastman, Paul Teicholz, Rafael Sacks, and Kathleen Liston, eds. (Hoboken, NJ: Wiley, 2008), xii-xiii.

assured by the fact that handling them independently in different views is not allowed.<sup>6</sup> These last two conditions are meant to assure that information is consistent across the entire model. Isikdag et al. summarize the critical characteristics of BIM as follows: 1) object oriented, 2) data-rich/comprehensive – models contain all the characteristics and states of the building, 3) three-dimensional, 4) spatially-related – building elements are associatively organized in the space, 5) rich in semantics, and finally, 6) allows generation of model views.<sup>7</sup>

It is important to distinguish that there are two different types of BIM tools: authoring tools and analytical tools. Authoring tools allow users to create BIM models, whereas analytical tools are designed to manage data from already existing BIM models. This data management can consist of information extraction, analysis of different conditions – clash detection or energy efficiency – 4D and 5D visualization, and more. In most of the cases tools have authoring-analytical integrated capabilities. Revit Architecture, for example, is mainly an authoring tool; however, it also has analyzing features to check the model for clash detection.

There are two main factors that hinder the construction of an accurate list of all the currently available BIM tools. The first one directly derives from the aforementioned lack of consistency among the conditions that qualify a tool as BIM. The second fact derives from the fact that the number of stand-alone and add-on tools that claim to be BIM tools grows at a very fast pace, making it impossible to catalogue every one of them. Nevertheless, the most influential authoring BIM tools named in the literature<sup>8</sup> and accepted by the different institutional programs include: ArchiCAD, Revit, Bentley Systems, Digital Project, Vectorworks, and Tekla Structures.

<sup>6</sup> Chuck Eastman, Paul Teicholz, Rafael Sacks, and Kathleen Liston, eds., *BIM handbook : a guide to building information modeling for owners, managers, designers, engineers, and contractors*, 2nd ed. (Hoboken, NJ: Wiley, 2011), 19.

<sup>7</sup> Umit Isikdag, Ghassan Aouad, Jason Underwood, and Song Wu. *Building Information Models: A review on storage and exchange mechanisms: Proceedings of CIM W78 2007 Maribor*, Slovenia, 2007, 135-144. Referenced in Jason Underwood and Umit Isikdag, preface to *Handbook of research on building information modeling and construction informatics: concepts and technologies*, (Hershey, PA: Information Science Reference, 2010), xxxii.

<sup>8</sup> See Eastman, Chuck, Paul Teicholz, Rafael Sacks, and Kathleen Liston, eds. *BIM Handbook : a Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*. 2nd. Hoboken, NJ: Wiley, 2011.

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## 2.3 *Context of Use* Problem

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### 2.3.1 *Context of Use*

*Context of use* is defined by the International Organization for Standardization (ISO) as the “users, tasks, equipment (hardware, software and materials), and the physical and social environments in which a product is used”<sup>9</sup>. While this definition is intended for all types of products, Maguire defines the same concept specifically referring to software applications:

When a product (or system) is developed, it will be used within a particular context. It will be used by a user population with certain characteristics. The user will have certain goals and wish to perform various tasks. The product will also be used within a certain range of technical, physical and social or organizational environments that may affect its use.<sup>10</sup>

In this thesis, the term *Context of use* refers to the specific settings and conditions influencing the utilization of BIM tools. Special emphasis is placed on two aspects of the *Context of use*: first, the social environment where the tools are applied, and second, the goals and tasks that the different users wish to accomplish with the tools. Both are recognized as crucial, in this thesis, for the emergence of user innovation in BIM.

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### 2.3.2 Diverse Locations

BIM tools, as stated in the introduction, are being utilized in varying *Contexts of use*. One example of these varying contexts is the fact that BIM tools are being used in several different locations or regions. These regions may have different construction systems, materials, liabilities structures, and base conditions that also influence the types of projects that are built in them (climate, types of soil, earthquake demands, etc.). An example of this is the types of building components – i.e., plumbing fixtures, mechanical

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<sup>9</sup> International Organization for Standardization (ISO), norm number 9241-100:2010. Retrieved from: [http://www.iso.org/iso/concept\\_database\\_cdb.htm](http://www.iso.org/iso/concept_database_cdb.htm).

<sup>10</sup> Maguire, Martin. "Context of use within Usability Activities" International Journal of Human-Computer Studies 55, no. 4 (October 2001): 453-483.

components or electrical fixtures – available for each region. As manufacturers and suppliers vary from country to country, so do the building components. Given that one of the basic conditions of BIM is the possibility to place components, called families, that contain not only the form, but also the specific information of the objects, having accurate libraries of objects that reflect available building components becomes crucial for the true optimization of the models. Therefore, the creation of national libraries for each country plays a key role in the full implementation of BIM. Different BIM software applications come by default with some libraries, mainly responding to generic conditions that are more similar to the ones needed in their countries of origin. Such is the case of Revit, which comes by default with an imperial and a metric library, and offers users 23 country-specific libraries plus one “Generic International Library”. While this gives a certain flexibility to the tool, these adaptation features clearly do not cover every region where the tool is being used.<sup>11</sup> A similar example is ArchiCAD, which has 26 localized versions that vary in language and also in the libraries available. Nevertheless, it is reasonable to assume these 26 versions are not able to completely satisfy the needs of the users in the 80 countries where ArchiCAD is currently being sold.<sup>12</sup>

Wagner Conde, a Customer Success Engineer for Autodesk in Brazil, indicates that one of the main reasons why Revit has not been fully adopted in that country is the unavailability of proper BIM components that fully resemble real building components. This is especially critical in the case of HVAC specialists who wish to work with Revit MEP because content creation for this discipline (mechanical equipment or specific duct fittings) is highly complex to build due to the connections necessary for pipes and ducts. Consequently, in 2011 Autodesk delivered its first Brazil-specific MEP library with approximately 200 components, to respond to the demands of Brazilian professionals. Conde explains that “engineers [in Brazil are] very interested in using Revit MEP, but

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**11** To illustrate this, while there are a few libraries for English speaking countries there is only one for Spanish speaking countries, specifically designed for Spain. Information retrieved from Revit Architecture 2012 installation interface.

**12** To illustrate this, while there are three versions in German, one for Germany, one for Austria, and one for Switzerland, there is only one version in Spanish that is meant to satisfy the requirements of the users in the eleven Spanish speaking countries where ArchiCAD is currently sold. Information retrieved from [http://www.graphisoft.com/company/about\\_graphisoft/](http://www.graphisoft.com/company/about_graphisoft/)

when they face the limitations of the available content, it's very difficult [for them] because it's not so easy to build families for Revit MEP [...]. We had a barrier, and that's why our purpose was to provide good content"<sup>13</sup>

Another example of this happens in Chile with structural rebars, because the way in which rebars are placed in walls is not compatible with the way in which Tekla – the most used program for modeling rebars in that country – places them in the 3D model.

According to Ricardo Rojas, an engineer from Rene Lagos Structural Engineers, the difference in how the rebars in Chile are built derives from a cultural and economic difference between Chile and the place of origin of the software (the United States). Rojas explains that man-hour costs in Chile are lower than in the US, while the cost of materials such as steel is higher. Therefore, while in the US structural designers will prioritize saving on man-hours over optimizing the use of materials, in Chile the system will work in the opposite way. Designers do not worry about designing a system that demands more man-hours to build if it means they can optimize the use of raw materials. Therefore, while in the US the structural rebar placement design tends to be fairly simple, uniformly distributing rebars of almost the same diameter along the structural walls, in Chile, to economize on steel, the rebars are not uniformly distributed. This non-uniform distribution means that the heads of the walls have thicker rebars – with diameters of 32 or 36 mm – than the middle section of the walls. When these thick rebars are placed individually for each level of a wall, they need long joints between levels. Therefore, what designers try to do is to use the complete length of a rebar (a maximum of 12 meters, or 40 feet) spanning two or three levels to avoid these joints, thus saving steel. This translates into more man-hours, given that it is longer and more complex to transport and install 12-meter rebars, but saves on material. The problem with BIM arises because rebars, for the software, are components hosted inside walls. As a result, it is not possible to have one-level walls with rebars that protrude into two levels. Therefore, the problem was solved through collaboration between the engineers and the software vendors to create macro routines that would enable the placement of such type of rebars using the BIM application.

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<sup>13</sup> Wagner Conde, interview by author. Online interview, (December 22, 2011).

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### 2.3.3 Diverse Projects

BIM software is being used to design and/or document different types of projects that greatly vary in size and complexity. While a project for a house will demand the creation of few, and sometimes only one, model(s), the design or coordination of a hospital will demand several models, and their coordination will require the application of different tools, much hardware, and diverse channels of communication between participants.

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### 2.3.4 Diverse Disciplines

BIM software is being used by different types of professionals. Not only are architects and designers using the tools, but also (as surveys indicate) engineers, contractors, and other specialists.<sup>14</sup>

This cross-discipline implementation of BIM tools generates two demands for BIM software. First, the tools need to satisfy the requirements of different disciplines which may have completely different tasks and workflows to fulfill with the tools. Second, they need to allow communication and information transfer between disciplines.

Addressing the first issue – satisfying the requirements of different disciplines – some BIM software has evolved from an original single application for design, into platforms of products, specifically tailored for particular disciplines. That is the case of Revit, which started with just one version for architectural design, but in 2005 released Revit Structure, followed in 2006 by the introduction of Revit Systems, now known as Revit MEP.<sup>15</sup> This is also the case of Bentley, which has released discipline-specific versions for Architecture, Mechanical, Systems, Electrical Systems, and Structure, among others. This diversification of the software gives different specialists specific tools and content according to their disciplines, but it is debatable whether just by doing so, they satisfy all the discipline-specific requirements. In a 2011 article, Vishal et al. indicate that “[e]xpectations of BIM vary across disciplines [...]. For design disciplines, BIM is an extension to CAD, whereas for nondesign disciplines such as contractors and project managers, BIM is more like an intelligent DMS [document

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<sup>14</sup> McGraw-Hill Construction. «The Business Value of BIM, Getting Building Information Modeling to the Bottom Line.» SmartMarket Report, 2009, 52.

<sup>15</sup> Retrieved from Autodesk User Group International forum (AUGI) [http://forums.augi.com/showthread.php?20803-Revit-Timeline-\(W-I-P-\)](http://forums.augi.com/showthread.php?20803-Revit-Timeline-(W-I-P-))



management system] that can quickly take off data from CAD packages directly.”<sup>16</sup>

Although the aforementioned and other BIM products have discipline-specific versions or modules, it is important to note that the different versions are very similar, working on the same file extension – RVT for all Revit versions, DGN for Bentley versions – and their differences lie mostly in the components and templates that they contain, plus some small but highly specific tools.

Regarding the second issue, the need for software to enable information transfer, unless the models that the different professionals generate for a project in their specific BIM platforms can be effectively transferred between them, the benefits posed by BIM will be completely lost, generating *islands of automation* that do not contribute to unifying the naturally fragmented work of the AEC industry. This problem has been solved by vendors, as mentioned in the previous paragraph, by having discipline-specific versions that work in the same file format. Nevertheless, the problem appears when the different specialists working in a given project use applications from different vendors. In those cases, the generation of open file formats, as the Industry Foundation Class (IFC), is crucial in enabling that optimal transfer.

While having BIM platforms that, through the combination of several software applications, are able to deliver discipline-specific abilities and content to different professionals may prevent the *islands of automation*, this generalized solution may create new problems by offering non-domain-specific tools. In a 1999 article Kiumars and Pittman, referring to the creation of AEC information modeling software, wrote that “such systems for the AEC industry will most likely need to offer dynamic schema definition in the future[,] thus allowing a schema to evolve over time, perhaps in a distributed fashion, such that the semantics and organization of information satisfies the needs of a diverse, expanding group of end-users and third-party developers.”<sup>17</sup> They conclude the article

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**16** Singh, Vishal, Ning Gu, and Xiangyu Wang. "A Theoretical Framework of a BIM-Based Multi-Disciplinary Collaboration Platform." *Automation in Construction*, no. 20 (2011): 136.

**17** The authors define schema as “an abstract specification of the content and organization of information in a system, the computer-based creation and manipulation of that information is generally specified through some Application Programming Interface (API) protocol.” Zamanian, M.Kiumars, and Pittman Jon. "A Software Industry Perspective on AEC Information Models for Distributed Collaboration." *Automation in Construction*, no. 8 (1999): 244.



by stating that “because of this diversity [of the AEC industry] and the fact that AEC information evolves non-sequentially by an organizationally disjointed team, we oppose the creation and deployment of any large, rigidly-structured schema intended to satisfy all AEC disciplines.”<sup>18</sup>

All of the above generates user needs that cannot be completely satisfied by the standard tools, creating opportunities for innovation.

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## 2.4 The Importance of the Adaptability in Digital Design Tools

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William Mitchell wrote in 2009:

Availability invites use. [...] Architects tend to think in terms of forms for which they have tools, and simultaneously, to look for tools to represent forms they have imagined. From time to time, this circularity gets broken when someone invents a new tool – a spline curve instrument, for example – that puts new shapes and constructions into play. On other occasions, architects decide that they want to break out of the conventions embodied in their current tools and either work freehand or improvise new tools to meet their requirements. In general, a designer’s toolkit represents a provisional equilibrium of capability and demand.<sup>19</sup>

Regarding BIM, the assumption would be that, in the same way as a new spline curve instrument adds the spline to the repertoire of forms available to the designer, the implementation of BIM as a tool for design influences the way in which architects design. Therefore, the need for BIM applications to be open and allow customization is imperative.

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**18** Kiumars Zamanian and Jon Pittman. "A Software Industry Perspective on AEC Information Models for Distributed Collaboration." *Automation in Construction*, no. 8 (1999): 247.

**19** William Mitchell, "Thinking in BIM," *Architectural Transformations via BIM, A + U: Architecture and Urbanism*, Special Issue (August 2009): 10-13.

As previously noted, in 2003 Mitchell et al. stated that:

Software tools encode numerous assumptions about the making of art and design—precisely the sorts of presuppositions that truly creative practitioners will want to challenge. And the more software tools emphasize ease of use or familiar metaphors, the more they must depend on restrictive assumptions in order to do so.

Furthermore, the authors stated the need for these technologies to be flexible enough to allow user adaptation and innovation: “Such tools [...] must be objects of critical reflection; they must be open to adjustment and tweaking, they must support unintended and subversive uses—not just anticipated ones.”<sup>20</sup>

The importance of flexibility for design tools is also mentioned by other authors. Referring to 3D parametric software, Salim and Burry spoke about *software openness*: a state where software is openly customizable. Software openness, according to the authors, requires open input – the ability to input different types of information to the tool that may come from different software or the physical environment through sensors – open process – the ability to customize the software through the model components it utilizes or through the Application Programming Interface (API) - and finally, open output – the ability to output the information from the software in different ways, such as rapid prototyping.<sup>21</sup>

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**20** William Mitchell, Alan Inouye, and Marjory Blumenthal, eds. *Beyond Productivity: Information, Technology, Innovation and Creativity*. Committee on Information Technology and Creativity, Computer Science and Telecommunications Board, Division on Engineering and Physical Sciences, National Research Council of the National Academies., (Washington, D.C.: National Academies Press, 2003), 4.

**21** Flora Dyls Salim and Jane Burry. "Software Openness: Evaluating Parameters of Parametric Modeling Tools to support creativity and multidisciplinary design integration." *ICCSA'10 Proceedings of the 2010 international conference on Computational Science and Its Applications - Part III*. (Berlin Heidelberg: Springer-Verlag, 2010): 492-494.

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## 2.4.1 Adaptation and Innovation in BIM Tools

As described in the previous sections, the high variation in the *contexts of use* of BIM tools generates a gap between standard tools and user-specific requirements. Overcoming this gap requires the adaptation of the tools to meet the demands of different users.

This approach to the problem of tool adaptation would imply that manufacturers should learn about the specific requirements of users and create variations of the original tool to meet these needs. This, in part, is the approach of smaller BIM-related companies that, by having a smaller set of customers, have the ability to communicate directly with their clients, to learn about their demands for the product, and incorporate – at least some of – them into their original software. That is, for example, the approach of Horizontal Systems, the creators of Glue, a web-based server that allows visualizing and managing BIM's online. With a group of clients of approximately 30 firms in 2011, they were able to contact their clients directly to inquire about their needs. Given that Glue was a Software as a Service (SaaS) that released a new version approximately every three months, Horizontal's ability to respond to user needs was high. Moreover, as the number of users was strictly limited and monthly subscription clients established a direct communication with the company, the process was easily manageable.<sup>22</sup>

As the group of users of BIM tools developed by bigger companies is quite large, the ability of these companies to communicate directly to each one of their customers and respond to their demands is proportionally low. Therefore, these developers implement different channels of communication with BIM users. Several blogs, forums, and product-specific networks allow manufacturers to learn about user needs. Still, as it is not possible for them to respond to all the user needs, different approaches can help overcome this problem. Mass-customization, for instance, allows producers to offer users customized products by establishing interfaces that enable user customization by the combination of available parts. This approach allows the user to customize a product – up to a certain level – without actually generating the need for the manufacturer to build one specific product for each user.<sup>23</sup> As defined by Pine in 1993, mass customization is “developing, producing, marketing, and delivering affordable

<sup>22</sup> Horizontal Systems was acquired by Autodesk in 2011 and Glue is currently in the process of becoming part of Autodesk 360.

<sup>23</sup> A famous example of mass-customization is Dell's approach to computer manufacture.

goods and services with enough variety and customization that nearly everyone finds exactly what they want.” He justifies mass-customization by explaining that, “a company that better satisfies its customers’ individual needs will have greater sales. With higher profits as well as a better understanding of customer requirements, the company can provide even more variety and customization.”<sup>24</sup>

The present thesis proposes an alternative approach to the varying *contexts of use* and the resulting heterogeneity of user needs in the realm of BIM tools. Given that BIM user requirements are highly heterogeneous (an issue aggravated by the fact that BIM’s contain large amounts of information), instead of expecting the software producers to adapt the tools, the thesis researches the possibility that the users, who have a better knowledge about the needs and the *context of use*, could be in charge of adapting the tools. Accordingly, user innovation theories are used as the framework of analysis of the problem in order to understand whether relying on the user to adapt BIM tools could be a successful approach to the problem of BIM adaptation.

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<sup>24</sup> Joseph Pine, *Mass Customization: the New Frontier in Business Competition* (Boston: Harvard Business School Press, 1993):44.



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**User Innovation  
Theory and BIM**

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# 3

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### 3.1 User Innovation Theory

According to Von Hippel, “user innovation” is the modification of existing products or the development of novel ones, done by users rather than manufacturers. The term “product” is used to refer to information products – i.e., software - as well as physical ones, while the term “user” can refer to individuals as well as firms that use the product to produce new ones.<sup>1</sup>

The process by which physical or information products evolve through the action of innovations made by users has been studied by many scholars. One of the first, as noted by Bogers et al. in 2010, was Adam Smith, who in 1776 wrote in his book *The Wealth of Nations*:

In the first fire-engines, a boy was constantly employed to open and shut alternately the communication between the boiler and the cylinder, according as the piston either ascended or descended. One of those boys, who loved to play with his companions, observed that, by tying a string from the handle of the valve which opened this communication to another part of the machine, the valve would open and shut without his assistance, and leave him at liberty to divert himself with his play fellows. One of the greatest improvements that has been made upon this machine, since it was first invented, was in this manner the discovery of a boy who wanted to save his own labour.<sup>2</sup>

Bogers et al. indicate that user innovation appears in the literature repeatedly in the 1960’s, but it was not until the seventies that the central role of users as innovators began being thoroughly studied, in the research conducted by Professor Eric Von Hippel.<sup>3</sup>

Papers on user innovation have been written regarding many fields, such as the sports-equipment industry (mountain-biking<sup>4</sup>

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<sup>1</sup> Von Hippel, Eric. *Democratizing Innovation*. (Cambridge, Massachusetts: MIT Press, 2005), 1 and 19.

<sup>2</sup> Adam Smith, *An inquiry into the nature and causes of the wealth of nations*. (1776; repr., London: Penguin, 1999), 114-115, quoted in Marcel Bogers, Allan Afuah, and Bettina Bastian. "Users as Innovators: A Review, Critique, and Future Research Directions." *Journal of Management* 36, no. 4 (July 2010): 858.

<sup>3</sup> Marcel Bogers, Allan Afuah, and Bettina Bastian. "Users as Innovators: A Review, Critique, and Future Research Directions." *and Future Research Directions* 36, no. 4 (July 2010): 859.

<sup>4</sup> Christian Lüthje, Cornelius Herstatt, and Eric Von Hippel. "User-Innovators and “Local” Information: The Case of Mountain Biking." *Research Policy*, no. 34 (2005): 951-965.

and windsurfing<sup>5</sup>) and the software industry, especially the cases of Linux<sup>6</sup> and Apache, which have been extensively studied in respect to their open-source nature. Special attention is given in this thesis to the study of user innovations in stressed panels for construction published in 1993 by Sarah Slaughter.<sup>7</sup>

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### 3.1.1 Types of Innovators

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#### A Manufacturer- Innovators and User-Innovators

User innovation studies observe that there are two types of innovators: manufacturer-innovators and user-innovators, focusing on the latter.<sup>8</sup> Bogers et al. divide the user-innovators into two groups: Intermediate User as Innovator and Consumer User as Innovator. Intermediate Users are firms that use a product to produce other goods, while Consumer Users are communities or individuals who act as end users.<sup>9</sup> In the present thesis, “user-innovator” will be used to refer to both Intermediate Users and Consumer Users who innovate.

#### B Lead Users

Inside the general group of users, the literature recognizes there may be a smaller group called Lead Users. Lead users are the ones whose needs are ahead of the market and therefore the ones more likely to generate innovation.<sup>10</sup>

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**5** Sonali Shah, "Sources and Patterns of Innovation in a Consumer Products Field: Innovations in Sporting Equipment." *Working Paper: MIT Sloan School of Management*, (2000).

**6** See Ilkka Tuomi, *Networks of Innovation*. New York: Oxford University Press, 2002. And also Bruce Kogut, and Anca Metiu. "Open source software development and distributed innovation." *Oxford Review of Economic Policy* 17, no. 2 (2001): 248 - 264.

**7** Sarah Slaughter, "Innovation and Learning During Implementation: a Comparison of User and Manufacturer Innovation." *Research Policy* 22 (1993): 81-95.

**8** Eric Von Hippel, *Democratizing Innovation* (Cambridge, Massachusetts: MIT Press, 2005), 3.

**9** Marcel Bogers, Allan Afuah, and Bettina Bastian. "Users as Innovators: A Review, Critique, and Future Research Directions." *and Future Research Directions* 36, no. 4 (July 2010): 859.

**10** Eric Von Hippel, Lead Users: A Source of Novel Product Concepts, *Management Science* 32, no 7 (Jul., 1986), 791.



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### 3.1.2 Reasons Behind User Innovation Emergence

Von Hippel uses the term “information asymmetry” to refer to the difference between the knowledge of manufacturers and users. While manufacturers have broad knowledge of model solution and the general needs of the market, users, on the other hand, have knowledge of their specific needs and their particular *context of use* of the product. This information asymmetry between producers and users of products is hard to overcome due to the tacit nature of knowledge and the difficulties in transferring it. Users’ knowledge – about their specific needs and the *context of use* of the products – is sometimes deeply related to skills that are mainly tacit. In the words of Polanyi, “the aim of a skillful performance is achieved by the observance of a set of rules which are not known as such to the person following them.”<sup>11</sup> As the knowledge is not explicit, but rather implicit, the transference of the rules and knowledge from the performer to others is hindered. In his 1966 book *The Tacit Dimension*, Polanyi summarizes this, stating “we can know more than we can tell.”<sup>12</sup>

Therefore, the transference of information about specific needs from the users to the manufacturers is difficult and costly. Von Hippel refers to this information that is costly to transfer as “sticky information,” and asserts that when transferring information from the point of origin – the user’s location – to the problem-solving site – the producer’s location – is difficult and costly, the locus of innovation will tend to shift from the producers to the users’ location.<sup>13</sup> Regarding the same subject, Lüthje et al. wrote that “user-innovators almost always utilize ‘local’ information – information already in their possession or generated by themselves – both to determine the need for and to develop the solutions for their innovations.”<sup>14</sup>

Additionally, user needs are very heterogeneous and again the “stickiness” of knowledge hinders the ability of manufacturers to learn from all those particular user-specific needs. Even when manufacturers get to know about the particular needs of the users,

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**11** Michael Polanyi, *Personal Knowledge. Towards a Post-Critical Philosophy* (Chicago: University of Chicago Press, 1958), 49.

**12** Michael Polanyi, *The Tacit Dimension* (Garden City, NY: Doubleday, 1966), 4.

**13** Von Hippel, Eric. “Sticky Information” and the Locus of Problem Solving: Implications for Innovation.” *Management Science* 40, no. 4 (April 1994): 429-439.

**14** Christian Lüthje, Cornelius Herstatt, and Eric Von Hippel. “User-Innovators and “Local” Information: The Case of Mountain Biking.” *Research Policy*, no. 34 (2005): 965.

responding to all these highly heterogeneous needs may be uneconomical.

