



## User Driven Innovative Building Design

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# User driven innovative building design

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**ABSTRACT:** During recent years there has been an ever-increasing focus on the possibilities to change the building process to raise quality on the final building products as well as on the activities of actors involved in the building process. One reason for this interest is the new opportunities evolving due to the broad introduction of advanced information and communication technology (ICT). VICMET is a general method for user involvement in every phase of the construction process and with a unique setup for each type of user. VICMET can use already created information in the building process and emphasis that the users are the key to next level of successful building projects. VICMET defines four spaces to support the activities in a innovative/creative design process; The Contextual Inquiry Space, the Conceptual Modeling and Game Space, the Functional Building Systems (FBS) Consolidation Space, and the Solution Space. In addition to these spaces there are supporting artifacts like Idea Bank and Good Story/Best Practice bank as well as Ontology containers and access to Communities of Practice and Interest. The project has so far validated the need for enhanced methods to involve end-users of buildings in a collaborative/participative creative and innovative building design process. The AEC professionals also appreciate development, enhancement and to some extent formalization of existing methods for user involvement in the building process.

**KEYWORDS:** User driven innovation, virtual construction, creative, building design, needs, functional building systems.

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## 1 INTRODUCTION

This paper focuses on development of a new methodology to involve end users of buildings in the innovative and creative design of the buildings. The so called Virtual Innovation in Construction method (VICMET) is explained as well as how we can expect the design process to change due to higher focus on formalizing end-user needs and requirements on building functionality. We present new opportunities for users to develop and articulate real needs concerning for example different functionalities of a building and its parts, but also the artifacts support-

ing the actual needs capture and requirements formulation during building design.

The modern (product) end-user is participative, creative, self organizing and community oriented emphasizing the need to include users in construction. Users hold the unique answer to complete a perfect design. Architects and engineers cannot in most cases optimally guess, sense or calculate the finished result without involving the users. Involving the users doesn't reduce the need for architects and engineers. Building construction focus has to change. There must be a wide understanding that users can be useful and that there must be a setup of optimal environment for users to participate and respond to relevant topics, and afterwards translate

their needs into design solutions. This means we need a high level knowledge on the specific users and the context they act in.

Advanced ICT tools give us possibilities to develop and introduce support for contextual inquiry and capture of user needs, ideas and innovative proposals for enhancement of new and existing services and building functionalities. We also have opportunities to further develop methods and tools to ensure effective user participation in design and evaluations of proposed building solutions.

The paper presents results from the on-going project User Involvement in Construction - Virtual Innovation in Construction, VIC, financed by the Danish Enterprise and Construction Authority and the Programme for User Driven Innovation. Project participants are the two main engineering and architecture companies in Denmark, Arkitema A/S and Ramboll A/S, and Aalborg University, Civil Engineering department.

## 2 BACKGROUND

Buildings are important ingredients in optimizing quality of our lives whether we talk about buildings for living, work, or different kinds of social services. Buildings are not ordinary products like mobile phones or cars. They are often produced as one of a kind by organizations existing only during the building project. There are great opportunities for innovation in this open environment but also challenges caused by the intra-organizational setting, entailing that much knowledge on how innovation is carried through within companies are not directly applicable.

Methods have been developed, particularly in the design industry, to uncover such needs, which cannot be revealed with the help of the prevalent methods. These methods are of an anthropological nature, and go under such terms as user-centered design, user-driven innovation, empathic research, and applied ethnography. The methods are concerned with studying and observing people in their daily routine, in order to understand what underlies their actions and behavior. The aim of the methods is thus to acquire knowledge about people and their behavior in a broad perspective, as well as about their feelings, values and inner driving forces. By involving users in the development process of, for example, a new domicile for a company, you can help to ensure their sense of ownership of the changes that the move will entail.

We describe user driven innovation as a 'systematic approach to develop new products and services, building on investigation or adoption of users life, identity, praxis, and needs including unrevealed needs' (Christiansson et al. 2008).