As the ability of producers to learn of particular needs and respond to them is low, user needs will not be met by standard products. Therefore, some users – the Lead Users – will tend to develop their own solutions or modify the existing ones to satisfy their particular requirements.

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### 3.1.3 Support for User Innovation

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In the present thesis, the support given by producers of a technology to its users is divided into two categories. The first is “direct support for innovation,” which consists of the actions done by the producers to directly assist a particular user-innovator. That is the case, for example, when producers work on the code behind an application created by a user and improve it, or promote the user innovation through different channels. The second category of support is “indirect support for innovation,” which refers to the aid given by the producers to all the users in general, which is described here as User Toolkits and User Communities.

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### A User Toolkits

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As explained in the last section, the highly heterogeneous nature of user needs poses a problem to manufacturers. In order to keep their competitive role in the market with efficient products producers need to address the varying needs of their users. Satisfying markets-of-one can be costly, and therefore, in order to maintain their competitive position, other strategies arise. One of them is the appearance of the “user toolkit,” a set of tools to allow users to design products (or modify existing ones), prototype them (in the case of physical products), and finally, test their innovation.<sup>15</sup> According to Thomke and Von Hippel, these user toolkits must comply with four requirements.<sup>16</sup> First, they must enable complete design cycles from idea to testing, allowing trial-and-error cycles or “learning by doing.” Second, they should be user-friendly. Third, they must “contain libraries of useful components and modules that have been pretested and debugged.” Finally, they must contain specific information about the physical production of the user-designed innovation.<sup>17</sup>

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**15** Eric Von Hippel, *Democratizing Innovation* (Cambridge, Massachusetts: MIT Press, 2005), 147.

**16** Stefan Thomke, and Eric Von Hippel. "Customers as Innovators." *Harvard Business Review*, (April 2002): 77.

**17** The last requirement only applies to physical products.

These user toolkits take different forms according to the type of product they are tailored for. Some of the user toolkits for physical products are developed so users can design and do prototype testing, and once the solution is mature, the manufacturer is in charge of producing it for the specific user. That is the case with a set of ingredients created by Nestlé for chefs to “design” specific sauces that would later be manufactured especially for them in the Nestlé plant.<sup>18</sup> In other cases, especially for software, these user toolkits take the form of an SDK (Software Development Kit). SDK’s allow users to develop their own software add-ins or plug-ins on existing software to enhance the original product and develop specific tasks. That is so for much of the BIM software that offers users the ability to access the API (Application Programming Interface) of their products.

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## B User Communities

The literature notes that, in general, user-innovators are inclined to develop user-to-user informal cooperation, as well as more organized forms of cooperation. Von Hippel explains that, given the heterogeneous nature of user needs and the stickiness of information, “it is likely that product-development activities will be widely distributed among users, rather than produced by just a few prolific user-innovators.”<sup>19</sup> This accounts for the appearance of user communities, which are defined by Von Hippel as “meaning nodes consisting of individuals or firms interconnected by information transfer links which may involve face-to-face, electronic, or other communication.”<sup>20</sup> These communities are channels of communication between users that help them solve problems faster, taking advantage of the group knowledge implicit in a large community. They can involve user-to-user assistance – e.g., forums for seeking help regarding different matters – as well as more organized forms of assistance – e.g., public posting of tutorials, help documents, and freely released innovations. In general, they revolve around a specific product, practice, or technology.

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**18** Eric von Hippel, User Toolkits for Innovation. *The Journal of Product Innovation Management* 18 (2001): 253-255.

**19** Eric von Hippel, *Democratizing Innovation* (Cambridge, Massachusetts: MIT Press, 2005), 93.

**20** *Ibid.*, 96.

Some of these communities are created and supported by producers, who use them as a way to communicate with users, and at the same time alleviate their own need to support users by replacing producer-to-user support with peer-to-peer support.

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### 3.1.4 Free Release of Innovations and Open- Source Initiatives

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In their 2006 study of the user communities in the musical instrument market, Jeppesen et al. researched why users were inclined to share their knowledge and innovations in firm-hosted communities, risking that their knowledge and innovations could be taken and profited from by other users or by the hosting companies.<sup>21</sup> The answer they find is similar to explanations of open-source motivations. Open-source studies indicate as possible incentives for freely releasing code the intrinsic and extrinsic rewards this can bring to a programmer. Kogut and Metiu in 2001 indicated that an intrinsic reward could be the satisfaction of helping the community, as these user developers “share membership in communities that sustain reciprocity and identity.” As an extrinsic reward, the authors identify an increase in the reputation of a programmer and subsequently of his or her market value.<sup>22</sup> They compare open-source to the way in which scientific research communities publicly disseminate their findings as a mechanism of validation of their work.

Von Hippel also likens users freely revealing innovation to open-source strategy. Additionally, he cites the difficulty of keeping innovation a trade secret as another possible reason behind free release.<sup>23</sup> Furthermore, he refers to Allen’s studies on “collective invention,” which is the cumulative advancement of technology made possible by free release of technical information to interested competitors.

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**21** Lars Bo Jeppesen and Lars Frederiksen. "Why Do Users Contribute to Firm-Hosted UserCommunities? The Case of Computer-Controlled Music Instruments." *Organization Science* 17, no. 1 (January-February 2006): 45-63.

**22** Bruce Kogut and Anca Metiu. "Open source software development and distributed innovation." *Oxford Review of Economic Policy* 17, no. 2 (2001): 249.

**23** Eric von Hippel, *Democratizing Innovation* (Cambridge, Massachusetts: MIT Press, 2005), 77-91.

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### 3.1.5 Social Creation of Meaning

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Tuomi refers to innovation as a social process that generates a change in social practices. Fischer, citing the invention of the telephone, argues that technological diffusion often relates to social aspects:

[T]he promoters of a technology do not necessarily know or decide its final uses; [...] they seek problems or needs for which their technology is the answer, but [...] consumers themselves develop new uses and ultimately decide which will predominate. The story suggests that in promoting a new technology, vendors are constrained not only by its technical and economic attributes but also by an interpretation of its uses that is shaped by its and their histories.<sup>24</sup>

Here, Fischer highlights that users determine the way in which technology is used, and therefore social dynamics and culture play a key role in any technological development. According to Tuomi, technology refers not only to objects, but also to the socially accepted uses that it implies. These accepted uses lend meaning to technology. Because innovation implies users sometimes giving new, originally unexpected, uses to technology, to Tuomi innovation is “more about creating meaning than it is about creating artifacts.” His user-centric view of innovation “sees these ‘objects’ as carriers of social practice and as artifacts that embed theories of meaningful use [that are] open for reinterpretation and for new applications.”<sup>25</sup>

Through this theory Tuomi argues that “innovations become innovations only when they start to play a role in meaningful social practice.”<sup>26</sup> Before that happens, they remain as artifacts devoid of social value. Only when people start using an innovation does it realize its potential and prove its significance. He grounds this social value in communities of practice, the ones in charge of associating value to innovations by their application in context.

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**24** Fischer, Claude. *America Calling: A Social History of Telephone to 1940*. Berkeley: University of California Press, 1992. Quoted in Tuomi, Ilkka. *Networks of Innovation*. (New York: Oxford University Press, 2002), 11.

**25** Tuomi, Ilkka. *Networks of Innovation* (New York: Oxford University Press, 2002), 13.

**26** *Ibid.*, 20.

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## 3.2 Application of User Innovation Theory to the Case of BIM

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### 3.2.1 Innovation Definition in the Context of BIM

BIM innovation research has mainly been focused on the innovative applications of BIM in the field of AEC. Underwood et al., for example, discuss *Innovation through BIM*, referring to possible waves of innovation that may result from combining BIM with other technologies, such as web servers, cloud computing, or sensor networks.<sup>27</sup> Some academic work, on the other hand, has instead focused on innovation *in* BIM, focusing on the prototypical or theoretical development of a specific innovation. That is the case, for instance, of the mobile application proposed by Kalenja in her 2009 master's thesis<sup>28</sup> or the model information updating system proposed by Fuller in his work.<sup>29</sup>

The approach to innovation in the present thesis differs from those perspectives, focusing mostly on the existing innovation *in* BIM; in other words, the changes in technology that help users to adapt the tools to specific requirements.

Abernathy and Clarke contend in their article "Innovation: Mapping the Winds of Creative Destruction," that innovation consists not only of disruptive technology; in some cases, refinements in preexisting technology coupled with a change in its channels of distribution may have a high impact on the industry. According to their model, there are four types of innovation: (1) architectural, (2) niche creation, (3) revolutionary, and (4) regular. The term "innovation" in the present thesis will be understood as the one presented in the last category, regular innovation, which, as they define it, involves "change that builds on established technical and production competence [... . T]he effect of these changes is to entrench existing skills and resources."<sup>30</sup>

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**27** Umit Isikdag, Jason Underwood, and Murat Kurouglu. "Building Information Modeling." In *Construction Innovation and Process Improvement*, edited by Akintola Akintoye, Jack Goulding and Girma Zawdie (Ames, Iowa: Wiley, 2012), 399-403.

**28** Adela Kalenja, "The Hard Hat and the Hand-held Communication with Hand-Held Computing in the Construction Process." MSc Thesis, Massachusetts Institute of Technology, 2010.

**29** Pierre Fuller, "A Simplified Software Architecture for Self-Updating Building Information Models (BIM)." MSc Thesis, Massachusetts Institute of Technology, 2009

**30** William Abernathy and Kim Clark. "Innovation: Mapping the Winds of Creative Destruction." *Research Policy*, no. 14 (1985): 3-22.

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### 3.2.2 The Process Behind BIM User Innovation

Slaughter notes that, in general, user innovation studies focus on innovations that have become commercial products. Although it can be argued that this statement is not completely accurate, given that part of the literature is dedicated to studying the highly diffused open-source ones, the present thesis agrees in that little focus has been given to the non-commercial, less diffused ones. Slaughter observes that one of the disadvantages of transferring the responsibility of problem-solving to users is the possibility of duplication of efforts. Hence, her study concludes that relying on user innovation for major adaptations of products, which may meet a need common to many users, may slow the evolution of the product. As with the cases studied in the present thesis, Slaughter noted that the user innovation cases studied by her were not results from Research and Development, but rather a direct response to a practical matter of the project in construction and its particular conditions.

While in general user innovation literature focuses on the producers and the market, and how both incorporate user innovation, Slaughter's research focuses more on the process of innovation, extracting insightful conclusions about the reasons behind user innovation and its advantages and disadvantages. Similarly to Slaughter's focus, the present thesis frames the discussion about innovation in the realm of BIM technologies utilizing the user innovation theory, with the goal of understanding the process behind user innovation and how it may benefit the adaptation and evolution of certain technologies (BIM). In the context of this research, a case is understood as the process underlying the development of a BIM user innovation, from the starting point of the need that the user intends to meet, to the current stage of development and distribution of the actual innovation.

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### 3.2.3 User Innovation Flow Diagram

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Deriving from the original user innovation theory, a preliminary diagram was built. This diagram shows the possible interactions between the users, the standard existing BIM tools, and the user-generated innovations.

A chronological reading of the diagram indicates the presence of the following steps:

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A

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Standard tools are introduced to the users.

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B

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A subset of advanced users emerges inside the larger group of users. These are the ones that the literature refers to as Lead Users, who will tend to innovate in order to satisfy their needs which are ahead of the market.

---

C

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In some cases – and therefore the dashed line – Lead Users will receive direct support for innovations from developers/vendors of the standard tools. This support can take the form of diffusion through firm-hosted information communities – blogs, forums, and others – or actual code development for the application.

---

D

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Then the user, in order to satisfy a specific need, starts developing an innovation that can consist in adapting a standard procedure or developing tools or components to interact with the standard BIM tools. This happens in the realm of their professional practice.

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E

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As the literature indicates, the user is in a privileged position to test the innovation. Therefore, the innovation goes through a process of trial and error until it reaches a point of acceptable maturity.

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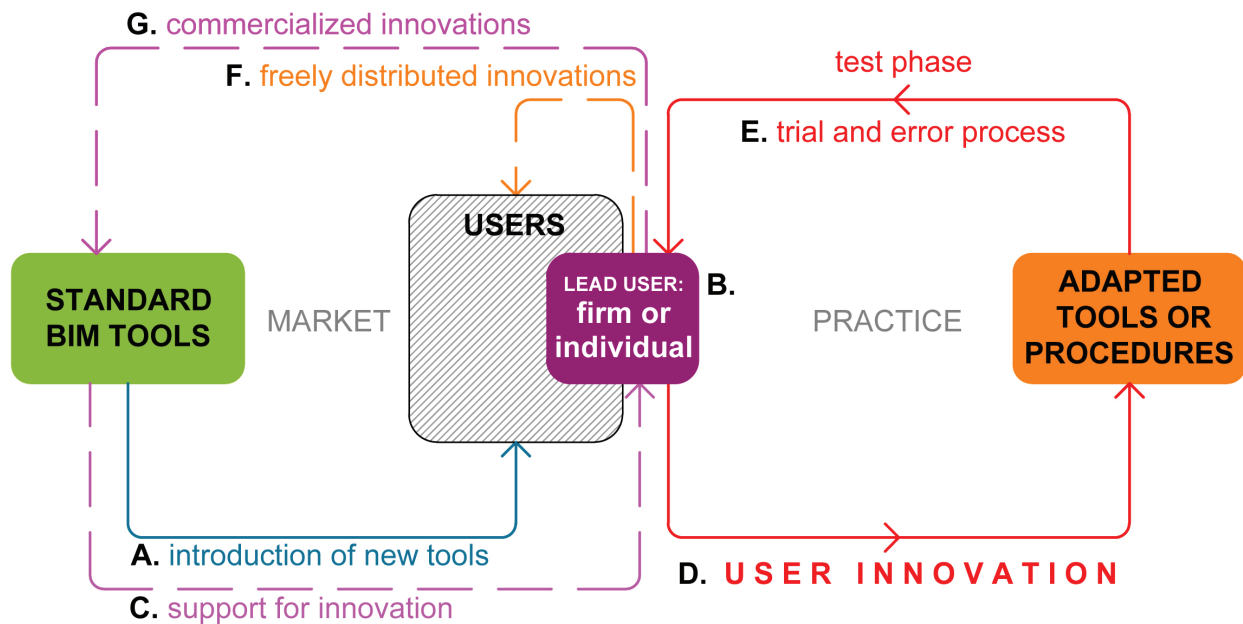
F

---

When the tool is mature enough, in some cases – again in dashed line – Lead Users freely reveal their innovations to the larger group of users, and the original developers of standard tools can also use the innovations at no cost.



**Figure 1**  
Preliminary User Innovation  
Flow Diagram for BIM.



two channels. One may be the direct commercialization of the innovation by its creator. The other may be that the original Standard BIM tool incorporates the innovation and thereby makes it commercially available to the larger group of users in subsequent releases of the tool.

H

When the innovation is adopted by the larger group of users (as a paid or free application) the process of user innovation starts all over again, and other lead users may innovate to adapt this innovation.

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### 3.2.4 Indirect Support for Innovation in BIM

Regarding user toolkits, the thesis recognizes the existence of two different sets generally present in BIM software. The first one relates to the parametric components most of the commercial applications come with by default. Main BIM software utilizes an object-based approach, relying on objects called “families” that represent parts of the buildings and contain information about those components and, in some cases, the ability to modify them through changes in their properties. Most BIM software has default packages of families that are installed along with the original application. New user-specific components can be created in most of this software through templates that include tools to create and parameterize these components. In that way, this first BIM-user-toolkit can be related to Thomke’s requirements for user toolkits (user-friendliness and the existence of a predefined library).<sup>31</sup> Nevertheless, the ease of use of the interfaces that enable users to develop new family components can be questioned. While their use in general does not require programming knowledge, it still requires the user to have advanced knowledge of very specific configurations of the BIM application being used; again,,in general, their use demands a very organized step-by-step approach where there is great opportunity for error.

The second user toolkit for BIM applications is the Software Development Kit that is typically freely released to all users. SDK’s allow users to create their own plug-ins, accessing properties of objects, reading and writing information, and automating different tasks. The options that these user toolkits open for users are immense. Nevertheless, these user toolkits require that users have strong knowledge about programming and at the same time a good understanding of the specific BIM application in use, as the hierarchies and highly structured nature of BIM components and relations have to be knowledgeably managed in the coding process.

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**31** See section 3.1.3 a.

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### 3.3 Case Study Methodology

This thesis takes the form of a descriptive case study.<sup>32</sup> Eight cases are analyzed in order to examine whether and how user innovation is shaping BIM tools and their use.

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#### 3.3.1 Sources of Evidence

Given that the cases studied are not yet widely published and only one of them has been discussed in journal articles or proceedings, the main sources of evidence for studying them were online *documentation* and in person or online *interviews*. In the case of CO-MIT Workshop there was also the opportunity to gather information through *participant observation*.<sup>33</sup>

For each case there was a preliminary phase where information was gathered from online documentation, information communities, professionals, and vendors. This information was used to understand the user involved – be it a firm or an individual – and the innovation developed. In a subsequent phase a semi-structured interview in person or online – with one exception of an email one – was conducted with a relevant actor of the case; directly with the user-innovator for the cases that were developed by an individual, and with key actors, such as BIM managers or Digital Design Specialists, for the cases where the innovator was a firm. There were two different approaches for these interviews. Cases with better online documentation allowed building of questionnaires to prepare a *focused interview* pointing to the key concepts and processes behind the innovations. For cases with no online documentation, first interviews were less structured, allowing a broad inquiry into BIM, innovation, and adaptation. Through these broad interviews, possible innovation cases to be studied were selected. Afterwards, new, more focused interviews were conducted regarding those specific cases.

---

**32** Descriptive case studies are defined by Yin as the ones that: “describe an intervention and the real-life context in which it occurred.” Robert Yin, *Case study research : design and methods*. 4th. (Los Angeles, CA: Sage Publications, 2009): 19-20.

**33** Yin states there are six sources of evidence for case studies: documentation, archival records, interviews, direct observation, participant-observation, and physical artifacts. Robert Yin, *Case study research : design and methods*. 4th. (Los Angeles, CA: Sage Publications, 2009): 101-114.

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### 3.3.2 Unit of Analysis

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The unit of analysis of the present case study, as stated in previous sections, is the process underlying the development of a BIM user innovation, from the starting point of the need that the user intends to meet, to the current stage of development and distribution of the actual innovation. The cases were analyzed to assess:

- the specific characteristics of the user-innovator,
- the user need that motivated the innovation,
- the process and resources devoted to the development of the innovation,
- the resulting innovation and its application in its *context of use*,
- the process of distribution of the tool (in the cases where it exists),
- and finally, whether the innovation has met the user need or changed the use of the original BIM tool.

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### 3.4 Criteria for Case Selection

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This study originally intended to present cases from different *contexts of use*, mainly according to their region, type of project, and type of discipline. However, the preliminary research indicated that innovation is not uniformly distributed and that it tends to accumulate in certain, more resourceful, *contexts of use*. Therefore, the original goal was modified, and the cases, although still portraying different contexts of use, do not represent all of them. In turn, cases were selected to exemplify different possibilities regarding four characteristics observed in the innovation literature in general and more specifically user innovation literature: types of users, motivations, availability of direct support from vendors, and different methods of distribution. The sample does not claim to be exhaustive or to portray all the types of innovations for all the types of context of use.

---

A  
Types of users

In his 1983 paper, Allen identifies four types of agents behind invention. While the first three types – non-profit institutions such as universities and government agencies, private firms, and individuals – had been already identified by the literature of his time, he proposes a fourth one: collective invention. Collective invention, as defined by Allen, is the development of a product or technology that is made possible by firms or individuals by the release of its “technical information to actual and potential competitors,”<sup>34</sup> thus allowing a cumulative advancement of the product.

While the first three types of agents named by Allen have been identified in BIM user innovation cases, collective invention remains in its early stages. Attempts to promote collective invention have been made in most of the cases studied, but almost none of them have been successful in improving the innovation through this means. The result of the preliminary research done in Chile, for example – searching for cases that corresponded to a specific region – showed that even though users had identified many needs, most of the time they did not have the necessary resources to innovate. This was on some occasions compensated for by vendors adapting BIM tools – i.e., to local building norms and methods of construction – in order to make the tools’ implementation viable for local users.

---

B  
Motivations

There were basically two types of motivations behind the development of innovations by the users. One was an exploratory motivation, a search to understand the limits of the tools and what was possible to achieve with them. The other motivation responded to a purely practical matter of solving a particular problem of a project. The exploratory motivations were only observed in individuals, working in their spare time, not in firms.

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<sup>34</sup> Robert Allen, "Collective Invention." *Journal of Economic Behavior and Organization*, no. 4 (1983): 1.

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C  
Direct Support from  
Vendors

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Innovations were receiving direct support from vendors in the form of actual coding or diffusion through blogs and conference presentations.

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D  
Distribution

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The preliminary research indicated there were different types of distribution. Some innovations were being released as open-source, some as free software, and some as commercial products. Additionally, some innovations were being kept as in-house developments.

The eight cases presented in this study were selected to represent different combinations of these four categories. The innovations were selected for their potential of changing the way in which users utilize BIM tools in their different *contexts of use*. Most of the innovations studied were or will be released to the public for a low price, or as freeware, and in some cases even as open-source. That allows the broader community of users to apply them in their projects and even to build their own adaptations on top of them, opening the possibility for BIM tools to grow in an organic way, dictated by the user interests and needs and not only dictated by the original developers and vendors of the technologies.

The original intention was to find cases that could depict innovation relating to different BIM tools. Nevertheless, all the cases found were related to Revit. The thesis does not intend to negate the possibility of user innovation emergence related to other BIM software, but merely portrays the findings of the research.



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# Cases

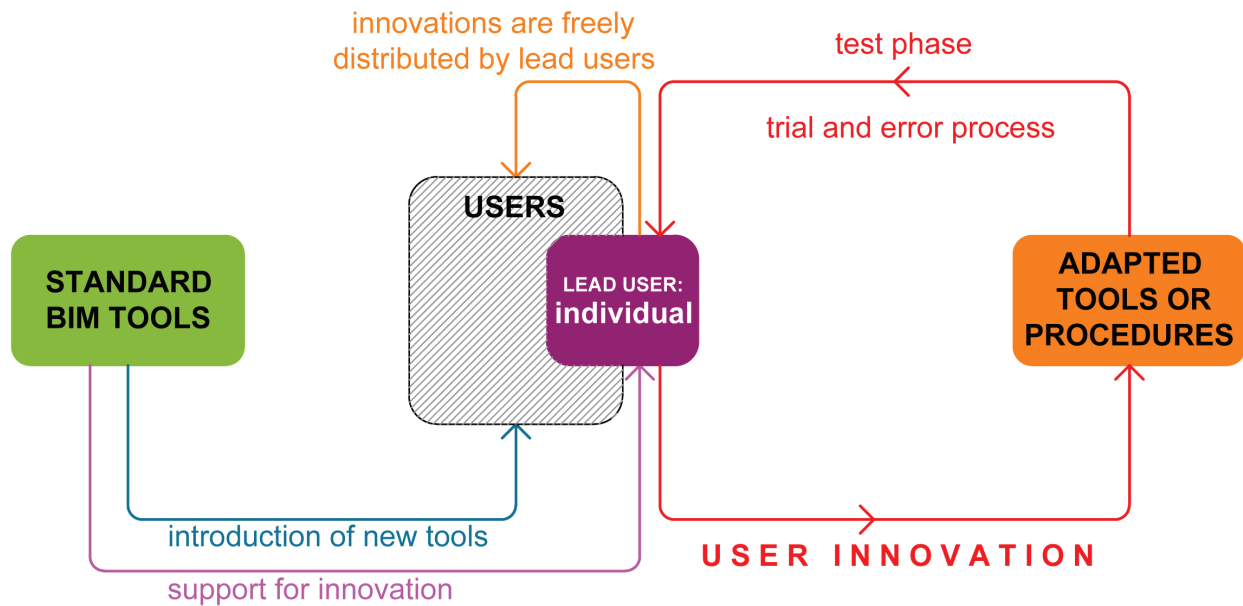
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Unless noted otherwise, the information presented in the case reports is extracted from personal interviews conducted with relevant actors from each case. The complete list of interviews can be found in Section 6.

## 4.1 Dynamo



**Figure 2**

Dynamo: User Innovation Flow Diagram.

**Description of Innovation:**

Visual programming plug-in for Revit

**Type of user-innovator:**

Individual (Architect)

**User need/motivation:**

Exploratory

**Distribution:**

Open-source

**Direct support from vendors:**

Yes (Diffusion - AU, blogs, and the Labs - and Coding)

**Diffusion from User-Innovator:**

Yes (User's blog)

---

#### 4.1.1 Description of the Innovation

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Dynamo is a plug-in for Revit and Vasari that displays a graphical interface for adding and adjusting parametric functions of BIM components. It was developed by Ian Keough, an architect who, at the time of the development, worked for a large engineering and consulting company in New York. The official information that accompanies the code describes it as “Visual programming for Revit”. Additionally, this information states:

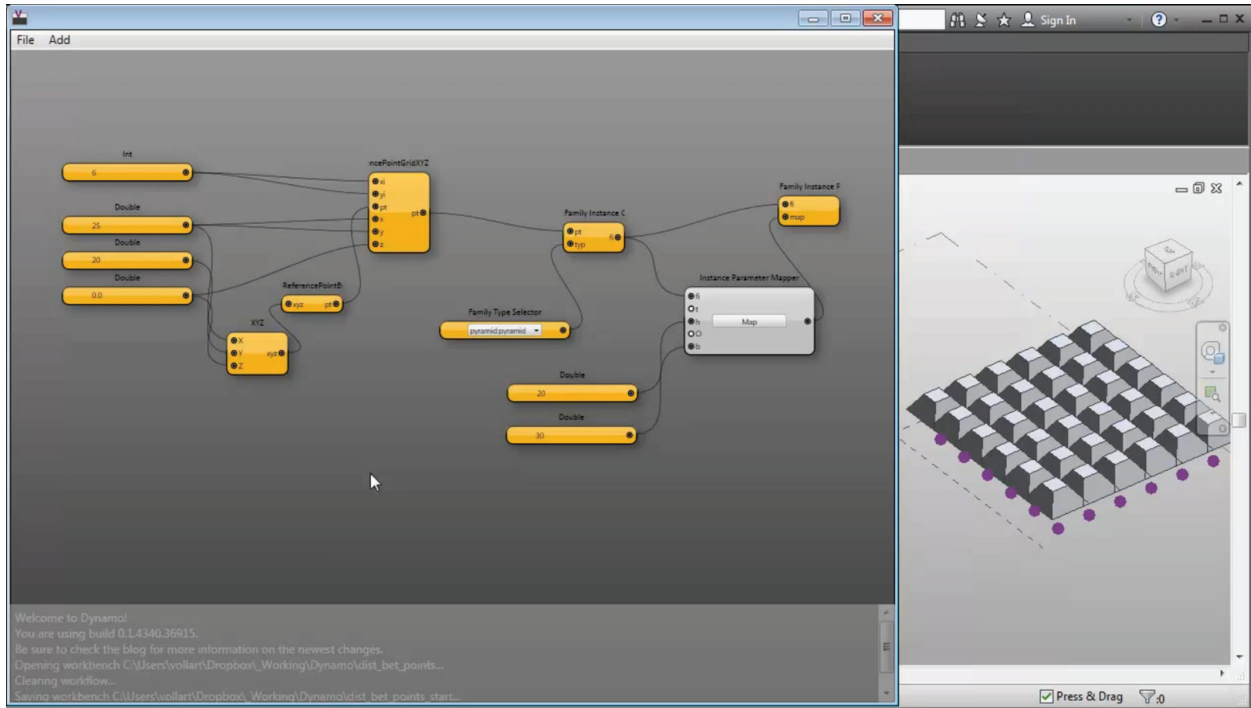
This project was started by Ian Keough. The intent of this project is to provide a code playground for building interesting parametric functionality on top of that already offered by Revit, and to do so with a graphical interface that allows you to share your work with others less inclined to write code themselves.<sup>1</sup>

Like Grasshopper – a widely adopted plug-in for the geometric modeler Rhino – Dynamo’s graphic interface allows users to control parameters of the model through programming language encoded in graphical elements or nodes.

Its current version was released (or uploaded) in January 2012. Currently, the tool allows users to directly interact with family parameters by inputting values to graphical elements. Additionally, it opens the possibility for families to be modified through information collected by sensors using an Arduino board or a Kinect sensor.

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<sup>1</sup> Note in the README file that accompanies the installer.



**Figure 3**  
Dynamo's User Interface.

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#### 4.1.2 Motivation / User Need and Goal

The motivation or user need for developing Dynamo was of an exploratory nature. In this case, there was no particular problem or requirement to solve through the development of the application.

Keough, the *user-innovator*, was interested in discovering new possibilities for the BIM tool he was using, Revit. He wanted to add a functionality that was missing from the standard product. With this innovation, he desired to further improve one of what, in his opinion, were the greatest strengths of the program: its parametric components. The goal was to build a tool that would allow families to interact and respond to each other's parameters, or to external inputs, such as information gathered by sensors. Additionally, the tool would allow conducting analysis, such as of daylighting, and using those analyses to drive family parameters.

With this innovation he acknowledges what he sees as one of the main desires of technology users: "When a software that [people] are using doesn't have the capability for doing something off the shelf, they would love it if there was a simple interface for building their own tools to do complex stuff."<sup>2</sup>

---

#### 4.1.3 Development and Testing Process

The first rudimentary version of the application was completed by October 2010. At that stage, the tool had no visual interface; it was just a programming library – in Keough's words, the tool was "a software library for adding functionality to Revit."<sup>3</sup> Afterwards, in 2011, the program was completely rewritten. In September 2011, Keough began posting descriptions and images of the development progress in his personal blog.<sup>4</sup> On October 2<sup>nd</sup>, 2011, he finally posted a link to freely download the program. Eighteen days after releasing the program, on October 20<sup>th</sup>, Keough released Dynamo's source code under the Apache Software License 2.0, expecting that this would accelerate the development of the application. Nevertheless, as of April 2012 he had not yet received feedback from users working with his code. On the other hand, he has received the attention and support of Autodesk developers.

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<sup>2</sup> Ian Keough, interview by author. Online interview, (February 16, 2012).

<sup>3</sup> Ian Keough, interview by author. Online interview, (February 16, 2012).

<sup>4</sup> Ian Keough, "ianCode", <http://iankeough.com/wordpress/?m=201109>

New capabilities have been added by Keough in subsequent releases of the tool. Some of the milestones of this evolution have been the addition of the Kinect connection capability in November 2011, and the addition of the connection to Vasari later in the same month. Additionally, frequent releases have fixed issues. Nevertheless, the application is still in a developmental stage and is not completely stable yet.

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#### 4.1.4 Support from Vendors / Developers

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As mentioned earlier, Dynamo's source code was made open-source with the intention to accelerate its development progress. Nevertheless, the only support Keough has received so far has come from Autodesk developers. Zach Kron and Matt Jezyk, who are part of the Project Vasari team, have supported Keough in two ways. One has been diffusion; Kron in his personal blog has repeatedly posted about Dynamo and its progress.<sup>5</sup> Kron and Jezyk also presented Dynamo in combination with Vasari at Autodesk University (AU) and at the New York Revit User group. The presentation for AU detonated the second type of direct support that Autodesk has given to Dynamo, actual programming. The class called "Autodesk® Project Vasari: Playing with Energetic Supermodels" dealt with energy simulation, using automated feedback loops to drive geometry.<sup>6</sup> In fact, in preparation for that presentation, some changes were introduced in Dynamo as well as in Vasari. Kron explains that, in order to output meaningful information for Dynamo to process, they needed to improve the calculations inside Vasari. They put two developers to the task. One was in charge of experimenting with the internal process of solar radiation in Vasari, and the other was in charge of making new Dynamo components that could receive and process the data coming from Vasari or Revit.<sup>7</sup>

Currently the official Vasari download webpage (<http://labs.autodesk.com/utilities/vasari/>) holds a direct link for downloading Dynamo, as well as a link to a help page with installation instructions and a short video tutorial.

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<sup>5</sup> Zach Kron, <http://buildz.blogspot.com/2012/04/vasari-talk-visual-programming-in.html>

<sup>6</sup> Autodesk University, "Autodesk® Project Vasari: Playing with Energetic Supermodels" [http://au.autodesk.com/?nd=event\\_class&session\\_id=10032&jid=1766330](http://au.autodesk.com/?nd=event_class&session_id=10032&jid=1766330)

<sup>7</sup> Zach Kron, interview by author. Online interview, (March 8, 2012).

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#### 4.1.5 Current State, Further Developments, and Diffusion

Keough believes there is no commercial potential for the tool, as there is no market of users interested in controlling their models through Kinect or Arduino, although the large number of designers using Grasshopper might lead one to think the opposite. Still, he leaves room for future possibilities. "Everybody is trying to think: what do we do with these models now? [...] We have these model assets, after we construct the building we still have these models. How do we keep it valuable? Can you use the model for the visualization of certain building systems or as a control interface for certain building systems? I change this parameter in my model and a window somewhere in the building closes."<sup>8</sup>

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#### Motivation for Freely Releasing the Innovation

The Apache License is a free software license that allows people to use a software application, distribute it, modify it, and commercially distribute modified versions of it, with the condition that the original copyright notice should be kept for all the parts that are being utilized from the original version.<sup>9</sup> According to Keough, the reasons for releasing Dynamo as open-source under the Apache License were three. First, he had no particular interest in commercializing the tool for the moment, as developing the tool up to a point of maturity sufficient to become a commercial product would be a very time-consuming task. As mentioned earlier, this application is being developed as a hobby for Keough and he does not intend to turn it into his actual job. Nonetheless, as the Apache license allows anyone to take Dynamo's code or part of it, work on it, and afterwards commercialize it, the license would allow Keough to turn Dynamo into a commercial product in the future. Despite this, he states that he has no further plans for Dynamo, as it is far from being a stable program.

The second reason named by the user innovator for releasing the tool as open-source is his intention to accelerate the development process of Dynamo by having other user-innovators contributing to the main source code.

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<sup>8</sup> Ian Keough, interview by author. Online interview, (February 16, 2012).

<sup>9</sup> Unlike other more open software licenses, such as the General Public License (GPL), the Apache license does not force subsequent modifications of the source code to also be released in the form of free software. Apache License allows programmers to "take their modifications private, i.e. to sell versions of the program without distributing the source code of the modifications." Bruce Kogut and Anca Metiu. "Open Source Software Development and Distributed Innovation." *Oxford Review of Economic Policy* 17, no. 2 (2001): 253.

Finally, he states that he desired to give free access to users, to make it easier for them to build more interesting projects with BIM tools, and, at the same time, have access to the code behind that. This, he thinks, would become an incentive for users to learn and build their own tools, or at least build on top of existing ones. The open availability of Dynamo, he thinks, “could potentially accelerate people participating in creating their own tools and growing these products organically.”<sup>10</sup>

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#### 4.1.6 User-Innovator’s Background

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Ian Keough is an architect who, by the time he began developing Dynamo, worked as an Associate Technical Designer for the engineering and consulting firm Buro Happold in New York. He is currently employed by Vela Systems as a Solution Architect specializing in BIM products. He explains he had little knowledge of programming before starting at Buro Happold and his first developments inside Buro Happold were small plug-ins to connect different software and to streamline workflows.

While in New York, Keough taught for a couple of years in the School of Architecture, Planning and Preservation at Columbia University (GSAPP). His course was based on CatBot, an open-source software he developed along with David Benjamin – another Columbia Professor – to connect Catia and the structural analysis software Robot.<sup>11</sup> As he currently lives in Los Angeles, he has “advised students in the building science department [at UCLA] on projects around writing code for the Revit API and using Dynamo and Arduino to control BIM models.”<sup>12</sup>

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**10** Ian Keough, interview by author. Online interview, (February 16, 2012)

**11** Ian Keough, ikeo-catbot, <http://code.google.com/p/ikeo-catbot/>

**12** Ian Keough, interview by author. Online interview, (February 16, 2012).



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#### 4.1.7 Summary and Conclusions of the Case

Comparing the model – and consequent flow diagram – that the development of Dynamo suggests to the original user innovation model, this case shows most of the originally predicted flows, with the exception of commercialization of the innovation. There is direct support for innovation – in the form of diffusion and also actual coding. Additionally, there is an ongoing iterative process of development where the innovator, by releasing his innovation for free through the web, intends to make the larger group of users part of that trial-and-error cycle. As stated by the user-innovator responsible for this development, this type of *collective invention* has not happened yet, as the larger group of users has acted as passive users rather than active contributors (or lead users) in the development process. Nevertheless, the direct support from the original developers has replaced the role of the larger community contributing to the maturing of the tool.

Additionally, this case exemplifies one of the ways in which innovations can be adopted by general users described by the user innovation theory. By releasing the program as open-source, Keough creates the opportunity for the larger user community to take advantage of his user innovation and at the same time gives advanced users, with programming knowledge, the opportunity to become lead users themselves by building new tools on top of his innovation. All the above can be related to the open-source movement and the role of user communities described by the user innovation theory. As indicated in the Open-source Initiatives section (3.1.3 A.), the literature identifies as reasons behind open-source initiatives the existence of intrinsic and extrinsic rewards for the innovator. When questioned on why he released Dynamo for free, Keough stated that he “wanted to give others the tools he didn’t have,” in other words, an intrinsic reward. Furthermore, he explained, “I want to provide the tools I didn’t have and I want to provide them in a way that is really easy for people to get at them, and in a way that can train people to make tools themselves.”<sup>13</sup> One extrinsic reward that can be identified in this case is the incipient recognition that Dynamo is starting to receive in the AEC industry, although still as an experimental tool rather than a practical and functional one. Another extrinsic reward is the advancement that releasing the code could bring to the tool, by having several developers. As stated by Keough, this collaboration has not happened yet, but it is a potential benefit. We can relate this approach of seeking collaboration or *collective invention* to the

<sup>13</sup> Ian Keough, interview by author. Online interview, (February 16, 2012).

development of other technologies that have benefited from having multiple programmers, such as Linux – of which Tuomi states that the open-source development behind Linux “creates complex new technology better and faster than the biggest firms in the software industry”<sup>14</sup> – and Apache server – of which Kogut and Metiu claim that its open-source development model “exploits the intelligence in the distributed system.”<sup>15</sup>

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**14** Ilkka Tuomi, *Networks of Innovation*. (New York: Oxford University Press, 2002), 1.

**15** Bruce Kogut and Anca Metiu. "Open Source Software Development and Distributed Innovation." *Oxford Review of Economic Policy* 17, no. 2 (2001): 259.

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#### 4.1.8 Specific Bibliography and Research Resources for the Case

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Autodesk Labs. Two New Free Addins available for Project Vasari. January, 2012. [http://labs.blogs.com/its\\_alive\\_in\\_the\\_lab/2012/01/two-new-free-addins-available-for-project-vasari.html](http://labs.blogs.com/its_alive_in_the_lab/2012/01/two-new-free-addins-available-for-project-vasari.html).

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Keough, Ian, interview by author. Online interview, (February 16, 2012).

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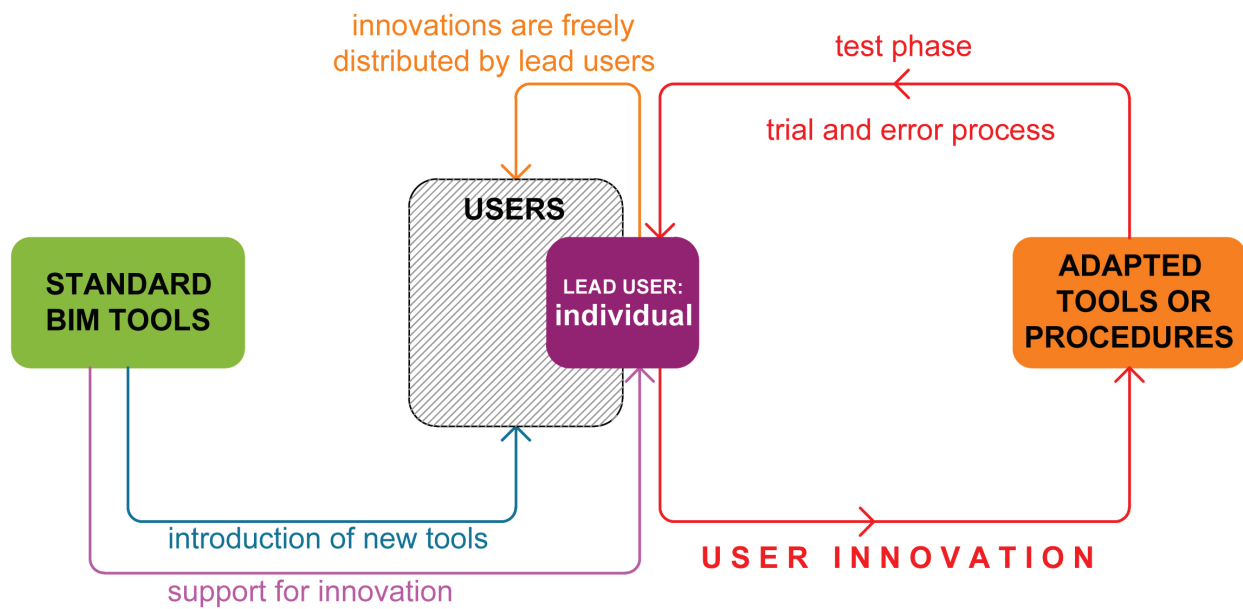
Keough, Ian, interview by author. Email interview, (April 18, 2012).

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Kron, Zach, interview by author. Online interview, (March 8, 2012).

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## 4.2 Revit Python Shell



**Figure 4**  
Revit Python Shell: User  
Innovation Flow Diagram.

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**Description of Innovation:**

Python scripting plug-in for BIM

**Type of User-Innovator:**

Individual (Software Developer)

**User need/motivation:**

Streamlining the API programming process

**Distribution:**

Open-source

**Direct support from vendors:**

Yes (Diffusion – blogs – and Coding)

**Diffusion from User-Innovator:**

Yes (User's blog)

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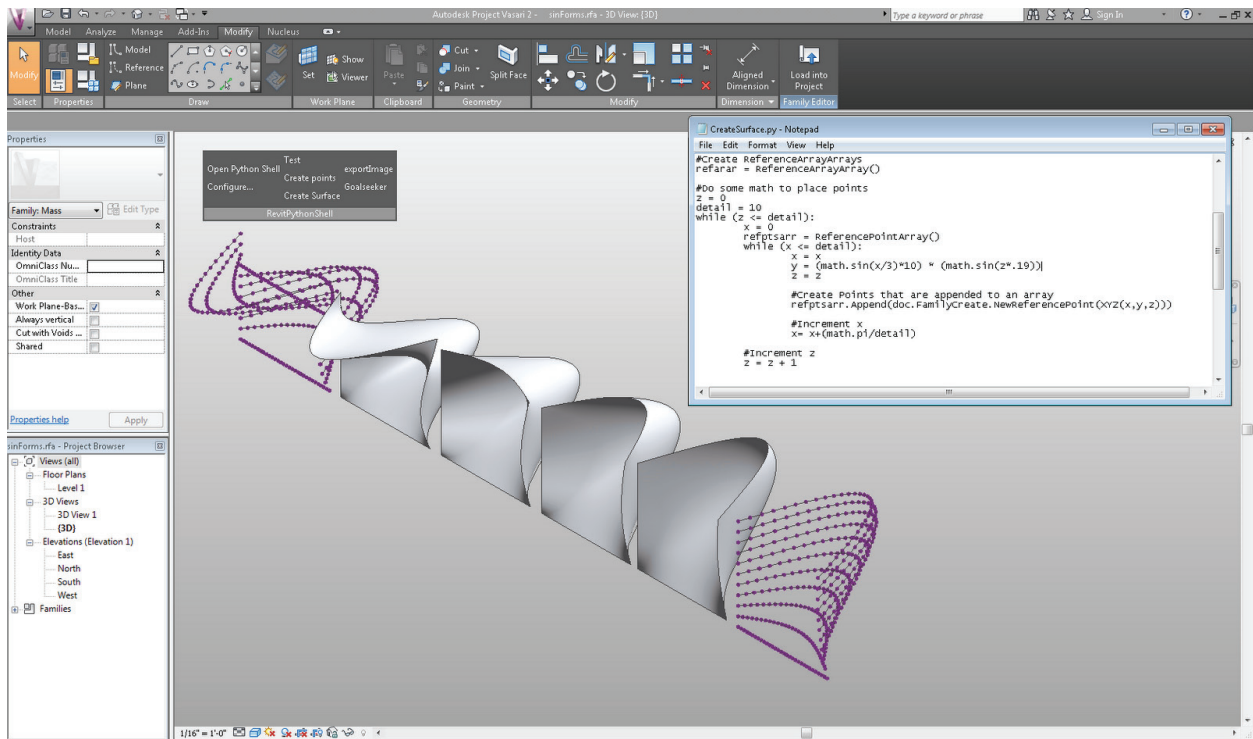
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#### 4.2.1 Description of the Innovation

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In December 2009, Daren Thomas, a software developer at the Swiss Federal Institute of Technology (ETH), released Revit Python Shell, a plug-in that enables scripting using Python language inside Revit. The goal of the application is to facilitate the access to the Revit API, thereby suppressing the need for restarting the program to test the application every time the code is modified. First introduced for Revit Architecture 2010, the shell embeds a .NET port of the Python language called IronPython as a plug-in in the Revit environment, eliminating the need to create plug-ins in an independent C# text editor / compiler.

The designer maintains a personal blog (<http://darenatwork.blogspot.com>) where he updates readers of the latest updates of the shell.



**Figure 5**  
Form Creation with Revit  
Python Shell.

---

#### 4.2.2 Motivation / User Need and Goal

In 2009, in the context of his work at the Swiss Federal Institute of Technology in Zurich (ETH), Daren Thomas built a tool called Design Performance Viewer (DPV). Working on top of Revit, DPV enables “instantaneous energy and exergy calculations and the graphical visualization of the resulting performance indices.”<sup>16</sup> During DPV’s development process, Thomas ran into the tedious repetitive cycle involved in coding external applications for Revit – writing the code, compiling the program, opening Revit, testing the add-in, closing Revit and starting the process all over again for every change that is introduced in the code. In order to avoid this repetitive and time-consuming task, Thomas decided to build a tool to speed up the process. About his motivation to build RPS, he says, “I was looking for a way to speed up the development cycle and settled on creating a host inside the host to execute my extensions.”<sup>17</sup>

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#### 4.2.3 Development and Testing Process

The process for the creation of the initial version released in 2009, as described by Thomas, took no longer than a month. After releasing the program for free as an open-source code, he has received valuable feedback from the users about bugs and also some help in the debugging process. He expects to receive more of this feedback in the future in order to keep the project alive.

---

#### 4.2.4 Current State, Further Developments, and Diffusion

A counter in the download page indicates that RPS for Vasari and Revit 2012 have been downloaded 320 times each.<sup>18</sup> Thomas clarifies that this quantity generally includes multiple downloads by the same person and he assumes that it is safe to assume that 30% are valid users. Even with a conservative calculation such as this, the number of users would be about 200 around the world. With that in mind, he is considering developing proper documentation for the tool, as it currently does not have any type of help or tutorials associated.

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**16** Arno Schlueter and Frank Thesseling. "Building Information Model Based Energy/Exergy Performance Assessment in Early Design Stages." *Automation in Construction*, no. 18 (2009): 153.

**17** Daren Thomas, interview by author. Email interview, (April 28, 2012).

**18** As of April 01, 2012.

Thomas' plans for the future for RPS are not clear. He has been focusing less of his work on the DVP – the original reason for creating RPS – thus making his dedication to the latter hard to justify as a work need. He may continue developing it in his spare time, but that is unclear for the time being.

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#### Motivation for Freely Releasing the Innovation

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The plug-in was released in 2009 as open-source under the MIT license. When asked about the reasons for freely releasing his tool, Thomas answers: “Why not? It isn’t something you can sell. We weren’t interested in polishing it up and creating a business out of it – [...] RPS is just to help us do our real work. Also, the whole project was only really possible because I could glue together other open-source stuff.”<sup>19</sup>

In essence, his reasons to release the tool for free were two. First, for him RPS was not a commercially interesting project and selling the tool was not the main goal of Thomas or the team. Second, Thomas had used code from other open-source projects (IronPython, IronTextBox2, and IronLab), so he wanted, on one hand, to contribute back to the community that had made his own development possible, and on the other hand, was not allowed to commercialize the code taken from other open-source projects.

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#### 4.2.5 Support from Vendors / Developers

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Thomas has had direct help in the coding process from the people from Autodesk mainly for two tasks: porting the application to Revit 2012 and then porting it to Vasari. He has also had support from Autodesk-related blogs *buildZ* and *the Building Coder*.

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#### 4.2.6 User-Innovator’s Background

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Daren Thomas is a Computer Scientist who has been working as a software developer for the past thirteen years. He has spent the last three years at the Institute for Technology in Architecture at the Swiss Federal Institute of Technology Zurich (ETH), “working on providing building performance metrics at early design phases to assist architects in developing emission free buildings.”<sup>20</sup> His connection to architecture is a direct result of his place of work.

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<sup>19</sup> Daren Thomas, interview by author. Email interview, (April 28, 2012).

<sup>20</sup> Daren Thomas, interview by author. Email interview, (April 28, 2012).



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#### 4.2.7 Summary and Conclusions of the Case

Comparing the model – and consequent flow diagram – that the development of Revit Python Shell implies with the original user innovation model, the present case shows most of the originally predicted flows, with the exception of commercialization of the innovation. As in the Dynamo case (section 4.1), the development of RPS presents direct support for innovation – in the form of diffusion and also actual coding. There is an ongoing iterative process of development where the innovator, by releasing his innovation for free through the web, intends to make the larger group of users part of the trial-and-error cycle. As stated by Thomas, this has occurred as some users have identified bugs in the application, which has helped Thomas fix them. Additionally, the most active support has come from the original vendors/developers who have contributed to making the tool available to the larger group of users.