The building may be regarded as a system that is going to be used by people in different types of organizations. ICT gives us opportunities to improve the designs of many user systems and certainly buildings through (development of) new design tools, virtual building prototyping and testing, virtual spaces for collaboration, and through in buildings embedded ICT systems. Unfortunately many user systems today lack effective fulfillment of user needs, as they very often are not properly taken into account.

The project goal of the Virtual Innovation in Construction (VIC) is to create an ICT supported methodology VICMET to involve building end user in a creative innovation process together with building designers, to capture and formulate end-user needs and requirements on buildings and their functionality.

## 3 STATE OF THE ART

User driven innovative building design embraces many knowledge domains. We have below highlighted some areas that are of special interest.

The innovation scene is changing as we apply more open business models, (Chesbrough 2006), also entailing uncertainties on intellectual property establishment. Innovation and development of new products is not taking place inside a single company and may very well require long term strategy development and implementation and return of investments. Innovation diffusion occurs within a social system or network (Rogers 2003). Increased interaction in a social network may increase the rate of diffusion, and is affected by opinion leaders and change agents (Pittaway et al. 2004).

Advanced ICT tools enhance our possibilities for effective, efficient and user-friendly collaboration in both physical and virtual environments. See for example Cisco TelePresence solutions (Cisco, 2009). Augmented reality enables us to different degree to superimpose e.g. virtual building models with reality. In this way we can see what is behind the wall, put non-existing furnishing and equipment into rooms. We can collaborate in real time in one physical room on the same building model (with photorealistic rendering on surfaces) and even connect many physical rooms to a common virtual room where participants can be represented by avatars. (Christiansson et al. 2009). Experiences from Danish design collaboration on digital virtual building models in praxis show that synchronous collaboration is useful in that more or less immediate access to different team members are at hand. This also puts high demands on the supporting ICT if the persons are not physically situated in the same room. There will be demand on preferably full size representations of distant persons in virtual rooms with common for all

participants perceptible access to the design artifacts and building systems under design as well as results such as weighed needs matrixes. Such ICT tools may today be rather costly.

Advanced ICT tools are developed and implemented on global scale pushing development of (de-facto) standards on levels from data communication, web services up to virtual building modeling and communication. Virtual building product and process models are matured and increasingly used (Eastman et al. 2008), and recommendations for new working methods are published (bips 2007). Connection of physical things and corresponding virtual models is support by RFID (Radio Frequency Identification) (Sørensen et al. 2008b).

The buildings themselves will also be more adaptive to different uses and responsive to the end user needs through embedded ICT supported systems. (Christiansson 2007).

#### 4 UNDERSTANDING THE USERS

Before a client ends up with a requirements specification on a building, we have to recurrently traverse the end-user needs capture and consolidation process. The end-users of a building are typically building inhabitants, external service providers, operation and maintenance personnel, and building

administration. The end-users are most often unique coming from different building usage contexts. They may in many cases have conflicting wishes and expectations on building performance, optimizing from their world of discourse. Wishes and needs on the functionality of the final building have to be formulated with common mutual understanding in a collaborative process we can call co-creation (Cherkoff & Moor., 2004; Prahalad & Venkatram, 2001).

#### 5 METHOD FOR DEVELOPMENT OF VICMET

The VIC method (VICMET) is itself developed in an innovative/creative design process. At the same time the building design process is transformed to better support creative and innovative building design, see Figure 1. The contextual design (CD) method (Beyer & Holtzblatt 1998) is giving inspiration in the VIC system development.