Revit Python Shell was a tool created for an intermediary purpose, to streamline the creation of another tool, in other words to streamline the act of programming in Revit API. As such, it is interesting that, more than being used as a tool for streamlining programming in Revit, it is being given recognition as a scripting tool to generate form through coding directly in the massing environment of the program. The tool has had large diffusion,<sup>21</sup> owing in part to the fact that it is currently the only tool that enables such capability. This situation can be related to the ideas of Tuomi of how technologies receive meaning through the use that people give them, especially the unintended uses.

Regarding distribution, the explanation behind the decision to release the application as open-source directly relates to motivations identified in open-source literature. Thomas is willing to dedicate part of his spare time to generate documentation for his tool to help users understand and apply the tool. This, of course, does not directly benefit Thomas, but may bring him extrinsic rewards; in other words, a growth in his software developer reputation. In fact, Thomas has become known among large architecture firms<sup>22</sup> and software companies. Furthermore, we can speculate that, given that RPS is currently the only scripting tool for Revit, this

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<sup>21</sup> Nathan Miller, The Proving Ground, Revit Python Shell, <http://theprovingground.wikidot.com/revit-api#toc2>

<sup>22</sup> In an interview conducted on April 2012, Joel Putnam from SOM Chicago indicated they have been in direct contact with Thomas to inquire about specific functionalities and that this collaboration resulted in some changes in RPS made by Thomas. Joel Putnam, interview by author. Online interview, (April 10, 2012).

de facto condition of the application may return economic benefit to Thomas at some point in the future. As Von Hippel indicates, “an innovation that is freely revealed and adopted by others can become an informal standard that may preempt the development and/or commercialization of other versions of the innovation. [...] his can result in creating a permanent source of advantage for that innovator.”<sup>23</sup> Independently of the truth of this last claim, Thomas is actively giving back to the community.

Finally, the fact that a skillful software developer like Thomas is compelled to create a tool to streamline the process of innovation that the existing user toolkit enables, might indicate that BIM user toolkits for innovation, or at least Revit ones, are not sufficiently user-friendly.<sup>24</sup> Therefore, if user-toolkits are not easy to use, innovation becomes a complex process and as such will be restricted only to advanced users with very specific skill sets (programming knowledge and a higher understanding of the hierarchical structure of BIM).

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**23** Eric Von Hippel, *Democratizing Innovation*. (Cambridge, Massachusetts: MIT Press, 2005): 86.

**24** User-friendliness is one of the main requirements that these sets of aides must comply with according to Thomke and Von Hippel. See section 3.1.3 a.

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#### 4.2.8 Specific Bibliography and Research Resources for the Case

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Thomas, Daren. Daren @ Work. Introducing Revit Python Shell. December, 2009. <http://darenatwork.blogspot.com/2009/12/introducing-revitpythonshell.html>.

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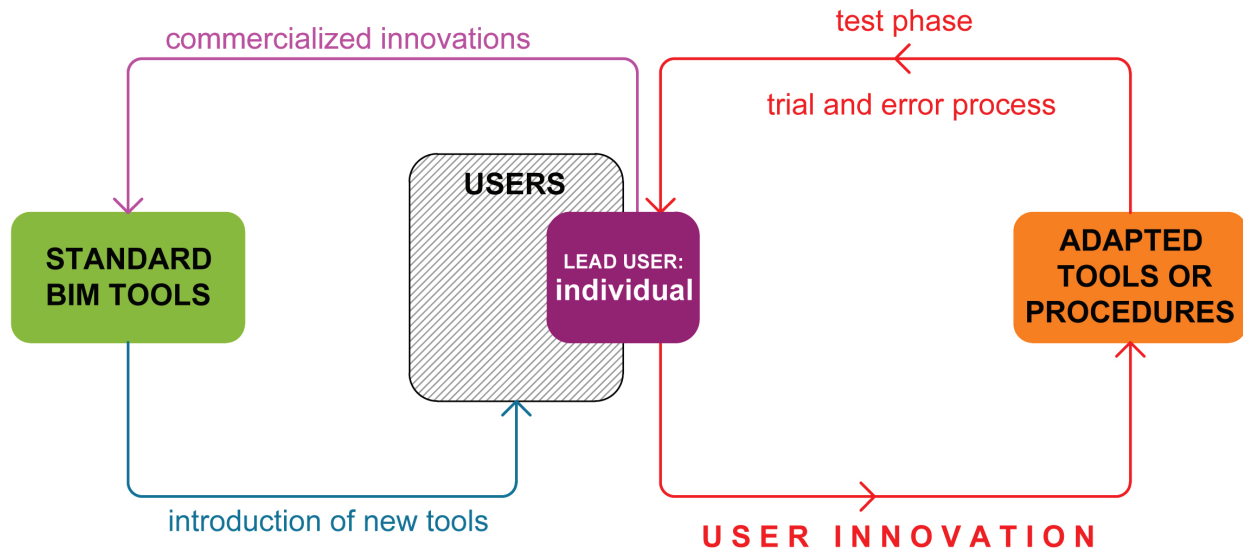
Thomas, Daren. [revitpythonshell](http://code.google.com/p/revitpythonshell/). <http://code.google.com/p/revitpythonshell/>.

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Thomas, Daren, interview by author. Email interview, (April 28, 2012).

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## 4.3 goBIM



**Figure 6**  
goBIM: User Innovation Flow Diagram.

**Description of Innovation:**

BIM visualization tool for mobile devices

**Type of User-Innovator:**

Individual (Architect)

**User need/motivation:**

Exploratory

**Distribution:**

Commercialization (Apple App Store)

**Direct support from vendors:**

No

**Diffusion from User-Innovator:**

Yes (User's blog and Acadia)

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#### 4.3.1 Description of the Innovation

goBIM is a mobile application originally designed for the iPhone. According to Keough, the user-innovator behind it, goBIM is “a model viewer, markup, and data querying environment”<sup>25</sup> for Apple iPhone in combination with Revit. The goBIM development consists of two parts: the “goBIM exporter” and the “goBIM application.” The first one is a custom Revit plug-in that transfers the database and geometric information from the model to a server location from where it is loaded to the “goBIM application” through a cellular network or wireless connection. In the application, the users can navigate through the model, select model components in order to retrieve their information, and add information through tags that can be pushed back to the original Revit model.<sup>26</sup>

The exporter was written using C#, while the game engine Unity3D was used to build the mobile application. The application was sold in the Apple App Store, from January 2010 to August 2011, for a price of \$5.99. While the initial version of goBIM was not designed for the iPad – as it was released prior to its introduction – iPad compatibility was added to goBIM in a subsequent version in May 2010, about a month after the release of iPad 1.0.

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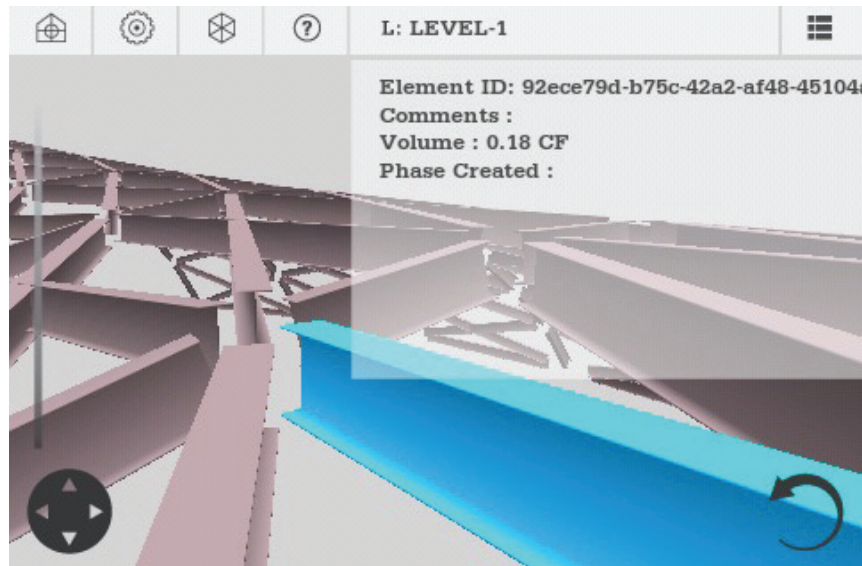
**25** Ian Keough, "goBIM: BIM Review for the iPhone." *ACADIA 09 : reForm() : building a better tomorrow : proceedings of the 29th annual conference of the Association for Computer Aided Design in Architecture (ACADIA)*. United States: Association for Computer-Aided Design in Architecture, 2009. 273 - 277.

**26** Ibid.

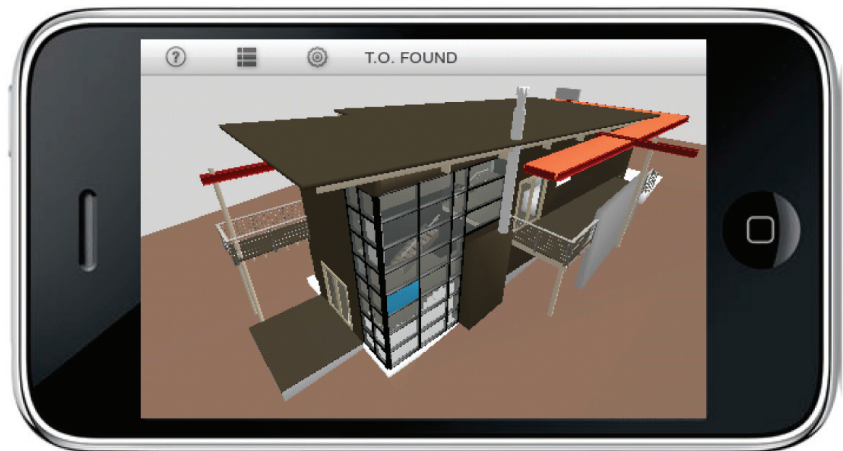
**Figure 7**  
goBIM screenshot.



**Figure 8**  
goBIM screenshot.



**Figure 9**  
goBIM screenshot in iPhone.



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### 4.3.2 Motivation / User Need and Goal

The motivation stated by Keough for developing goBIM was to explore the capabilities of translating a 3D model into his own mobile phone. This project was born as an exploration, without the intention to solve a concrete problem or work for one specific project.

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### 4.3.3 Development and Testing Process

The development of goBIM began in December 2008. In October 2009, although the application was not yet available to the public, goBIM was presented at the Acadia conference in Chicago. Finally, in January 2010, after a year of development, the application was published to the Apple App Store. The considerable amount of time dedicated to the initial development process was due in part to the fact that it was being done in the user-innovator's spare time, and in part to the large amount of time devoted to learning the specific programming environment for the iPhone.

Shortly after its publication in the App Store, the application started receiving attention from the AEC industry. Referencing notes in several blogs, a descriptive article in the *Journal of the American Society of Civil Engineers*<sup>27</sup> and a mention in the proceedings of the *10th International Conference on Construction Applications of Virtual Reality*<sup>28</sup> broadcasted the capabilities of the application.

After the initial release, five consecutive versions fixing problems and adding functionality were published through the store.<sup>29</sup> By the end of January 2010 goBIM had its own API which allowed users to create applications to build objects directly in goBIM, write files, and post them to FTP.

In August 2010, after 18 months of being in the App store, the application had been downloaded over 1400 times from 52 different countries.<sup>30</sup>

<sup>27</sup> Jenny Jones, "Application takes BIM on the go." Edited by American Society of Civil Engineers. *Civil Engineering*, (2010): 36.

<sup>28</sup> Pauwels, Pieter, Ronald De Myer, and Jan Van Campenhout. "Visualisation of Semantic Architectural Information within a Game Engine Environment." *10th International Conference on Construction Applications of Virtual Reality (CONVR 2010)*. Senday, Miyagi, 2010. 222-225.

<sup>29</sup> Versions: 1.0 January/2010, 1.1, 1.2 May/2010 (Rhino exporter and iPad compliancy), 1.2.1 May/2010 (fixed reported crashes on first generation iPhone), 1.3 January/2011 (change of file format). A 1.3.1 version that would include several new capabilities was described in Keough's blog, but was never released. Information extracted from: <http://go-bim.iankeough.com/wordpress/>

<sup>30</sup> The following is the list of downloads per country: United States 805,



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#### 4.3.4 Support from Vendors / Developers

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The designer states he did not receive direct support from developers.

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#### 4.3.5 Current State, Further Developments, and Diffusion

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In August 2011, after 18 months on the App Store, the application was taken down when Keough was hired as a Solution Architect for BIM Products by Vela Systems, a software company that develops mobile and web applications for the AEC industry, specializing in field management and productivity. By hiring Keough, the goal of the company was to merge the goBIM technology with their existing technology, Field BIM Solution, to create a new application called Field BIM interactive. The first beta version of this merged tool was released on February 16, 2012.

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#### 4.3.6 User-Innovator's Background

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Refer to section 4.2.6.

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#### 4.3.7 Summary and Conclusions of the Case

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Comparing the model – and consequent flow diagram – that the development of goBIM implies with the original user innovation model, the present case shows most of the originally predicted flows, with two exceptions: free distribution of the innovation and direct support from vendors. This may indicate the existence of a correlation between the two. On the other hand, commercialization appears to reinforce the relevance of the iterative process of development, as it implies more users that can act as testers, in comparison to an in-house development that is only used by a few people. In other words, the more users, the more easily bugs will be discovered. Moreover, as users are paying customers, this will generate a demand to fix the problems and add improved functionalities. Due to the growing community of iPhone, iPad, and

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United Kingdom 86, Australia 68, Canada 57, Norway 42, Netherlands 39, Denmark 38, South Korea 32, Sweden 28, Germany 26, Mexico 21, France 18, Brazil 17, Chile 17, New Zealand 15, Italy 12, Japan 12, Spain 8, Ireland 7, Portugal 7, Hong Kong 6, South Africa 6, China 5, Taiwan 5, Switzerland 5, United Arab Emirates 4, Belgium 3, Turkey 3, Qatar 2, Argentina 2, Singapore 2, Estonia 2, Austria 2, Colombia 2, Greece 2, Czech Republic 1, Lebanon 1, Panama 1, Lithuania 1, Thailand 1, Israel 1, Guatemala 1, Indonesia 1, Finland 1, Saudi Arabia 1, Uruguay 1, Russia 1, Bulgaria 1, Honduras 1, India 1, Hungary 1, Malaysia 1. Ian Keough, e-mail message to author, April 18, 2012.



BIM users, and the fact that the application was indeed a pioneer in the field of BIM mobile applications, the tool received attention from the media, which in turn drew more users to buy the application.

Regarding the distribution of the innovation, even though the program was released as a commercial product, it is safe to assume that the pursuit of income may not have been the only reason behind releasing the application to the larger public, given the relatively low total income of the project.<sup>31</sup> Indeed, the fact, that the user-innovator was hired by a large software company to develop similar software demonstrates the relevant effects of publicly releasing certain types of applications.

Other BIM mobile applications have been released since the introduction of goBIM. Nevertheless, there is still no comparable tool in the segment price range, demonstrating that there is still much opportunity for innovation in the area of BIM mobile applications.

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#### 4.3.8 Specific Bibliography and Research Resources for the Case

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Keough, Ian. "goBIM: BIM Review for the iPhone." *ACADIA 09 : reForm() : building a better tomorrow : proceedings of the 29th annual conference of the Association for Computer Aided Design in Architecture (ACADIA)*. United States: Association for Computer-Aided Design in Architecture, 2009. 273 - 277. Keough, Ian. <http://go-bim.iankeough.com/wordpress/>.

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Keough, Ian, interview by author. Email interview, (April 18, 2012).

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Kron, Zach, interview by author. Online interview, (March 8, 2012).

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Pieter Pauwels, Ronald De Myer, and Jan Van Campenhout. "Visualisation of Semantic Architectural Information within a Game Engine Environment." *10th International Conference on Construction Applications of Virtual Reality (CONVR 2010)*. Senday, Miyagi, 2010. 222-225.

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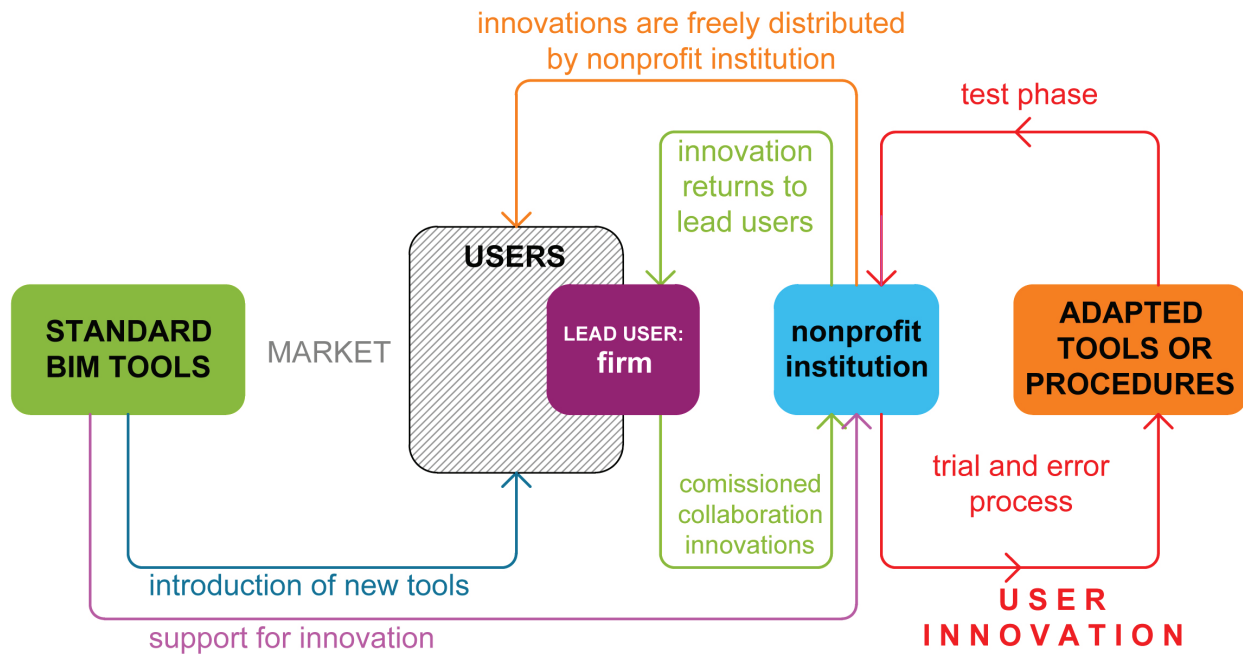
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**31** 1,400 users downloading the application for \$5.99, would result in a total revenue, after Apple's 30% commission, of about 5,900 dollars.

## 4.4 MIT - CO Workshop



**Figure 10**

MIT-CO Workshop: User Innovation Flow Diagram.

**Description of Innovation:**

Research initiative on BIM innovation development

**Type of User-Innovator:**

Non-profit Institution (University) + Private firm

**User need/motivation:**

Exploratory

**Distribution:**

Free through a webpage

**Direct support from vendors:**

Yes (Training and coding assistance)

**Diffusion from User-Innovator:**

Not yet

At the time of submission of this first thesis draft (May 11, 2012) this case is still in progress, as the final presentation of the class is scheduled for May 22, 2012. The thesis author is currently participating in the workshop as one of its students.

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#### 4.4.1 Description of the Innovation

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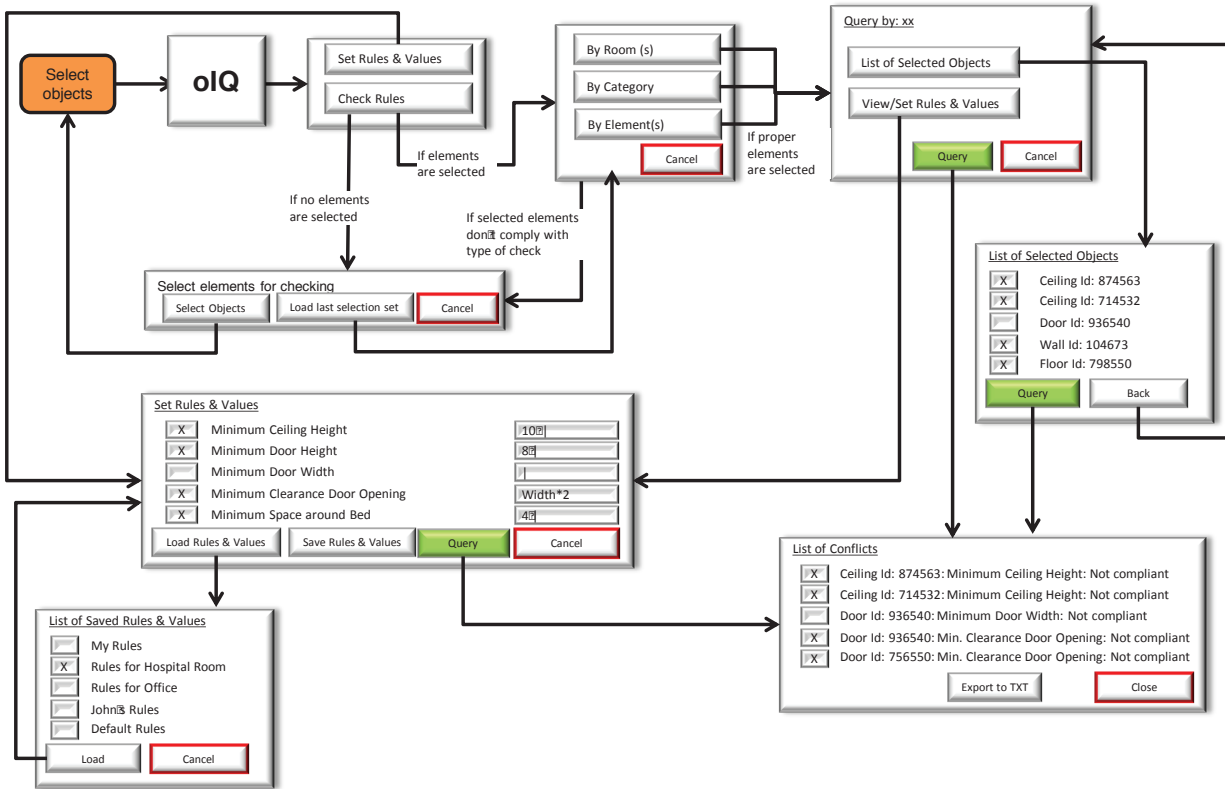
The Design and Computation group (DCG) at the School of Architecture and Planning at MIT, is currently<sup>32</sup> offering a workshop called Computational Design Lab: Reinventing BIM. The class is guided by Professors Terry Knight and Takehiko Nagakura, and is being held in collaboration with the Los Angeles-based firm CO Architects, through the active participation of Jennifer Knudsen, Associate Principal, and Alex Korter, Senior Associate. The class is composed of twelve students, mainly DCG graduate students, but also includes one undergraduate student from the Architecture Department and one graduate student from the Real Estate program.

The main goal of the workshop is, as the class syllabus states, to “examine and question the capabilities of [Revit] (and BIM more generally), and to identify challenges and opportunities within the framework of the software.” Students are expected to work in pairs to “propose exploratory tools that augment or transform existing software capabilities in creative and innovative ways, to develop conceptual prototypes based on their ideas, and then [to] test their prototypes.”<sup>33</sup>

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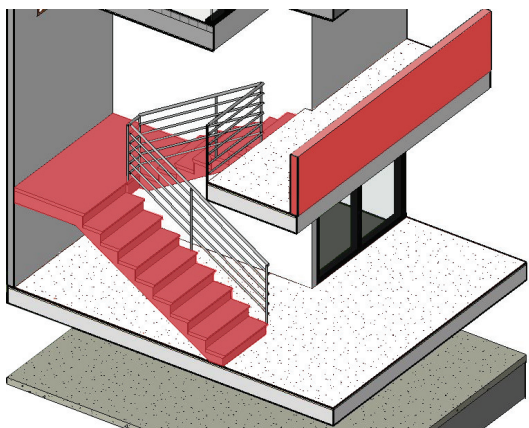
<sup>32</sup> Spring semester of 2012.

<sup>33</sup> “4.S52 Computational Design Lab: Reinventing BIM.” Syllabus. Department of Architecture, Massachusetts Institute of Technology, 2012.



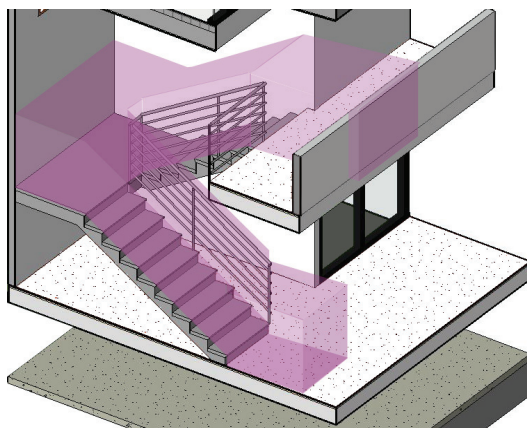
**Figure 11**

User interface flow chart of the object Interaction Query tool (oIQ). A context awareness tool that allows assessing complex interactions between model elements, designed by the student team composed by the author and Moa Carlsson.



**Figure 12**

oIQ's uses virtual volumes to find complex interaction between model elements.



**Figure 12**

oIQ's conflict visualization.

A list of five possible topics – massing and form generation tools, catalogue of parametric forms, visualization, building code and BIM, and on-site tools – was proposed to the students. Starting from these or other subjects, the students had to develop a preliminary research project on the state of the art in a particular area and propose and develop a working prototype for a BIM tool. The proposals from the six teams in the class range from tablet applications for on-site visualization to plug-ins for extracting and analyzing data from Revit. Some projects have required the acquisition of hardware and the production of 3D printed models, all of which is being financed by CO Architects, with funds – \$9,000 – given to the class.

The final projects of the workshop will be presented on May 22, 2012.

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#### 4.4.2 Motivation / User Need and Goal

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Around December of 2010, CO Architects' Principal James Simeo, a former student of Terry Knight at UCLA, began conversations with the latter to develop a joint effort between their architecture firm and MIT. In the beginning, the nature and concrete products expected from the project were not clear. As stated by CO Architects, they had made attempts to establish an academia-firm joint work earlier<sup>34</sup>, with the University of Southern California (USC), but these efforts had not prospered, in part due to the fact that the concrete interests of CO in doing such a type of work were not completely delineated.

By October of 2011, almost a year later, the nature and topics of the workshop were much clearer. Out of a long list of subjects proposed by both CO and MIT, a set of five research topics was selected.

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**34** Although this collaboration was not specifically related to BIM.

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#### 4.4.3 Development and Testing Process

The class meets on a weekly basis, to review the progress of the projects, having Knudsen or Korter generally present through video conference. For some special occasions, such as the workshop kick-off and the midterm review, one of the architects from CO has flown to Boston to be present at the review.

In addition to the weekly meetings, the class maintains a blog, accessible only to the participants, where students post their weekly advancements and all other participants can leave comments on each other's work.

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#### 4.4.4 Support from Vendors / Developers

The workshop has received support from Autodesk in the form of training and development assistance for the students. Two initial sessions, one on Revit Modeling and the other on Revit API, were specially conducted by Autodesk for the class at the beginning of the semester. People from Autodesk also attended the midterm review and will be present at the final review of the class as well.

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#### 4.4.5 Current State, Further Developments, and Diffusion

Neither CO Architects nor the class faculty have concrete plans for the future of the projects. Nagakura states that the innovations will probably be released to the public through a website, but there are no specific plans for its development. Questioned whether there would be a problem for CO with making the products publicly available for free despite the fact that they have financed the class, they have clearly indicated this does not pose a conflict for them. Knudsen, in fact, points out that she understands sharing is a key ingredient in how projects are currently developed and that they believe they get more out of sharing than of keeping the developments to themselves. "Especially in the academic environment, I think it's all about sharing," she says.<sup>35</sup> Korter emphasizes that their goal for developing this workshop is primarily "to help us in our day-to-day process and how we use the tools. If somebody else benefits from it, too, it's fine. We're not in it for the commercialization of the products or anything like that. We just want to make our work better and more efficient."<sup>36</sup>

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<sup>35</sup> Jennifer Knudsen and Alex Korter, interview by author. *CO Architects* Online interview, (May 04, 2012).

<sup>36</sup> Ibid.

Both CO Architects and MIT state that this initiative is being used as a pilot to test the potentialities of this kind of joint (private/academia) exploratory venture. While Nagakura is considering applying a similar structure for future classes, CO thinks this experience will help them better delineate ways in which to establish academic research collaborations in the future. Although the projects will not reach maturity by the end of the semester, CO sees potential in the projects and has demonstrated interest in bringing some of the students to their office to continue developing the projects or to propose similar ones.

Professor Nagakura states that there would be interest in continuing similar academic work, and that this workshop has served as a pilot to test the boundaries of this type of endeavor and the opportunities that can arise from this type of work.

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#### 4.4.6 User-Innovator's Background

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CO Architects is a Los Angeles-based architecture firm that designed its first pilot BIM project in 2002. After the completion of that project, they started shifting their whole practice to use BIM tools. In 2010 they earned a BIM Excellence Award from the AIA Technology in Architectural Practice (TAP), for their Palomar Medical Center West project. Currently, they claim 99% of the projects in their office are designed using BIM.

A few years ago they had an architect in charge of developing some applications and adaptations, mainly in Revit. Nevertheless, they currently do not have anyone in the firm dedicated to the task. In general, they use the out-of-the-box tools, incorporating plug-ins that are freely distributed through the web.

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#### 4.4.7 Summary and Conclusions of the Case

Comparing the model – and consequent flow diagram - that the development of the MIT-CO Workshop implies with the original user innovation model, the present case shows the introduction of a new type of actor in the model, the academic institution, which articulates new types of relations and information flows in the system. The research has helped delineate the user needs in a dialectical manner, as the students have made proposals that balance the academic research motivations with the more functional interests from CO Architects.

Regarding direct support for innovation, this case shows that the presence of a prestigious academic institution such as MIT incentivizes the contribution of the vendors/developers, a fact that may be attributed to the associated diffusion for their standard tools that may result from this type of endeavor. The collaboration between a private firm (with real, concrete down-to-earth needs), an academic institution (mainly interested in the theoretical framework and the novelty of the work), and standard tools' developers (with a broader knowledge of the tools, and their strengths and limitations) appears as an interesting way to incentivize exploratory innovations that may be groundbreaking but concrete at the same time. The balance between private, more functional concerns, and academic, more abstract concerns, has to be carefully guided in order to foster projects with the potential of becoming the seed of larger functional innovations, without losing the spark of being exploratory initiatives. The risk is, on one hand, that the research can become too exploratory, resulting in innovations that are novel and groundbreaking, but in no way useful for the architecture firm. On the other hand, if the functional needs start gaining too much importance, the resulting innovations may be too practical and solve specific tasks, but not push the boundaries of the technology as the research originally intended.

The interaction with academia also opens the possibility for further developments and improvements of the tool beyond what is possible to achieve inside a private architecture firm. Through academic diffusion, the resulting innovations may attract the larger community and validate themselves as possible paths to explore.



Another interesting finding of this case is that, because currently the architecture firm is not generating innovation inside their firm, they declare they are adopting apps to be added to the standard tools to add functionalities. This type of development is analyzed in the next case (Free BIM Apps, section 4.5.)

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4.4.8  
Specific Bibliography  
and Research  
Resources for the Case

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“4.S52 Computational Design Lab: Reinventing BIM.” Syllabus. Department of Architecture, Massachusetts Institute of Technology, 2012.

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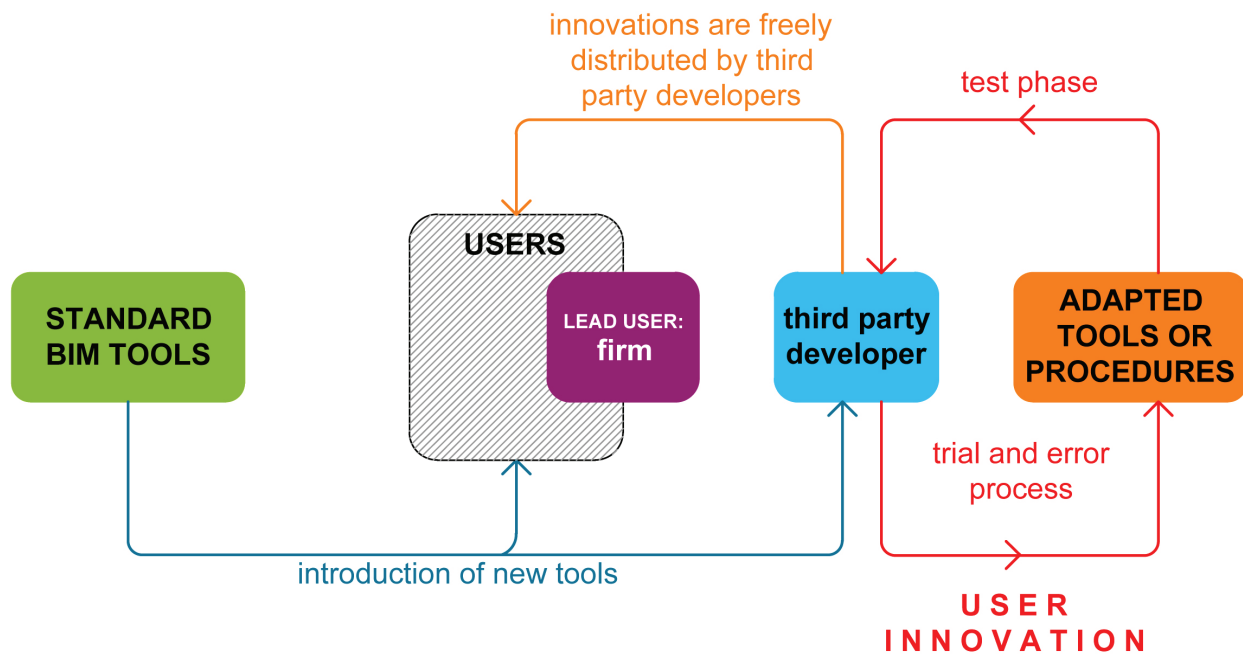
Knudsen, Jennifer, and Alex Korter, interview by author. *CO Architects* Online interview, (May 04, 2012).

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Nagakura, Takehiko, interview by author. *MIT*. Cambridge, MA, (May 1, 2012).

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## 4.5 Free BIM Apps



**Figure 14**  
Free BIM Apps: User  
Innovation Flow Diagram.

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**Description of Innovation:**

Freely released plug-ins for BIM

**Type of User-Innovator:**

Private firm (Third-party developer)

**User need/motivation:**

Promotion, marketing

**Distribution:**

Free through a webpage

**Direct support from vendors:**

No

**Diffusion from User-Innovator:**

Yes (User's webpages)

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#### 4.5.1 Description of the Innovation

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##### Case apps

In December 2011, Case, a consulting firm based in New York, released a website called *Case apps*.<sup>37</sup> A repository for Revit plug-ins, the page was created by Case to share the applications with registered users. Federico Negro from Case explains they have approximately forty or fifty in-house apps<sup>38</sup> that they use for their daily work. From that pool, approximately once a month, they select a tool and post it for free on *Case apps*. Currently, the webpage contains six add-ins.<sup>39</sup> Each one of them facilitates performing one of the following tasks: change and replace line styles, export revision cloud data to a text file, update door marks, export families from a model and organize them in libraries, reuse and share selection sets, and extrude rooms to 3D masses.

According to Negro, this community has approximately one thousand users<sup>40</sup> and is open for registration.

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##### AEC apps

*AEC-apps* is defined by Case as “a crowd sourced database of all the applications relevant to the AEC Industry.”<sup>41</sup> In this webpage, software developers can post information about their tools with links to download them for free, or for a price, and community participants have the ability to rank the tools. It is relevant to note that the applications in *AEC-apps* not only contain Revit plug-ins as *Case apps*, but also Rhino plug-ins and even standalone tools for the AEC industry. The company’s intention is to build a platform that enables community validation, similar to Rhino Jungle.

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**37** <http://apps.casea-inc.com>

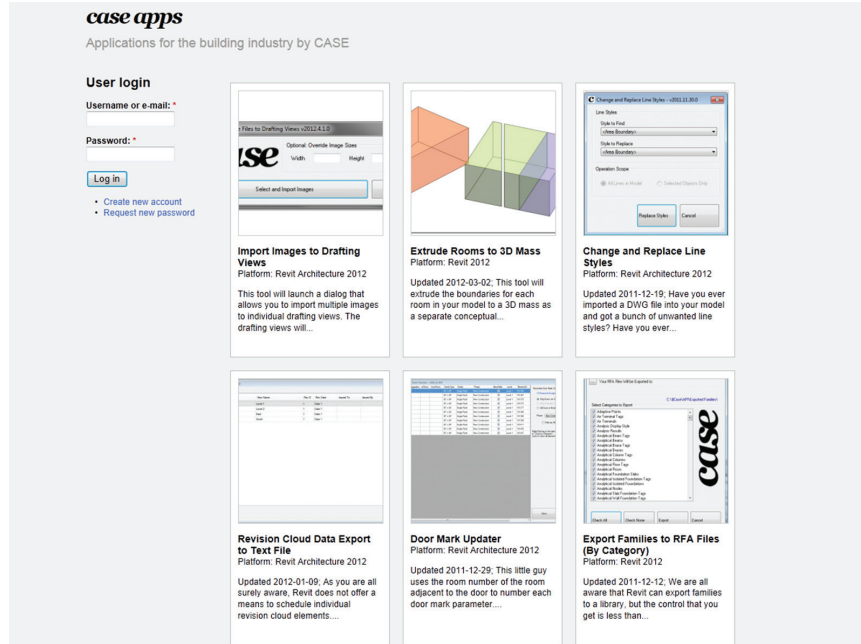
**38** Federico Negro, interview by author. Online interview, (March 22, 2012).

**39** As of March 26, 2012

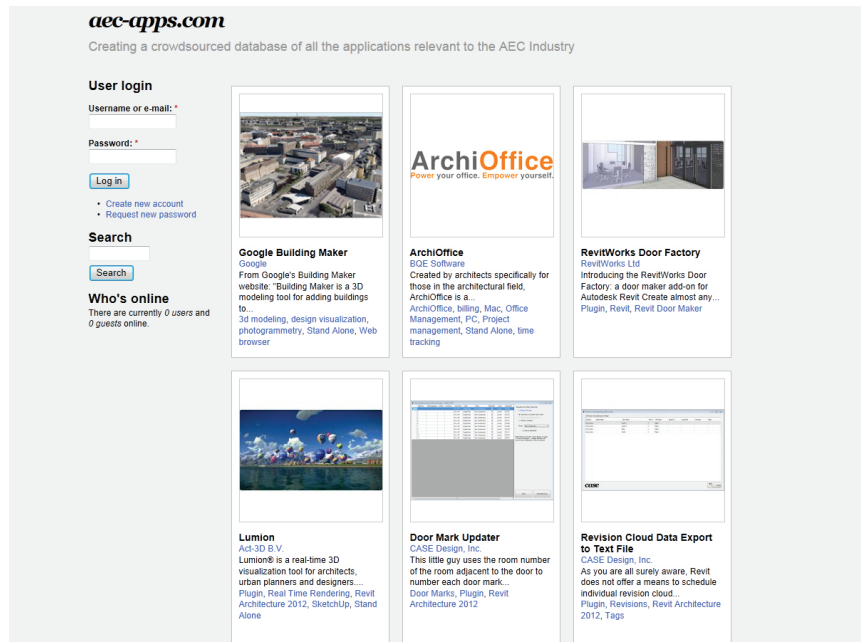
**40** Federico Negro, interview by author. Online interview, (March 22, 2012).

**41** Case, AEC-apps, <http://apps.case-inc.com/>

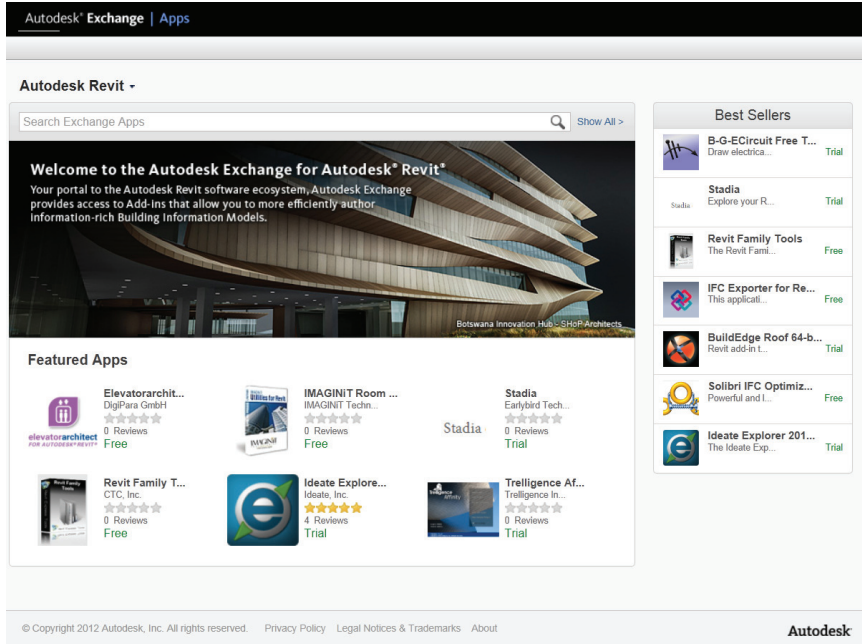
**Figure 15**  
Case Apps screenshot.



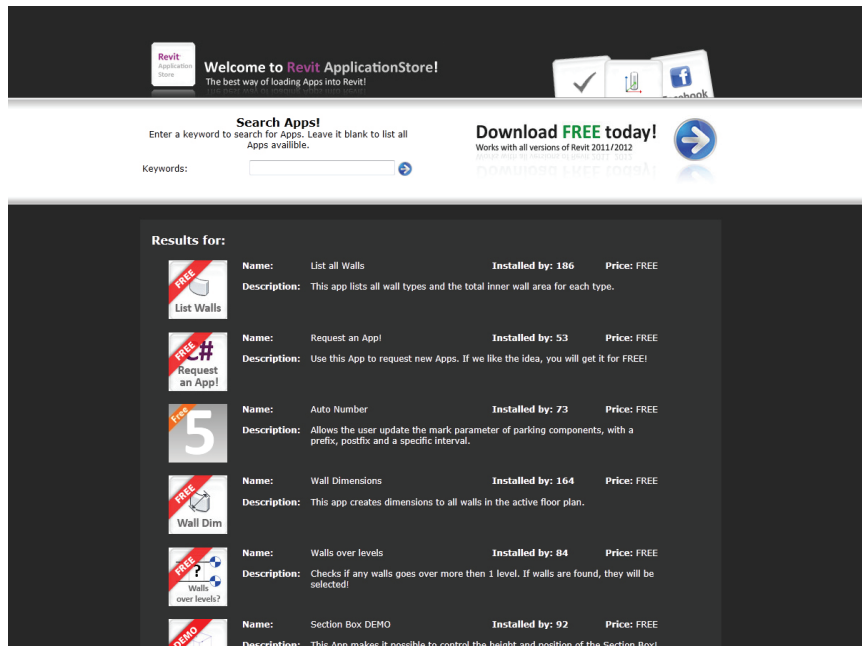
**Figure 16**  
AEC-Apps screenshot.



**Figure 17**  
Autodesk Exchange Apps screenshot.



**Figure 18**  
Revit Application Store screenshot.



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#### 4.5.2 Motivation / User Need and Goal

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Case has two main goals for freely releasing BIM plug-ins through their websites. The first is to promote their work and propagate the use of Revit plug-ins, and the second is to build a community of users, similar to the existing communities for Rhino and Grasshopper, that can recommend plug-ins and discuss related topics.

Regarding their first motivation, promotion, Case believes that most people in the AEC industry are still unfamiliar with applications for their architectural tools apps. In fact, Negro, one of the partners of Case, claims that the idea of modifying and adding to the out-of-the-box tool is still strange to most AEC participants. Therefore, releasing these applications for free can help AEC users become familiar with the process of customization of BIM tools. Moreover, Case uses these platforms as a way to market their practice. As stated by Negro, Case believes that instead of going out to sell their work, “the best way to attract clients is giving them added value for free.”<sup>42</sup> They strategically attract people to their webpages with free content, not limited to applications, but also other material such as video tutorials, AEC- and BIM-related news or events, and best practices and standards, in the belief that these visitors will get acquainted with Case’s work and eventually, if they wish to get help for customization, they will choose Case.

Regarding their second motivation, community building, Negro states that they would like to build a community of users similar to the ones that already exist for Rhino and Grasshopper. These two design applications are being supported by large, open-source-oriented communities that, according to Negro, have made great contributions to the development of the tools. Similarly, they hope their initiatives, especially *AEC-apps*, evolve into a space where users and developers share information about AEC applications and build a reputation ranking that validates and backs the tools.

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<sup>42</sup> Federico Negro, interview by author. Online interview, (March 22, 2012).

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#### 4.5.3 Development and Testing Process

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While the developments in *Case apps* are done in-house, *AEC-apps* offers a variety of tools from different developers.

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#### 4.5.4 Support from Vendors / Developers

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Besides the occasional answer to questions posted in the Autodesk Developer Network (ADN) forum, Case reports that they have not received any support from software vendors to develop these or other similar solutions.

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#### 4.5.5 Current State, Further Developments, and Diffusion

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Case plans to continue building their two platforms, releasing their apps for free, and promoting community interactions. They are currently studying the possibility of consolidating both platforms in one place.

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#### 4.5.6 User-Innovator's Background

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Case Design is a BIM consultancy firm based in New York. As part of their consulting practice, they develop client-specific software to help their customers improve their design and management processes. Their clients come from different areas of the AEC industry and among them are large companies from the United States such as Skidmore, Owings and Merrill (SOM), Robins & Morton, and KPF. The firm is currently composed of seventeen people, including, architects, engineers, programmers, staff personnel, and a development team based in Uruguay. They maintain diverse channels of communication, such as workshops, conference talks and online sites, where they promote BIM and other technologies' utilization.

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## Similar initiatives

The free release of add-ins as a way to indirectly promote other types of developments appears to be a common practice in the BIM environment. Similarly to the cases already described, other initiatives are being deployed. An example of this is the Revit Application Store,<sup>43</sup> which currently contains 22 apps,<sup>44</sup> some for free and some downloadable for a fee. The site and most of its applications are developed by Astacus Labs, part of Astacus AB, a Swedish company with a team of developers in India that outsources technologies and processes based on CAD, GIS, and BIM.

Even Autodesk itself is creating an application store for its products, the Autodesk Exchange Apps platform, where developers can submit their apps to be published. A special store for AutoCAD that can only be accessed through AutoCAD 2012 is already online with approximately 180 apps.<sup>45</sup> Some of them are free and some can be downloaded for a fee. Most of them were authored by third-party developers, not Autodesk. The page dedicated to Revit apps is online and open to anyone,<sup>46</sup> and currently has approximately 70 applications.<sup>47</sup>

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### 4.5.7 Summary and Conclusions of the Case

Comparing the model – and consequent flow diagram – that the development of these free BIM Apps' platforms implies with the original user innovation model, the present case shows the emergence of a new type of actor: third-party developers. It could be argued that the fact that these third-party developers are not users or in direct contact with users discredits these cases as user-innovation ones. Nevertheless, the innovations supplied by these new actors educate the industry about the possibility of adapting tools. Furthermore, they give less advanced users, who lack the resources for innovating, access to small customizations. At the same time, these free applications may bring users closer to innovating, as they can help familiarize them with in-house innovations and tool development. All of the above validates them as a case to study within the scope of the present thesis.

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**43** Revit Application Store, <http://www.revitapplicationstore.com/search.php>

**44** As of May 07, 2011.

**45** As of May 07, 2011.

**46** Autodesk Exchange Apps for Revit, <http://apps.exchange.autodesk.com/RVT/Home/Index>

**47** As of May 07, 2011.



These third-party developers act as mediators between the standard technologies and the group of users, establishing a dialogue between the original technologies and specific user needs. The growth of this type of development – freely released applications in a web platform – point to the fact that the industry is in need of mechanisms to adapt the standard tools in order to satisfy heterogeneous needs. The emergence of vendor-supported versions of this type of platform – e.g., Autodesk Exchange – indicates that this need for adaptation is being acknowledged by the original developers. Moreover, the fact that the new functionalities that these apps supply are not being included in the original tools, but rather externalized to these applications, may indicate that developers recognize the segmentation of needs and choose this approach to address heterogeneity.

Additionally, regarding the decision to freely release the innovations, we can point out that in this case the extrinsic rewards are being openly sought by the innovators. Third parties are using the freely released applications to earn reputation and promote their work in the AEC industry.

A final remark on this case is the interest, declared by one of the third-party developers, in developing a user community through these free apps pages. In that way, third-party developers acknowledge the added value that communities can bring to the tools, and consequently to their developers.

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#### 4.5.8 Specific Bibliography and Research Resources for the Case

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Case. AEC\_Apps. <http://aec-apps.com/>.

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Negro, Federico, interview by author. Online interview, (March 22, 2012).

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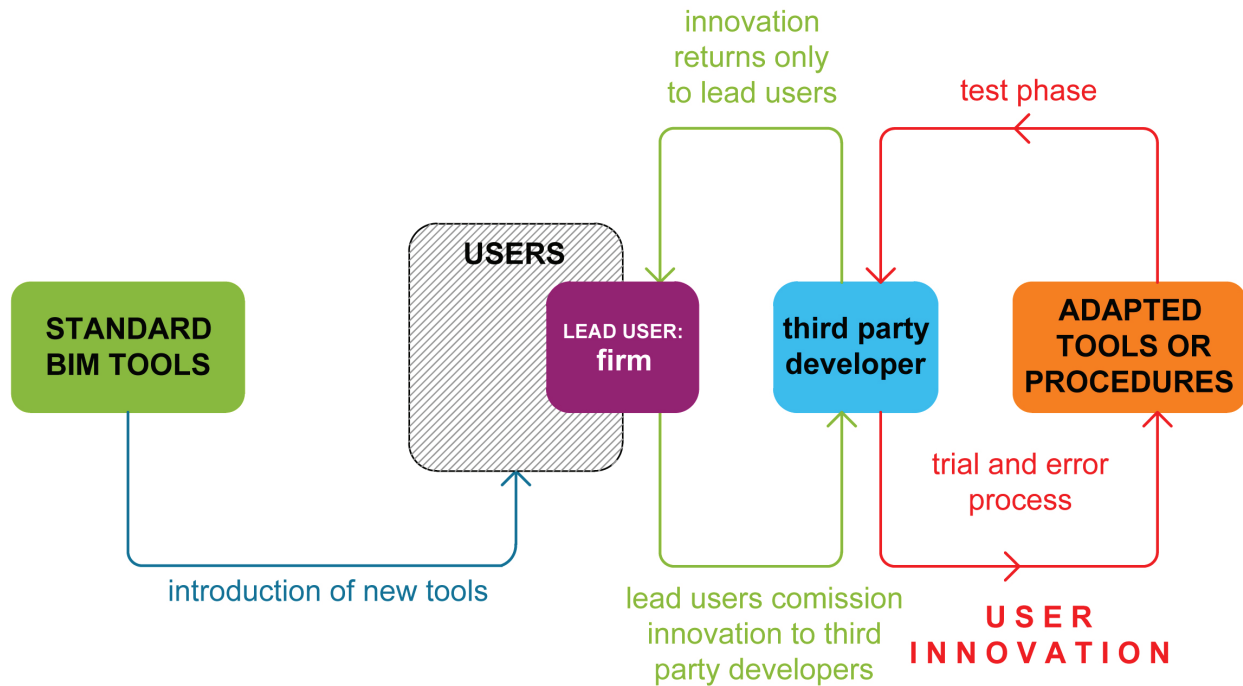
Negro, Federico, interview by author. Online interview, (April 5, 2012).

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Revit Application Store. <http://www.revitapplicationstore.com/search.php>.

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## 4.6 SOM BIM Dashboard



**Figure 19**

SOM BIM Dashboard: User Innovation Flow Diagram.

**Description of Innovation:**

QA/QC and project typology platform for BIM

**Type of User-Innovator:**

Private firm (Architecture) + Private firm (Third-party developer)

**User need/motivation:**

Optimization of design procedures

**Distribution:**

In-house development, but considering resealing parts of the tool

**Direct support from vendors:**

No

**Diffusion from User-Innovator:**

Yes (AU and conference presentation)

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#### 4.6.1 Description of the Innovation

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The SOM BIM Dashboard is a Quality Assurance / Quality Control platform that allows SOM to extract information from their existing BIM's in order to assess the ways in which they are designing and also to recommend best practices. The innovation is being built by SOM in partnership with Case, a third-party developer and consulting firm. The innovation has been developed in three phases, the third of them currently in progress.

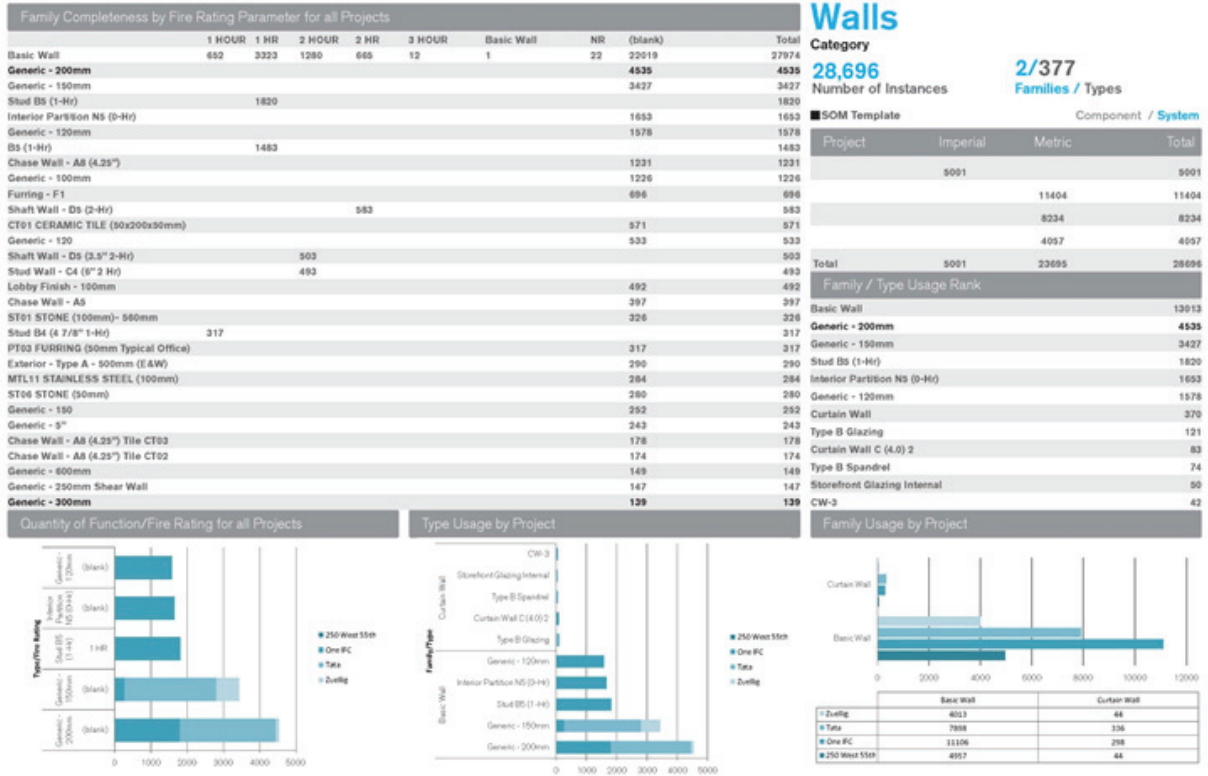
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#### First Phase

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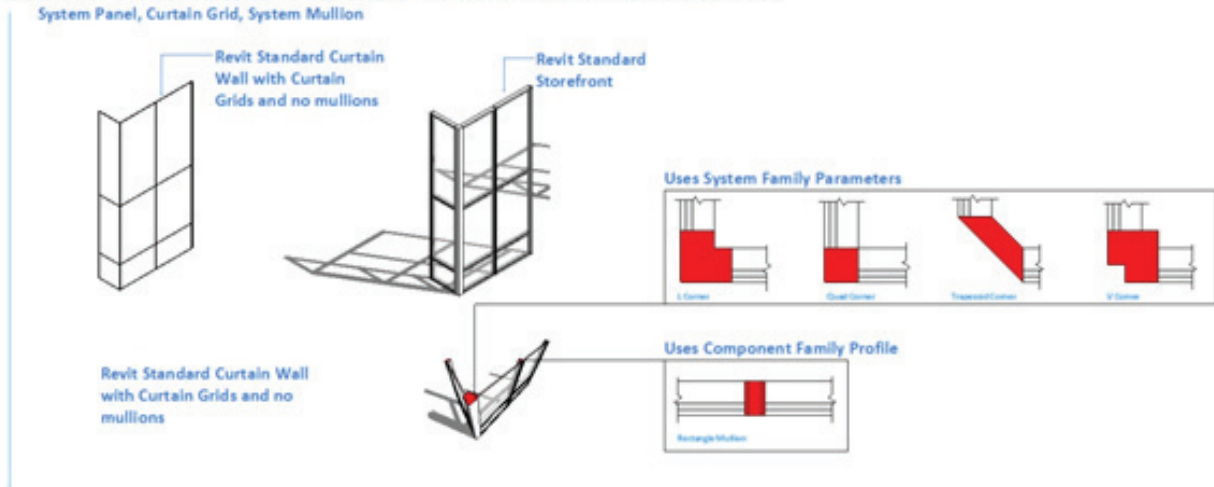
In the first phase, Case built an information extractor and tested it with sixteen models from six different projects provided by SOM. The goal of this extraction was not to retrieve the actual components, but instead, to extract information about objects from the different models that would allow comparing design decisions and logics behind different projects. The information could reveal, for example, which types of walls have been specified by SOM in their projects the last five years, information that would allow the firm to understand the way in which they have been working, evaluate it, and optimize it. The process actually allowed SOM to realize that even though they had internal standards, those standards were not being implemented.

The information extracted from the models was arranged by Case in reports that compared, for example, all the types of walls or doors being used in those projects, highlighting key information, such as the most used types. Case and SOM used this information to build the "SOM Revit Best Practices and Guidelines", a set of Revit project files containing the standardized components and, associated to each component, multiple annotations explaining the best practices and workflows for utilizing each component type within its typical building context. The last part for this first phase was the creation of an internal wiki page, the "SOM BIM Wiki", which was designed to inform and engage a larger audience inside SOM.

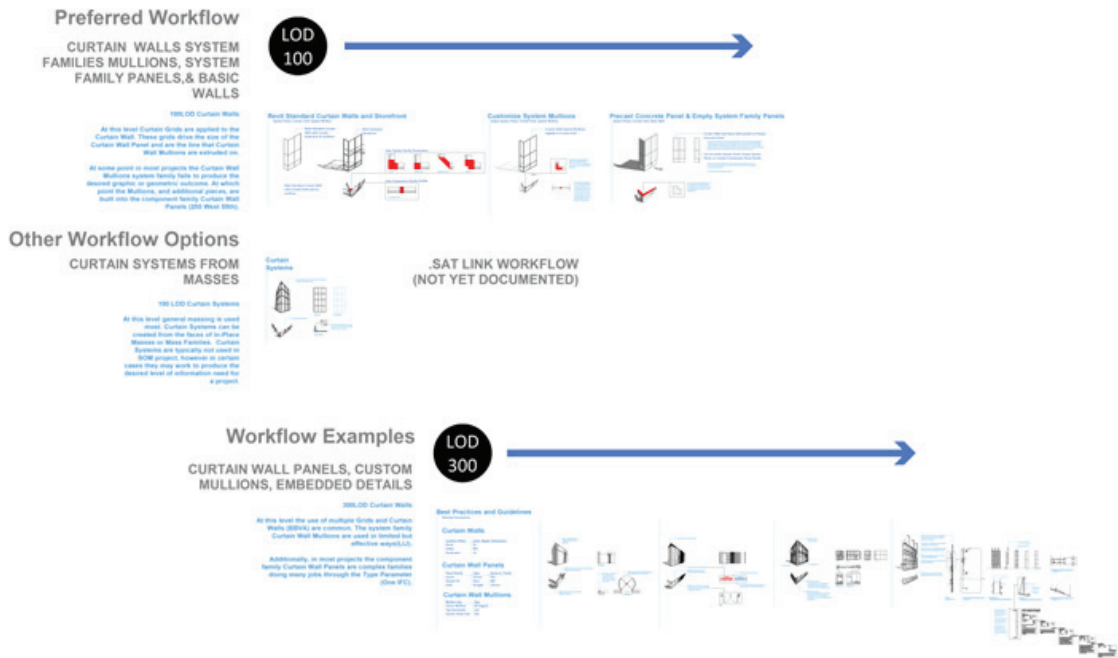


**Figure 20**  
SOM Wall Evaluation done with information harvested through the Dashboard.

# Revit Standard Curtain Walls and Storefront



## SOM Revit Best Practices and Guidelines: Enclosure Systems



LATEST UPDATE: 09/21/2010

NOTE: Level of Development (LOD) 200 is conceptually outside the intent of this file. Defining the difference in development between a 100 and 200, or a 200 and 300 level component is counter to the necessary freedom required in the design process. The idea, then, is to define a starting point, as well as an end point for reference.

**Figures 21 and 22**  
SOM Revit Best Practices  
and Guidelines.

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## Second Phase

The second phase of the innovation development, deployed in 2011, took approximately five months, and consisted in the construction of a tool that allows SOM to extract the information in-house without the need to involve Case in the process. The latter built a Revit plug-in, called “Harvest Model Data,” that automates the information extraction. While the duration of the extraction process will vary according to the size and number of components in the model, Robert Yori, a Senior Digital Design Manager at SOM, calculates that what manually would take them a week to accomplish, with the tool only takes them one hour.<sup>48</sup> All the models of a project are connected in order to enable analysis of the whole project instead of just individual models. Each time data from a new model is “harvested” the tool prompts the user to indicate the project to which it belongs and records that data for future harvests. When applied periodically, the harvesting procedure can be used to understand the evolution of projects in time, for example, how large files become in relation to key dates of the projects. The harvested information can be visualized as a database or also through visualization tools such as Tableau.

According to Yori and Robert Mencarini, another Senior Digital Design Manager at SOM, currently the tool is mostly being used at SOM’s New York office. Additionally, the second phase involved the creation of an SQL server to centrally manage the harvested information, and a web interface to visualize and manage project reports. In this platform, the harvested information can be filtered by user, office, project, or other criteria.

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## Third Phase

The third phase of the tool is currently under development. Please refer to section 4.6.4.

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<sup>48</sup> Yori, Robert, interview by author. New York, NY, (April 19, 2012).

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#### 4.6.2 Motivation / User Need and Goal

Skidmore, Owings and Merrill (SOM) began using Revit in 2000, and by 2010 the firm had accumulated a long list of projects designed in Revit, along with a large body of implicit knowledge about standards and best practices for the tool. Nevertheless, given the tacit nature of that knowledge – i.e., it was not captured in any documents – the firm was worried about two things: first, that content was being created across the firm in many different ways, often duplicating family creation efforts, which resulted in reduced efficiencies and also in a lack of standardization for their work. For instance, the same door could be modeled by different people resulting in many different types of Revit doors representing the same real door. The second concern of SOM was that, given the tacit nature of the knowledge, when personnel in the office changed, most of the time the knowledge was lost. Therefore, SOM was interested in standardizing their work and making their implicit knowledge explicit. Consequently, in 2010 SOM approached Case and another consulting company with the intention of outsourcing their standard content creation. Basically, their goal was to extract the vast amount of information, such as family types, contained in the models they had built for the past five years.

The proposal from Case, rather than just complying with the basic request from SOM of extracting information from a set of models, consisted of a tool that could automate the information extraction from the models to an Access database.

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#### 4.6.3 Development and Testing Process

As mentioned before, the innovation has been developed in three phases. The first phase, developed in 2010, took approximately six months and consisted of four deliverables: the model reports, the SOM Revit Best Practices and Guidelines, the wiki page, and a set of components and settings. The actual tool to extract the information was not delivered to SOM at that time. The development of the first phase required extensive involvement between Case and SOM, as the former would do preliminary information extractions, present them to the architecture firm, and SOM would then select which information they were interested in for the final reports. This process took several iterations between the two firms in order to arrive at the final product. The first phase was only implemented in the New York office, and it was used as a pilot test in order to evaluate whether the SOM BIM Dashboard would be a valuable contribution to the work firm-wide.

The second phase was developed in 2011 and took approximately five months. The deliverables for that phase, as mentioned, were the Revit plug-in, the SQL server, and the web interface. Additionally, new Revit project files with standardized components, and a full revision of the BIM Wiki were included in this phase.

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#### 4.6.4 Current State, Further Developments, and Diffusion

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Currently, Case and SOM are developing the third phase of the project, which consists of three parts. First is building a tool to output objects from models and store them in organized libraries. This was the original requirement of SOM, but since the Dashboard has focused on knowledge extraction rather than component extraction, SOM has been making up for this using one of the free tools posted by Mario Guttman on his webpage.<sup>49</sup>

The second part of the third phase will be a full automation of the harvesting process, eliminating the need for manually opening the model and running the plug-in.

The third part of the present phase consists of improvements in the platform infrastructure at a firm-wide level in order to streamline the work and enable real-time interaction with the harvested information in all SOM offices, not just the New York one.

Additionally, Yori and Mencarini indicate that SOM has considered the possibility of releasing at least part of the tool as part of an open-source initiative. They believe that by doing so, the Dashboard would be able to evolve without SOM's need to constantly support it, especially since Revit has one release per year which forces them to do yearly upgrades to the application. That process is costly in terms of time and money for SOM, and therefore they are considering ways to avoid it. Of course, as they have already spent money on this innovation, the decision is not easy and requires a thorough consideration. Indeed, releasing the tool would also require some dedication of SOM and Case staff time, as they would need to take the tool to a level where it

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<sup>49</sup> Mario Guttman is a San Francisco based architect who has done extensive work related to BIM and added functionalities. He was a firmwide BIM manager at HOK until 2010, and currently works at Perkins+Will. He maintains a personal webpage where he posts free – and paid – applications (<http://whitefeet.com/>).



can work autonomously without the support of either of the firms. SOM believes that having highly customized internal tools creates a difficulty for new people to adapt. Regarding this, Mencarini points out that they are trying to “avoid getting locked into our own customizations which you always want to have enough of to stay competitive, but after a while they actually become an anchor.” Yori emphasizes they are not a software company and therefore their intention is to have efficient tools to develop their design work, rather than profit out of the tools directly. Additionally, they indicate they would like to give back to the community.

Aside from the development for SOM, Case has been working on the development of a similar, non-proprietary tool. Their goal is to have an application that will allow information extraction and analysis from BIM models that could be sold to different AEC firms.

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#### 4.6.5 Support from Vendors / Developers

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Besides the occasional answer to questions posted in the Autodesk Developer Network (ADN) forum, neither SOM nor Case have received any support from software vendors to develop this innovation.

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#### 4.6.6 User-Innovator's Background

SOM is an architectural and engineering firm originally founded in 1936. They have a history of user innovation, having generated very sophisticated digital design tools in the past. For instance, in the 1980's they created AES (Architecture Engineering System), a database-driven modeling tool, for their internal work. According to Carl Galioto, a former SOM partner, AES is regarded as one of the precursors to current BIM tools.<sup>50</sup> Subsequently, they became early BIM adopters, when in 2003 they decided to use BIM for one of the most emblematic projects at the time, the World Trade Center Tower One, also known as the Freedom Tower. Currently, BIM tools are an important part of the repertoire of tools in use in the firm.

Robert Yori and Robert Mencarini are both Senior Digital Design Managers at SOM, currently working in this firm's New York office.

For background on Case refer to section 4.5.6.

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#### 4.6.7 Summary and Conclusions of the Case

Comparing the model – and consequent flow diagram - that the development of the SOM BIM Dashboard suggests with the original user innovation model, the present case shows, as some of the previous cases presented, the emergence of a new type of actor: the third-party developer. This third-party developer (Case) is not only in charge of developing an innovation according to the requirements indicated by the user (SOM). On the contrary, the third party developer gets involved in the process of delineating the user's need. That is, instead of just extracting the families from the existing models as SOM originally required, Case proposed a tool that would enable a qualitative and quantitative analysis through an automated process. Therefore, the third-party developer's involvement becomes active, and the architectural knowledge of the developers probably plays a key role in this occurrence.

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**50** Carl Galioto, "A Brief History of Digital Design and BIM at SOM." *A+ U Architecture and Urbanism*, no. Special issue (August 2009): 52.

The incipient intention of releasing the tool for free to the community appears as a new phenomenon not seen in the previous cases for user-innovators who were firms. The reasons for that plan are in part similar to those identified by the literature – a motivation to give back to the community – and in part a way of externalizing the costs of innovation. Through its open release, this tool may become a standard, which would mean that the industry could take the role of pushing the innovation forward.

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4.6.8  
Specific Bibliography  
and Research  
Resources for the Case

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Galioto Carl. "A Brief History of Digital Design and BIM at SOM." *A+ U Architecture and Urbanism*, no. Special issue (August 2009): 52.

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Negro, Federico, interview by author. Online interview, (March 22, 2012).

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Negro, Federico, interview by author. Online interview, (April 5, 2012).

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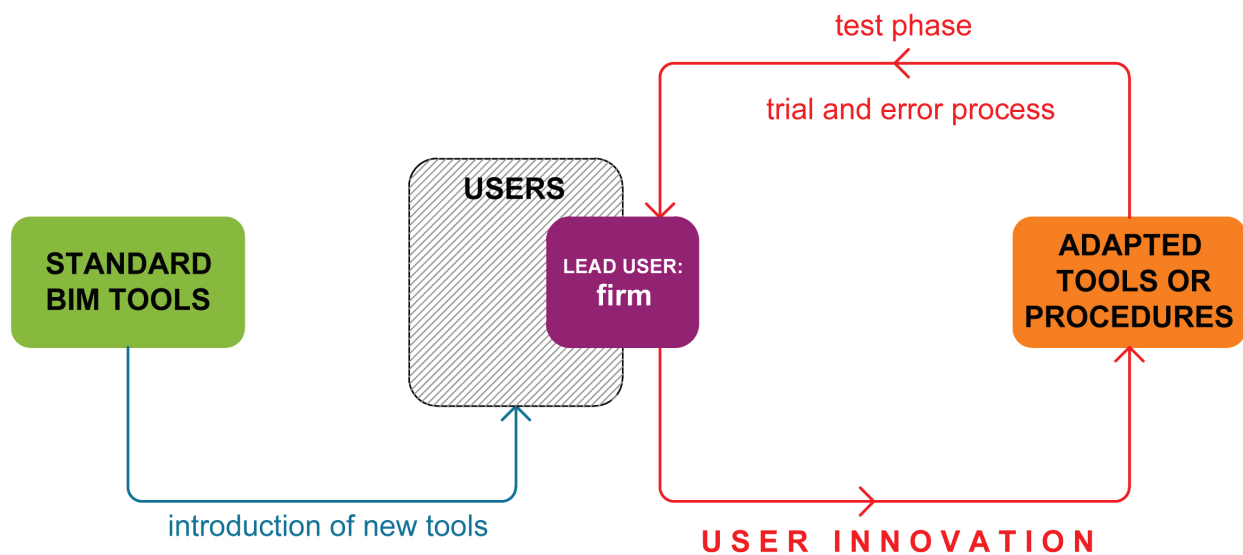
Yori, Robert. "BIM2.0: Transitioning an office to Mainstream BIM." PowerPoint Presentation for Autodesk University, 2010. [http://au.autodesk.com/?nd=class&session\\_id=7060](http://au.autodesk.com/?nd=class&session_id=7060).

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Yori, Robert, and Robert Mencarini, interview by author. New York, NY, (April 19, 2012).

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## 4.7 HOK Curtain Wall Generator



**Figure 23**

HOK Curtain Wall Generator:  
User Innovation Flow  
Diagram

**Description of Innovation:**

Rhino to Revit geometry transfer tool

**Type of User-Innovator:**

Private firm (Architecture)

**User need/motivation:**

Information transfer from geometric modeler to BIM

**Distribution:**

In-house development

**Direct support from vendors:**

No

**Diffusion from User-Innovator:**

No

HOK has designed approximately 20 applications for their internal use. These applications are located in a central repository where internal users can utilize them when needed to. This case focuses on one of their applications, called Curtain Wall Generator (CWG).

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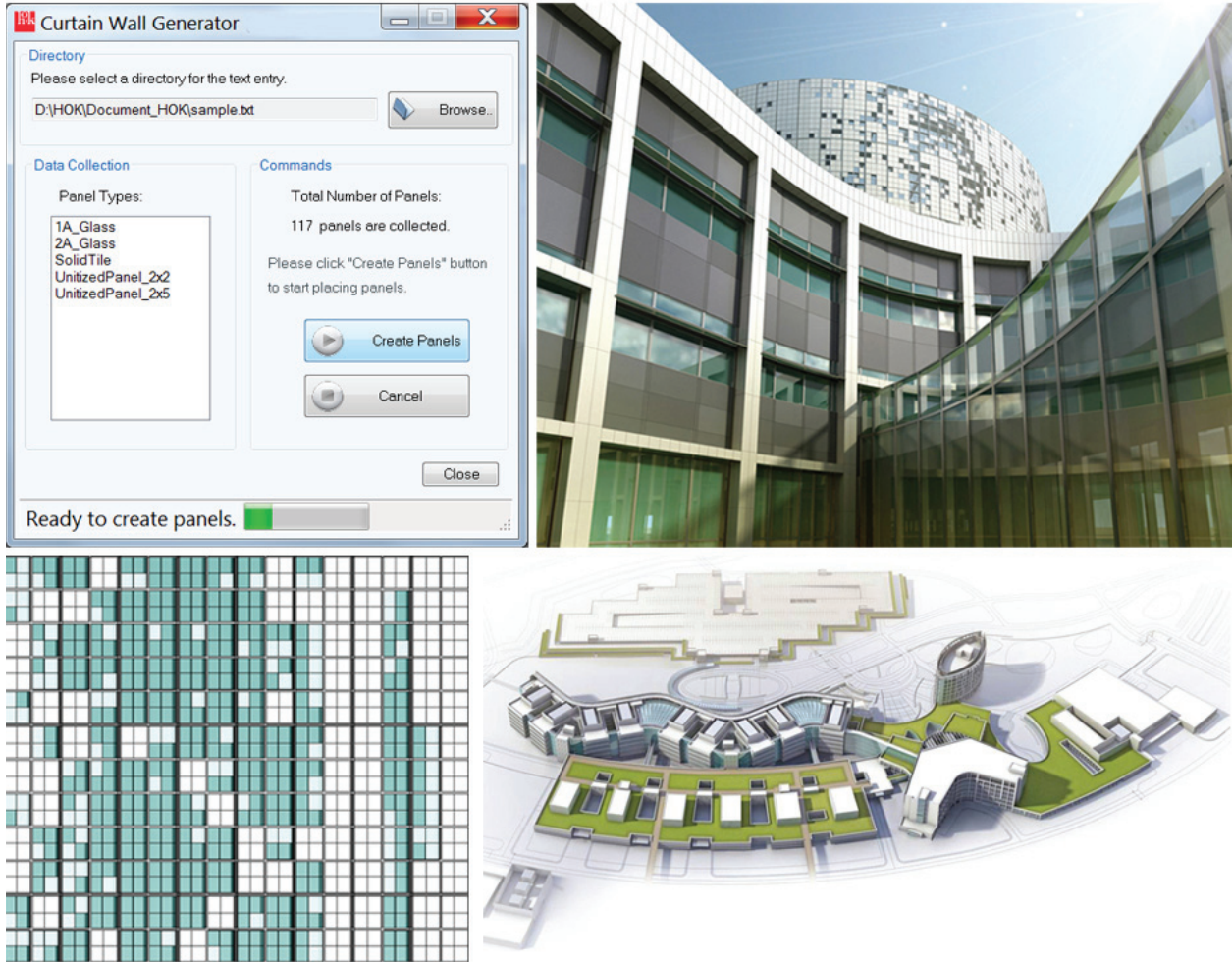
#### 4.7.1 Description of the Innovation

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The Curtain Wall Generator is an application built to transfer information from a glass facade designed in Rhino-Grasshopper to Revit. The tool recreates the original design – done in Rhino – in the BIM environment using custom native curtain-wall panels.

Actually, the tool consists of two parts, the first being a Rhinoscript that extracts the information from Rhino and generates a text file indicating the type and edges of each panel in the facade. The second part of the tool is a Revit plug-in that reads the text file and instantiates the panels in the program.

The Rhino tool first checks the Rhino model and outputs a file containing four facts for each panel of the facade: type, first point, second point, and third point. Subsequently, when the Revit tool is activated, it reads the text file and checks the availability of all the panel types in the Revit file. Then, the plug-in proceeds to build the facade, instantiating each panel according to the type and points indicated in the text file. Doing this process manually for the current project, Greg Schleusner, a firmwide BIM Manager at HOK, calculates, would take one person approximately a week and open the possibility for several human errors. The application on the other hand, updates two facades (with 28,000 panels in total) in approximately four hours, and assures HOK the facade design in Revit is exactly as indicated in the original Grasshopper definition.



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**Figure 24**  
Top left: HOK Curtain Wall  
Generator: User interface.

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**Figure 25**  
Top right: KMCMC facades.

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**Figure 26**  
Bottom left: Detail of  
KMCMC facade.

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**Figure 27**  
Bottom right: KMCMC  
project by HOK.

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#### 4.7.2 Motivation / User Need and Goal

In general, the motivation of HOK for developing different add-ins comes from the requirements of different project teams to solve specific problems presented by the projects. James Vandezande, the Director of HOK buildingSMART, states that their customizations are not driven by exploratory approaches or an interest in pushing the boundaries of the tools. Instead, all of their innovations respond to specific needs and their development has to be justified by a quantifiable return on the investment. "We don't do it because it's cool; we do it because it's going to save us money."<sup>51</sup> However, they do not have a system to quantify the return on investment of their innovations yet.

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#### 4.7.3 Development and Testing Process

The CWG was developed in April 2011, specifically for a hospital project in Germany, the Kaiserslautern Military Community Medical Center (KMCMC)<sup>52</sup>. The project has two large glass facades, one consisting of 8,000 panels and the other consisting of 20,000 panels. Five different types of panels compose the shell and their placement is driven by an image that indicates the position of each type of panel. These facades were originally designed in Rhino, using Grasshopper, by a designer from HOK's Washington DC office.

After consulting with Greg Schleusner, the same Washington designer built a script to output information on Rhino facades to a text file. Afterwards, an outside designer/software developer was specially hired to develop a Revit plug-in that uses the information in the text file to recreate the facade in Revit. The development of the Revit plug-in took approximately two weeks.

Since the KMCMC hospital design was finished, HOK has not used the Curtain Wall Generator again. The firm is considering possible ways in which to modify the application to generalize it, enabling its use in other projects. However, this has not happened yet.

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**51** James Vandezande, interview by author. New York, NY, (February 21, 2012).

**52** Lachmi Khemlani, "HOK's 2nd Annual BIM Awards." *AECbytes*. January 26, 2012. Retrieved from: [http://www.aecbytes.com/feature/2012/HOK\\_BIM\\_Awards.html](http://www.aecbytes.com/feature/2012/HOK_BIM_Awards.html)



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#### 4.7.4 Support from Vendors / Developers

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HOK states that they have not had direct support from software vendors.

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#### 4.7.5 Current State, Further Developments, and Diffusion

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Vandezande states that HOK is not interested in commercializing their customizations. He firmly believes that “a firm needs to decide whether they are in the software business or the architecture business, and I know it’s very clear that HOK is in the architecture business [...] .To that end, we just keep our stuff internal.”<sup>53</sup>

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#### 4.7.6 User-Innovator’s Background

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HOK is an architecture firm with approximately 1,700 employees. Founded in 1955, the firm has 25 offices worldwide.<sup>54</sup> In 2005 the company began a process of BIM implementation using Revit,<sup>55</sup> and currently, they use it for 95% of their projects.<sup>56</sup> The company has a firm-wide BIM team of seven people, as well as BIM managers for each region, which adds up to a group of approximately 25 people dedicated to BIM across the whole firm. Some innovations are done locally, but in general the firm-wide BIM team works as a knowledge center for all the offices. The team conducts biweekly meetings with all the BIM managers where they present project case studies and talk about the latest applications’ additions. As these meetings are not enough to keep the 1,700 employees informed, in addition to the meetings the firm is starting a monthly newsletter, informing all employees about new tools, among other matters.

James Vandezande is the Director of HOK buildingSMART, based in the New York City offices. In 2006 he founded the New York City Revit user group. Greg Schleusner is a firm-wide BIM manager at HOK, based in the New York City offices.

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**53** James Vandezande, interview by author. New York, NY, (February 21, 2012).

**54** Information retrieved from: <http://hok.com/>

**55** Lachmi Khemlani, "Technology Adoption and Implementation at HOK." AECbytes. November 25, 2008. Retrieved from: [http://www.aecbytes.com/feature/2008/HOK\\_CaseStudy.html](http://www.aecbytes.com/feature/2008/HOK_CaseStudy.html)

**56** James Vandezande, interview by author. New York, NY, (February 21, 2012).



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#### 4.7.7 Summary and Conclusions of the Case

This case exemplifies the basic original user innovation model, an in-house development that, on one hand, does not receive support from the developers, and on the other, is not meant to be released to the larger group of users, either commercially or for free. The case, as well as the other in-house tools that HOK has, show interesting insights about the way in which these types of tools – built in-house in a large firm – are developed. HOK has several tools that have been specially developed to solve a particular need of a project, but are currently not in use. In fact, some of them, as explained by Schleusner, are too hard to use, and as the original developer who made them has left the firm, nobody fully understands their relevance or how to use them.

From Schleusner's comments and the observation of HOK's developments, some key characteristics that this type of innovation should have can be derived. Innovations should be: user-friendly, generalized, centrally available, properly communicated, and well documented. Tools need to be easy to use for all designers, not just the ones with programming skills, and they need to have comprehensive documentation that means that even when the original developer of the tool leaves the company, users can still apply the tool without the need of external support.

Also, innovations need to be general enough so they can be applied in more than just the project for which they were originally created. Furthermore, centralization and communication appear as a central factor of the success of internal innovations. In other words, besides the programmer of the firm, there may be other designers in the firm generating small applications to streamline their own work. (In this case Schleusner states they have two; one of them was responsible for the Rhino script part of the Curtain Wall Generator.) One way of promoting innovation across the firm and streamlining work is to promote this type of initiative and transform the personal implementations into firm-wide solutions. Schleusner states they are trying to foster such initiatives, but it depends on the user having a very specific skill set (knowing how to design and also being fluent in coding), and not many people are actually good at both. Communications, of course, is key in the whole process. A good communication channel must be established to ensure that users know about the existence of the different innovations and are knowledgeable enough to use them correctly.

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4.7.8  
Specific Bibliography  
and Research  
Resources for the Case

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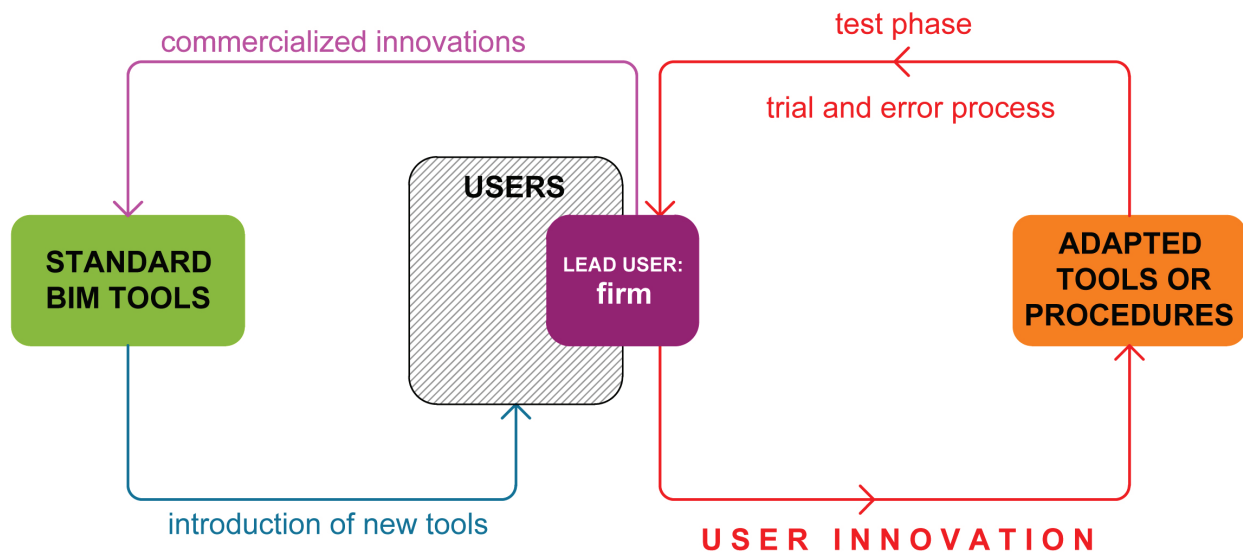
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## 4.8 ICABIM



**Figure 28**

ICABIM: User Innovation  
Flow Diagram.

**Description of Innovation:**

Method for evaluating BIM user needs and user innovations

**Type of User-Innovator:**

Private firm (Construction)

**User need/motivation:**

Streamlining modeling and information extraction

**Distribution:**

In-house development (but considering commercialization to original vendor)

**Direct support from vendors:**

Yes (diffusion)

**Diffusion from User-Innovator:**

Yes (AU presentation)

---

#### 4.8.1

#### Description of the Innovation

---

Rather than focusing on one specific innovation, the case about ICABIM focuses on the process underlying their innovation development in general, as they have established different procedures in order to justify the importance and validate the results of their innovations.

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#### 4.8.2

#### Motivation / User Need and Goal

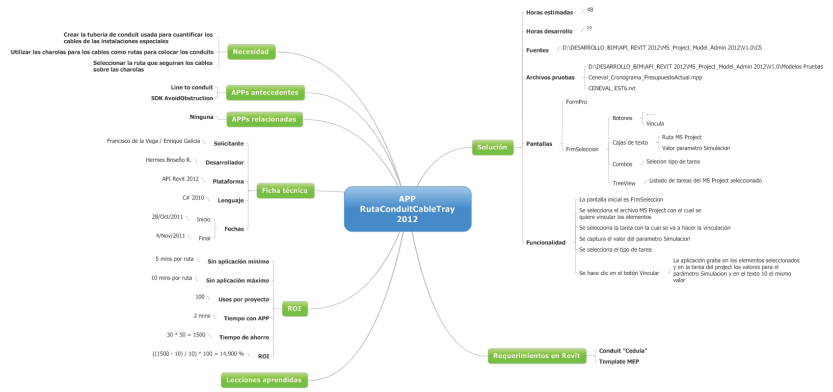
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In 2009, ICA, the largest construction company in Mexico, established an internal group called ICABIM in charge of delivering internal BIM services for the company. Among other tasks, this unit is in charge of innovating using the API of their BIM software. In a presentation at AU 2011, Enrique Galicia, a former VDC Coordinator at ICABIM, explained that their reasons for generating internal tools were to “improve productivity on modeling activities, increase the possible outcomes of models with scanners, mobiles, and other platforms, enhance better practices of Project Management and Lean Construction, support Quality and precision, [and] improve quantification performance.”<sup>57</sup>

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<sup>57</sup> Harry Mattison and Enrique Galicia, . *Autodesk Revit Construction Modeling and API for Builders*, PowerPoint Presentation for Autodesk University 2011. Retrieved from: [http://au.autodesk.com/?nd=class&session\\_id=9528](http://au.autodesk.com/?nd=class&session_id=9528)

**Figure 29**  
Evaluation of one specific innovation already developed by ICABIM.



**Figure 30**  
Innovation explanation (taken from the AU presentation).

### How does the App Work

Using a visualization template we can see the variances, on colors and detect which elements require to have their own rebar to diminish their variance in the model.

No Diferencia	✓	
Dif_Var_0%	✓	
Dif_Var_25%	✓	
Dif_Var_50%	✓	
Dif_Var_75%	✓	
Dif_Var_100%	✓	

By this users can prioritize which elements to build rebar on.

Autodesk University © 2011 Autodesk

**Figure 31**  
Innovation's return of investment (taken from the AU presentation).

### Time Savings Achieved with API Command

**1** Base Element  
4 Hour to  
20 segs  
x  
30 Times  
**2**

Variance Analysis Elements

Time Saved: **120 Hours**

Autodesk University © 2011 Autodesk

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### 4.8.3 Development and Testing Process

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#### Identifying Possible Useful New Applications

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ICABIM has created approximately 60 internal applications<sup>58</sup> to aid the work of the 55 people<sup>59</sup> currently working in ICABIM. In order to identify the most relevant requirements of their BIM users, ICABIM defined a Road Map to help them tackle the most relevant needs. Through interviews, surveys, and a webpage they asked the different ICABIM teams for their wish list. Thereupon, this list of possible innovations was evaluated according to each implementation's impact, time of development, and the savings it would generate, in order to identify the most relevant applications, the ones that would return a larger benefit in comparison to their corresponding manual processes. Additional considerations were included in the evaluation – for instance, whether the need was sufficiently common to the AEC industry to expect that the application would eventually be developed by other developers, which would eliminate the need for ICABIM to develop it in-house. Currently, ICABIM has a list of 50 possible applications to build.

Although the initiative appears to have been carefully planned, Hermes Briseño, an Information Technology Coordinator at ICABIM, argues there is room for improvement. Some of the demands of the internal users, for example, responded only to current needs, and lacked a larger perspective of requiring tools for the more general needs that repeat between projects. If attended to, these overly specific demands would result in very specific applications that could not be generalized for the whole team or for more than one project. Briseño states that a more successful approach has been having a coordinator, for example, for all the teams ICABIM has on site. That coordinator has an overall view of the work being done in the field; hence, he can identify common requirements, and tasks that repeat across the different projects. It is also relevant to consider the possible duration of the development, Briseño indicates, as many times the projects evolve faster than the time it would take the innovation to be implemented.

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<sup>58</sup> Enrique Galicia, entrevista de autor. Online interview, (14 de March de 2012).

<sup>59</sup> Hermes Briseño, interview by author. Online interview, (April 18, 2012).

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### Developing the Applications

Once a need is identified and validated, the development of the corresponding tool may take between one day and one week. Currently, most of the time the developers at ICABIM start from an already existing application to develop a new one. After the innovation is developed, the user who originally suggested the tool acts as a beta-tester. Finally, when the tool is robust enough to be deployed for the whole BIM group, documentation and tutorials regarding the tool are created.

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### Post-creation Evaluation

For the purpose of the evaluation of the tools after their generation ICABIM has created a comparison matrix that shows four facts for each of their applications: (1) the amount of time the manually performed task would take, (2) the amount of time the automated task takes, (3) the number of hours saved, calculated according to the number of projects where the tool has been applied, and (4) the number of hours the tool took to develop.

---

### 4.8.4 Support from Vendors / Developers

Vidali, the BIM Manager at ICA, states that ICABIM is informally working with Autodesk representatives to establish an alliance. Given the size of ICA and that ICABIM has become a power-user of their applications, Autodesk, he says, is interested in them as a center for research and development. In 2011, ICABIM's work received diffusion from Autodesk in a class at AU done by ICA in conjunction with Autodesk.<sup>60</sup>

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<sup>60</sup> Harry Mattison and Enrique Galicia. "Autodesk Revit Construction Modeling and API for Builders" PowerPoint Presentation for Autodesk University 2011. [http://au.autodesk.com/?nd=class&session\\_id=9528](http://au.autodesk.com/?nd=class&session_id=9528)



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#### 4.8.5 Current State, Further Developments, and Diffusion

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ICABIM plans to continue growing their work, improving their existing innovations as well as innovating in new areas. In general, they state they have no intention of releasing their applications to the general public. Nevertheless, this might happen through Autodesk, which has demonstrated interest in buying at least one of their applications. This application, built for the purpose of streamlining the placement of irrigation sprinklers on a golf course, allows ICABIM to output X, Y, and Z coordinates of points from Autodesk Civil 3D and use them as the placement coordinate for a sprinkler inside Revit. Briseño states that the manual placement in the project of each sprinkler would have taken approximately 15 days, while the automated process only takes half an hour.

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#### 4.8.6 User-Innovator's Background

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Founded in 1947, ICA is the largest Mexican construction firm. In 2009 the company started an internal group, of originally six people, dedicated to offer BIM services to the different units of the firm. Their first explorations in the BIM API developments were very experimental; they were learning by doing until April 2010, when they attended an Autodesk Revit API course in Poland.

By 2011 the group had grown to 55 people. Currently, their work is organized in two areas. While half of ICABIM is devoted to model and input information, the other half is dedicated to extracting information from the models. Due to the fast pace of construction and the unavailability of good internet connections – to efficiently communicate BIM information between ICA's office and the construction sites – once the model is developed by the first team, this second group moves to the field where they work extracting information and doing proper modifications according to how things are modified in the construction. A third group of two people is in charge of developing and adapting applications for the other two groups.<sup>61</sup>

While ICABIM has participated in more than 40 projects, they do not participate in all the projects of ICA. According to Briseño's calculations, this would require a BIM service team of approximately 600 people.

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<sup>61</sup> Hermes Briseño, interview by author. Online interview, (April 18, 2012).

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#### 4.8.7 Summary and Conclusions of the Case

ICA's case demonstrates in a very structured way the pursuit of user innovation in the context of BIM. Given that ICABIM is composed of a large group of people – 55 – heterogeneity of needs can be observed inside the group, proving that heterogeneity is not only a problem for disaggregated groups of users applying BIM in different *contexts of use*. Even inside the same *context of use*, heterogeneous user-needs may generate a large array of demands.

Accordingly, the rational approach to the problem of varying needs that ICABIM has developed appears as an interesting model to analyze. Comparing the amount of time a possible development would take versus the time its deployment would save – in other words, the return on investment of the tool – and also contrasting that information with the possibility of solving more than one requirement through the same innovation, ICABIM generates a matrix that allows them to define in a more objective way which innovations to pursue.

Each user need is carefully evaluated to identify repetitive requirements, to understand the validity of the request, and to analyze the possibility of solving the requirement without the need to actually build a tool (e.g., buying an already developed tool or waiting for someone else to develop it). This rational process, and the fact that the innovation seems to be structured and well communicated and documented across the team, makes the case an interesting referent. This process can be compared to the previous case (HOK Curtain Wall Generator, section 4.7), where the lead user firm recognized the need for setting minimum standards for the innovations, even though they had not implemented them yet.

A relevant aspect of ICABIM's work is the process behind the developments: how they collect information about what internal users require to optimize; how they organize and select the ones to develop; and how they measure the return on investment of the tools. It appears that they have generated and validated a process to determine the best tools to develop and justify the investment in the development. The fact that the AU presentation of ICA was especially focused on the company's API tool development processes confirms the interest of the case. Nevertheless, Briseño's remarks indicate that even a well-organized system of mathematical analysis can benefit from the subjective insight of an educated observer, a lead user inside an advanced group.

That is to say, the group of users inside a lead user firm will behave in the same way as the larger community of users. There will be advanced users that are ahead of the group, and can perform skillfully, identifying niches and opportunities for innovation. Therefore, the lead user firm needs to establish protocols in order to listen to this type of lead *internal* user that can give valuable feedback and play a key role in the firm's user innovation process.

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4.8.8  
Specific Bibliography  
and Research  
Resources for the Case

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# Conclusions

# 5

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## 5.1 Comparison of Cases

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### A Types of users

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Regarding the original criteria established for selecting the cases, comparison of the eight user innovations studied reveals common features between them as well as particularities.

The cases studied show that private firms, as well as individuals and nonprofit institutions, are engaging in innovation in order to satisfy their specific needs. Having multiple types of innovators enriches the innovation process and discussion, as their approaches to the problem and the resources they can devote vary. Establishing joint collaboration, for example, between private firms and academic institutions, can boost the innovation trend, as it promotes discussion and brings together different kinds of knowledge and objectives that can be mutually beneficial.

On the other hand, *collective invention* has also been sought in some of the cases (open-source cases), but group collaboration has not yet been fully successful. As portrayed by Allen,<sup>1</sup> *collective invention* is a slow process that requires that motivated participants see the potential of distributed collaboration. As Kogut and Metiu state, "open-source exploits the intelligence in the distributed system."<sup>2</sup> Nevertheless, relying heavily on this distributed model of development may slow down the process.

### B Motivations

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The cases studied portray two types of motivations driving the innovations: exploratory and problem-solving. The exploratory innovations are being developed for an experimental purpose; they are being carried out to research how to push the boundaries of the existing standard technologies and improve the functionalities of BIM tools. On the other hand, most of the innovations studied have been created to solve a very specific need. In general, those needs are specific to a project (e.g., transferring a curtain wall from a geometric modeler to a BIM application). However, in some cases the innovations have been able to transcend the specific project for which they have been developed (e.g., RPS).

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<sup>1</sup> See: Robert Allen, "Collective Invention." *Journal of Economic Behavior and Organization*, no. 4 (1983): 1-24.

<sup>2</sup> Bruce Kogut and Anca Metiu. "Open Source Software Development and Distributed Innovation." *Oxford Review of Economic Policy* 17, no. 2 (2001): 259.

**Table 1**

Case summary and emergent user innovation patterns in BIM

Case	Description of Innovation	Type of User-Innovator	User need/motivation
4.1 <b>Dynamo</b>	Visual programming plugin for BIM	Individual (Architect)	Exploratory
4.2 <b>Revit Python Shell</b>	Python scripting plugin for BIM	Individual (programmer)	Streamlining the API programming process
4.3 <b>MIT-CO Workshop</b>	Research initiative on BIM innovation development	Non-profit Institution (University) + Private firm (Architecture)	Exploratory
4.4 <b>goBIM</b>	BIM visualization tool for mobile devices	Individual (Architect)	Exploratory
4.5 <b>Free BIM Apps</b>	Freely released plugins for BIM	Private firm (Third-party developer)	Promotion, marketing
4.6 <b>SOM BIM Dashboard</b>	QA/QC platform for BIM	Private firm (Architecture) + Private firm (Third-party developer)	Standardization and optimization of design procedures
4.7 <b>HOK - Curtain Wall Generator</b>	Rhino to Revit geometry transfer tool	Private firm (Architecture)	Information transfer from geometric modeler to BIM application
4.8 <b>ICABIM</b>	Method for evaluating BIM user needs and user-innovations	Private firm (Construction)	Streamlining modeling and information extraction

Distribution	Direct support from vendors	Case	
Open source (Apache license)	Yes (Diffusion - AU, blogs, and the Labs - and Coding)	<b>Dynamo</b>	<b>4.1</b>
Open source (MIT license)	Yes (Diffusion - blogs - and Coding)	<b>Revit Python Shell</b>	<b>4.2</b>
Free through a webpage	Yes (Training and coding assistance)	<b>MIT-CO Workshop</b>	<b>4.3</b>
Commercialization (Apple App Store)	No	<b>goBIM</b>	<b>4.4</b>
Free through a webpage	No	<b>Free BIM Apps</b>	<b>4.5</b>
In-house development, but considering free release	No	<b>SOM BIM Dashboard</b>	<b>4.6</b>
In-house development	No	<b>HOK - Curtain Wall Generator</b>	<b>4.7</b>
In-house development (but considering commercialization to original vendor)	No	<b>ICABIM</b>	<b>4.8</b>

**Key**

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**Type of User**

- Individuals
- Nonprofit + Private Firms
- Private Firms

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**User Motivation**

- Exploratory
- Specific-Problem

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**Distribution**

- Open-source or Freeware
- Commercialized
- In-house

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**Direct Support**

- Support
- No Support

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## C Innovation Distribution

The cases in this study display different models of distribution. While individuals and the academic institution seem to favor releasing their innovations as open-source, private firms seem to favor keeping the innovations in-house. Interestingly, referring to possible public distribution of the tools, three of the private firms interviewed point to the same fact: given that they are not a software company, they have no intention of commercializing their innovations. However, they take dissimilar approaches to this common idea. The first firm – HOK – decides to keep the tools in-house; the second firm – SOM – says they are considering the possibility of releasing their innovation, or at least part of it, for free; and the third firm – Co – is sponsoring a workshop that will release all the innovations developed for free.

Finally, the public distribution of tools – for free or for a fee – as discussed in section 3.1.4 benefited the development of the innovations in all the cases studied.

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## C1 Motivations and consequences for releasing for free

The motivations for and consequences of freely releasing their innovations are similar to what is indicated by the literature: intrinsic and extrinsic rewards for the innovators. Namely, innovators who have released their innovations as open-source declare their interest in giving back to the community. Additionally, their reputations have grown as a consequence of their innovations' open release.

Another motivation for user-innovators to freely release their developments has been, as Keough (with Dynamo) declares, to boost the progress of their innovations through *collective invention*. As Allen<sup>3</sup> indicates, this *collective invention* would help the tool progress through cumulative advances. These advances have happened insofar as the original developers of the standard tools have taken interest in Keough's application and devoted resources to improving the program and promoting it through different channels. However, the users who have downloaded the innovation have not contributed to its advancement and therefore the progress of the tool is still slow.

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<sup>3</sup> Robert Allen, "Collective Invention." *Journal of Economic Behavior and Organization*, no. 4 (1983): 1-24.



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C2  
Diffusion from user

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Most of the innovations studied have had some kind of diffusion by the user. Generally, this diffusion has been done through online channels – e.g., maintaining a blog to post updates about the refinements of the innovations – but in some cases it has also been done through conference presentations.

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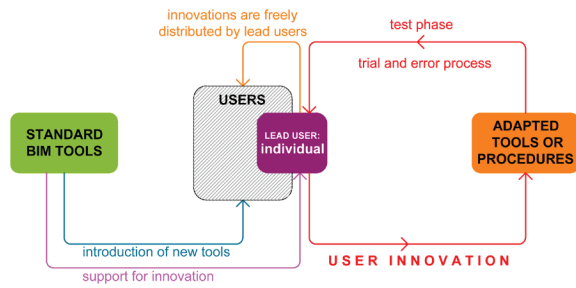
D  
Direct support from  
vendor

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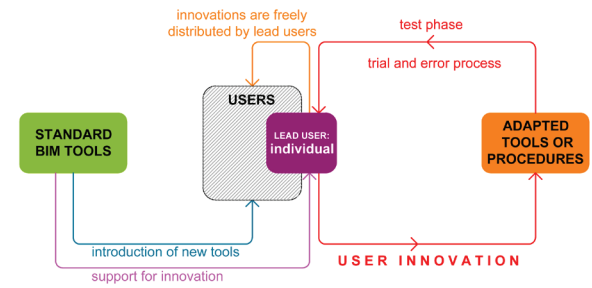
As discussed in section 6.2, both open-source innovations studied – Dynamo and RPS – have received direct support from the vendors in the form of diffusion (e.g., blog postings and conference presentations) and in the form of actual programming. Of the other innovations – in-house developments and commercially distributed innovations – some have received support, but only in the form of diffusion.

**Figure 32**  
**User Innovation Flow**  
 Diagrams of the eight cases studied.

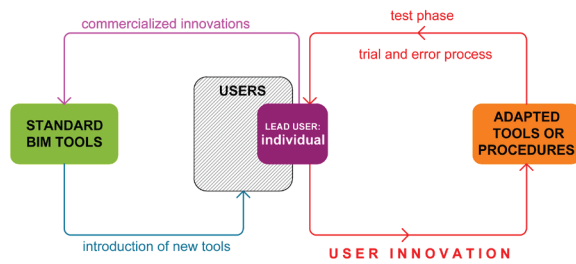
**01 Dynamo**



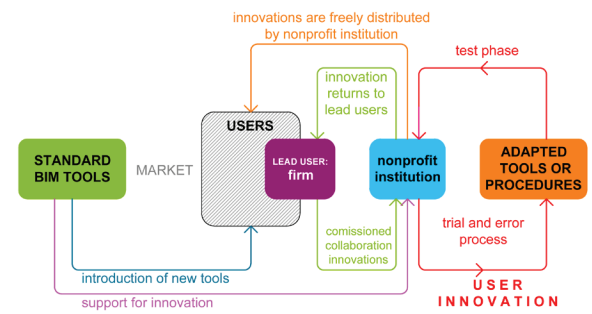
**02 Revit Python Shell**



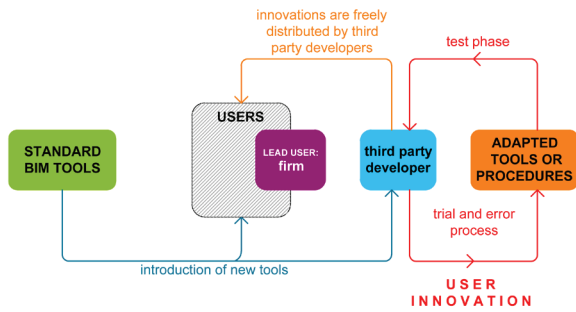
**03 GoBIM**



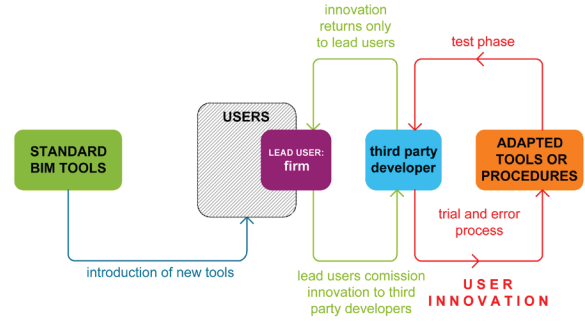
**04 MIT-CO Workshop**



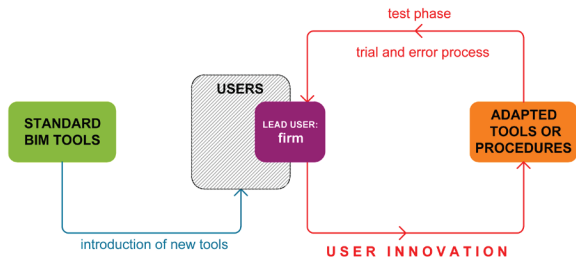
### 05 Free BIM Apps



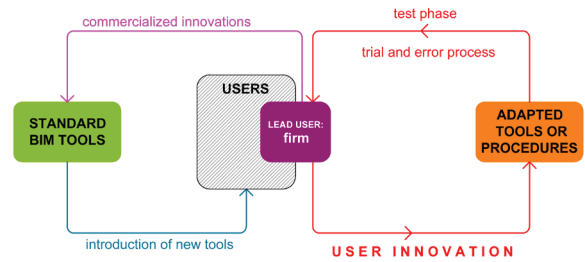
### 06 SOM BIM Dashboard



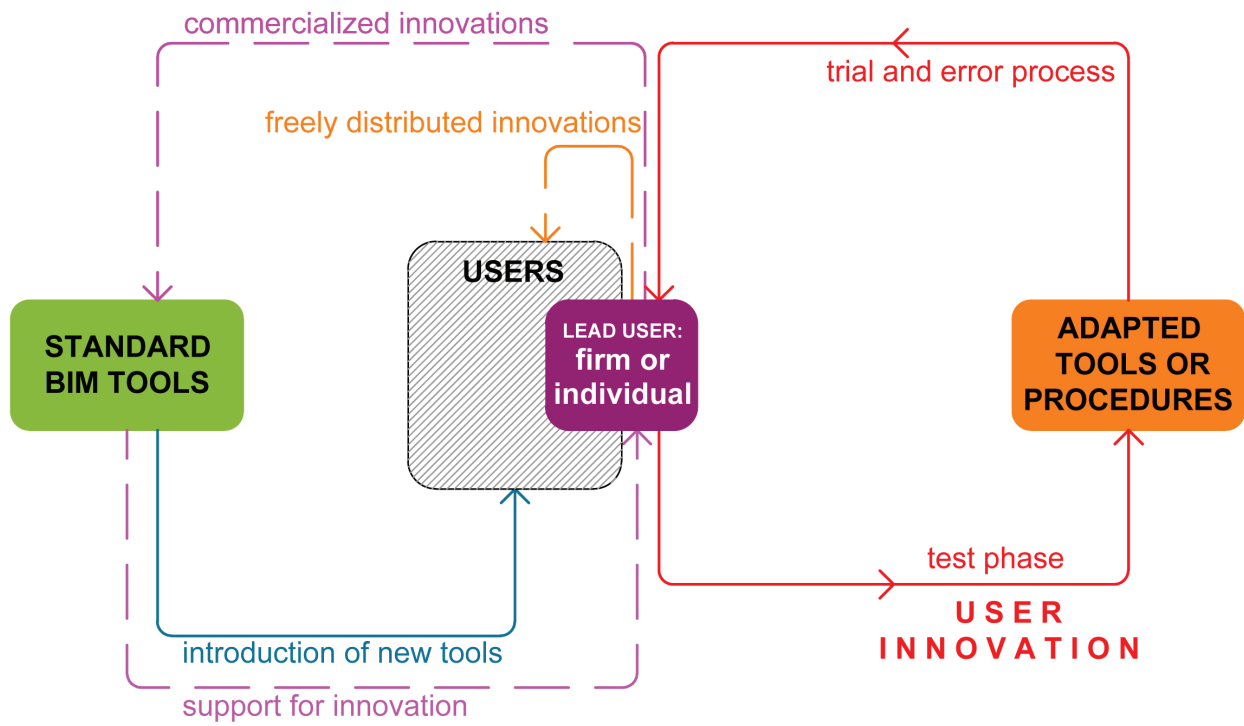
### 07 HOK Curtain Wall Generator



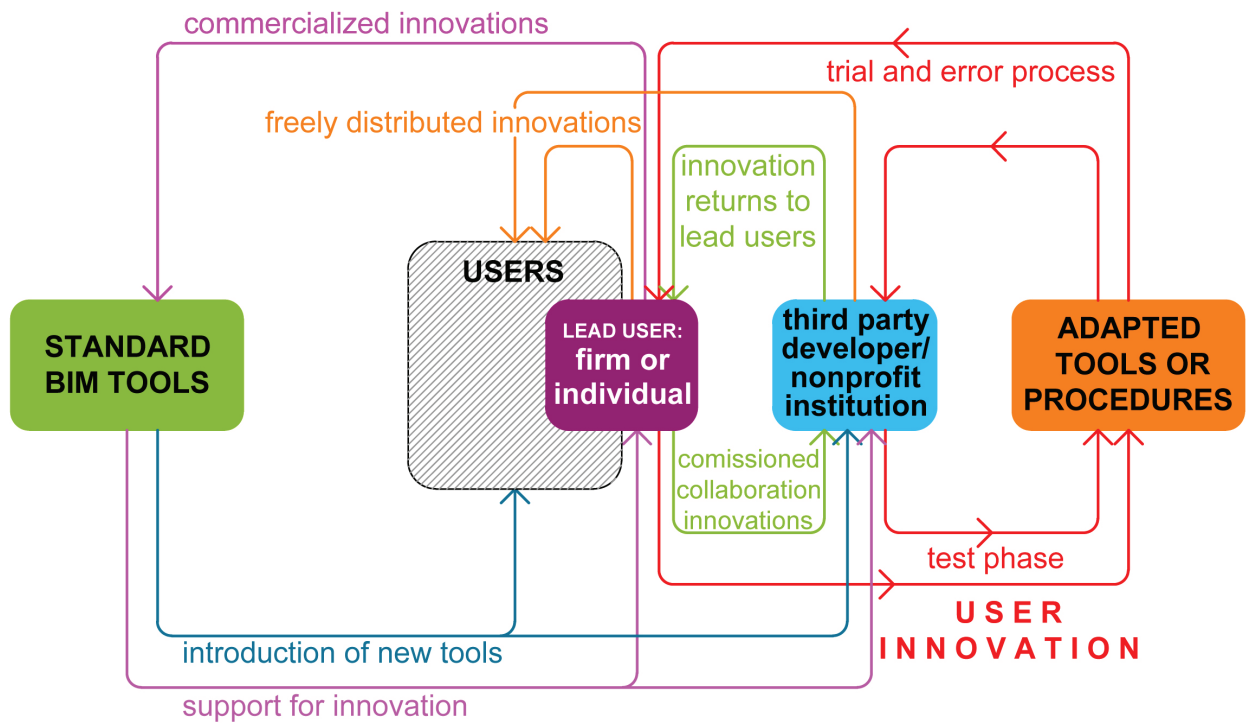
### 08 ICABIM



**Figure 33**  
Preliminary User Innovation  
Flow Diagram for BIM.



**Figure 34**  
Final User Innovation Flow  
Diagram for BIM: the result  
of adding the eight cases'  
diagrams.



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## 5.2 Findings

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The study of these eight cases, as well as the preliminary research carried out, demonstrates the following regarding user innovation in BIM:

- **User innovation is not uniformly distributed**, as it depends on the resources present in the different *contexts of use* (e.g., skillful programmers, time dedication). Therefore, there may be regions or disciplines, for example, that are not able to adapt the tools, lagging behind the more advanced regions or disciplines.

- That most of the cases studied were in some degree open to the public or were considering this possibility attests to what user innovation and open-source theories state: **the model of property restricted software is sometimes inefficient and the collective creation model appears to be the logical path for some types of innovation.**<sup>4</sup>

- The releasing of innovations as **open-source or freeware has reported intrinsic and extrinsic rewards to their creators**. Among the intrinsic rewards, innovators pointed to reciprocity (e.g., help because they have also been helped by others) and altruism (e.g., wanted to give to less advanced users). Among the extrinsic rewards, innovators have gained reputation and recognition through their innovations, a fact that has translated into job opportunities, among other benefits.

- Relating to the ideas proposed by Tuomi and Fischer, **some innovations have gained new meaning through social practices**. That is to say, innovations, such as RPS, originally designed to solve a specific requirement, may gain validation through alternate uses and values that the community assigns to them.

- There has been a **correlation between type of distribution of the innovation and availability of direct support from vendors**. While open-source initiatives tend to have some support in the form of diffusion and even actual

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<sup>4</sup> Kogut and Metiu state that the “rapid growth of open source development suggests that the traditional methods of software development are often inefficient.” Kogut, Bruce, and Anca Metiu. “Open Source Software Development and Distributed Innovation.” *Oxford Review of Economic Policy* 17, no. 2 (2001): 249.

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programming, commercially distributed user innovations generally lack this type of collaboration. Similarly, innovations that are freely released with the purpose of marketing a private practice also tend to lack support.

- An alternate explanation of which types of innovations receive support from vendors could be that, instead of a correlation between open-source and the availability of support, a correlation exists between the level of possible impact of a tool and the vendors' willingness to actively support the innovation. As the two innovations that have received programming support are tools that propose a drastic change in the way the standard BIM tool is used, it could be argued there is a correlation between potential impact of an innovation and the availability of direct support from vendors.

- Commercialization of the projects may discourage support from original vendors, but this does not necessarily mean that the innovation's progress will be slower than for the open-source ones. In fact, the cases studied indicate the opposite trend. The commercially released innovation studied, goBIM, had a large group of users (1,400) and therefore, this community of users influenced the pace of its development.<sup>5</sup> Namely, **more users means more testers, which can accelerate the debugging process.** Raymond explains the efficiencies of a distributed model of debugging in the following terms: "given a large enough beta tester and co-developer base, almost every problem will be characterized quickly and the fix obvious to someone."<sup>6</sup> In the case of goBIM, users were only acting as testers and not debuggers. Still, the case shows that this distributed model of testing stresses the program in several ways, accelerating, if not the debugging, at least the identification of the bugs. On the other hand, given that its users are paying customers, the pressure for the user-innovator to fix the bugs will be greater than for a user-innovator who has released his/her innovation for free.

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<sup>5</sup> A large community of users is not equivalent to a large community of lead users, but as this is a paid application it can be assumed that its group of users are motivated to use it, since the cost of the application filters out the people who just want to "play" with the tool, from the ones who are motivated enough to pay and use the application.

<sup>6</sup> Eric Raymond, *The Cathedral and the Bazaar*, (Cambridge, Massachusetts: O'Reilly, 1999), quoted in Eric von Hippel, *Democratizing Innovation*, (Cambridge, Massachusetts: MIT Press, 2005), 94.

- Summarizing the last two points, **publicly releasing an innovation benefits it, and the larger the group of users, the quicker bugs will be identified.** In this respect, advantages can be claimed on both sides of the freely-release-versus-commercialize-for-a-fee decision. On one hand, a large group of paying users will probably be more demanding and pressure the improvement of the development more than an equivalent group of free riders. On the other hand, open source projects may benefit from users not only identifying bugs, but also fixing them. Nevertheless, this last situation has not happened yet for the cases studied.

- As stated in section 3.2.2.h, **when an innovation is released to the larger group of users, the process of user innovation may (re)start all over again. In other words, there is the possibility** that lead users other than the original innovator adopt the innovation and work on top of it. Nevertheless, that has not been true for the cases studied.

- **Heterogeneity of needs can be addressed through small apps**, add-ins that are installed on top of standard applications. In that way, producers of standard technologies can generate variations that address requirements that repeat across a certain region, discipline, or type of project. This will not obviate the need for users to adapt the tools, but may solve repetitive problems, so lead users can focus on their particular needs instead of duplicating efforts by developing the same solution that similar lead users are developing. This, of course, requires that the producer of the standard technology learn about repetitive needs between similar *contexts of use*, but channels such as information communities (e.g., forums and blogs) may be a proper channel to gather such knowledge. Establishing differentiated channels according to different *contexts of use* may simplify even more the task of identifying common patterns of user needs. That vendors are starting to establish platforms for crowd-sourcing and releasing these apps, and the fact that third-party developers are doing the same as a marketing strategy, proves that this is an emergent trend and may be a path to solve the need for intensive adaptation of the technologies. As one of the cases shows – *AEC-apps* – crowd-sourcing this type of endeavor can be a good strategy for lowering the effort dedicated to building such a platform



and obtaining a wide variety of apps, not just the ones that the maintainer of the platform creates. In that way, the platform can gain content faster and consequently, attract more users. Associating that platform with some kind of community that rates and validates the app also seems like a good strategy for supporting and guiding users.

- The private-firm, in-house innovation cases studied demonstrate some **key aspects for the success, or failure, of an innovation** to be adopted by a larger group of users. The innovation must be:

- **General:** Even when most of the time tools are developed to meet a particular need, they need to be generalized so they can be applied to other circumstances, or else they run the risk of becoming useless. The procedures established by ICABIM show that even when the tools are not generalized, reusing the code to build another innovation may be a beneficial path in order to build cumulative innovations and generate a large body of knowledge to help develop innovations faster and more easily.

- **User-friendly:** The user innovations studied were sometimes developed in spare time, without devoting many resources to the development. This may work when the innovation is being used by its original developer or by a small group of users who are in direct contact with the developer. However, if an innovation is to be generalized as a standard tool for a group, users must be able to utilize it easily and, hopefully, intuitively. Expecting that users will endure a steep learning curve to use a small application diminishes the chances of success in the implementation of the innovation.

- **Well documented:** Similarly to the previous point, an innovation that is only being applied by its creator or by a small group who are in contact with him or her could work. Nevertheless, if a tool is to be spread across an organization or a scattered group, it needs to be self-explanatory. Users need to be able to access information about how to use the tool without needing to contact the developer. In that way, it is ensured

that even if the developer is no longer available to the group – has left the firm, for example – users will get the proper assistance to understand and successfully apply the tool.

- **Centralized:** Inside large organizations, innovations should be centrally stored and managed in order to make them easily available to any user. Firms may have some individuals who, even if they are not hired as developers, build small innovations in order to improve and facilitate their own work. HOK, for example, stated they were trying to foster that kind of initiative and they had taken part of a user-created tool and added it to a larger innovation. This is a good way to achieve innovation, especially in the cases where firms have few resources for innovating. Turning those personal innovations into robust applications and centralizing them is a good practice. Relating this to the previous conclusion, the more users a tool has, the better the tool will become. In other words, giving broader access to the innovation may benefit the innovation as well as the users and the organization.

- **Communicated:** Putting innovations in a central location, available to all users, may not be enough to promote their use. Private firms' experience shows that alternative diffusion efforts may help in the adoption of an innovation. Also, the cases studied show that almost all individual users kept a blog to discuss repairs and improvements of the innovation.

While some of the firms that have not been completely successful in spreading their applications internally acknowledge that some or all of these conditions are lacking in their organization, these are very similar to the points that ICABIM refers to when explaining their strategy of BIM user innovation.

- The group of users inside a lead user firm will behave in the same way as the larger community of users. There will be advanced users that are ahead of the group, and can perform skillfully, identifying niches and opportunities for innovation. Therefore, **the lead user firm needs to establish protocols in order to listen to this type of lead *internal* user** that can give valuable feedback and play a key role in the firm's user innovation process.

- Putting in place an assessment process to analyze and evaluate the relevance of user needs and the return on investment of building an innovation to solve a particular need appears to be an organized way to pursue innovation. However, it could be argued that this process may inhibit interesting exploratory projects, since (for example) it is hard to know whether projects like Dynamo would pass such an evaluation process. Nevertheless, for a large company with many BIM users and limited resources for innovation, it may be a good approach to understanding needs and having a way to meet many needs by optimizing limited resources.

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## 5.3 Conclusions

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1

Through the presentation of the eight cases studied, the thesis has demonstrated the existence of innovation in the case of BIM tools' adaptation. Users from different *contexts of use* are innovating mainly through the creation of plug-ins to input, manage, and extract different types of information in BIM's. However, this research has demonstrated that although user needs appear to be uniformly distributed across different *contexts of use*, user innovation is not, as it depends on availability of resources that are not homogeneously present across different contexts.

2

Different patterns of innovation arise from the study, as diverse combinations between types of users (private firms, individuals, nonprofit institutions, or collective invention), motivations (exploratory or specific need-oriented), types of distribution (open-source, freeware, and in-house), and direct support (promotion, coding, or none) generate very dissimilar innovations.

3

The innovation patterns – namely, the actors, actions, and relations they establish – that the different cases show are based on the model originally described by innovation theory (section 3.2.2). However, as new actors are included in the process (third-party developers or universities), the complexity of the model grows as many variations and exceptions are included. Some cases may even be rejected as user innovation (e.g., case 5.4, free BIM applications). However, they are used in this thesis to demonstrate that different emerging initiatives and collaborations are substituting for the lack of easily customizable BIM tools. Although resources necessary for user innovation are still scarce, and BIM tools are not easily customizable, users are supplying these needs by establishing collaborations with third-party developers and universities or by downloading small applications that add functionalities to standard tools.

4

All of the above demonstrates that, while there is user innovation in BIM, there is still room for improvement.

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## 5.4 Future Steps

The present study opens up many questions that could be considered further in future research. For instance, one path to explore would be to study the reasons why private firms that used to be recognized as user-innovation pioneers in regard to digital design tools (such as SOM and HOK), while still interested in innovating, are currently not devoting the same amount of resources to the task. Of course, economic reasons and a change in the pace at which commercial digital design tools progress nowadays come to mind. Nevertheless, an in-depth analysis to assess why firms that 20 years ago created their own CAD tools are not leading the way in digital design innovation today could shed light on the whole issue of user innovation with regard to BIM.

Moreover, as most of the cases studied in this thesis are still ongoing projects, another path to explore would be to follow some of them over time to observe their evolution. This could deliver valuable information on the progression of innovations, especially for the open-source projects, as it would allow understanding whether, eventually, collective invention comes into place and the innovations are transformed into fully functional applications. Even in the cases where the innovation fails to become a robust tool, the follow-up process would still be a valuable contribution to understanding and learning about the user-innovation process in BIM. Additionally, including cases of user innovation related to other BIM software, not just Revit, could illuminate whether the user innovation in BIM is similar across the different applications or there are specific software conditions that influence the ways in which users can innovate.

Finally, yet another path to explore would be to add more cases to the study, from different regions, especially the ones that are not innovating. This would make possible understanding of the limitations that are preventing user innovation in those contexts. That study could shed light on what needs to be improved in the user toolkits, or what types of needs should definitely be addressed directly by the original vendors in order to satisfy user needs in varying *contexts of use* that are

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6



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## Figures

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2. *Dynamo: User Innovation Flow Diagram*. Image by the author.
3. *Dynamo's User Interface*. Frame extracted from video: [http://wikihelp.autodesk.com/Vasari/enu/Community/Work\\_in\\_Progress/Dynamo\\_for\\_Vasari](http://wikihelp.autodesk.com/Vasari/enu/Community/Work_in_Progress/Dynamo_for_Vasari) (accessed April 9, 2012).
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11. *User interface flow chart of the object Interaction Query tool (oIQ)*. Image by the author.
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