The Confluence 'enterprise wiki' from Atlassian, <http://www.atlassian.com/>, was chosen to serve as a hosted project web also housing the VIC Public Space, Figure 2. VIC Confluence is mainly used as a dynamic content management system also used to take real time notes during physical and virtual meetings. The main structure of VIC Confluence is Help, Project basis (contact info, activity plans, templates etc.), Economy, Activities (according to activ-

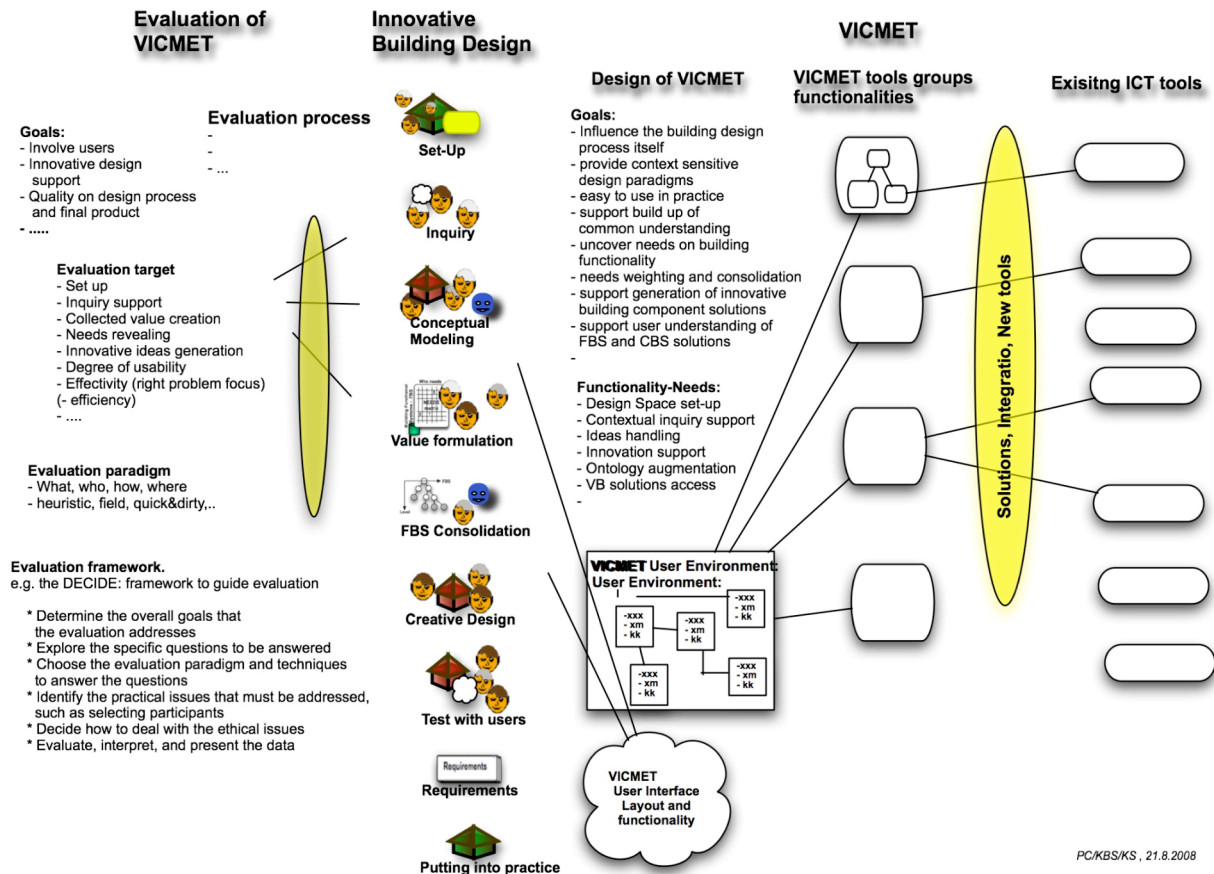


Figure 1. gives an overview of the two parallel processes namely design of the VICMET and improvement of the building design process to better handle early user needs and requirements capture as well as functional building system design and mapping to component (building parts) building systems.

ity plan with storage and support of project synchronous and asynchronous collaboration), Meetings, VIC publication, and References (Literature, digital models, projects, software).

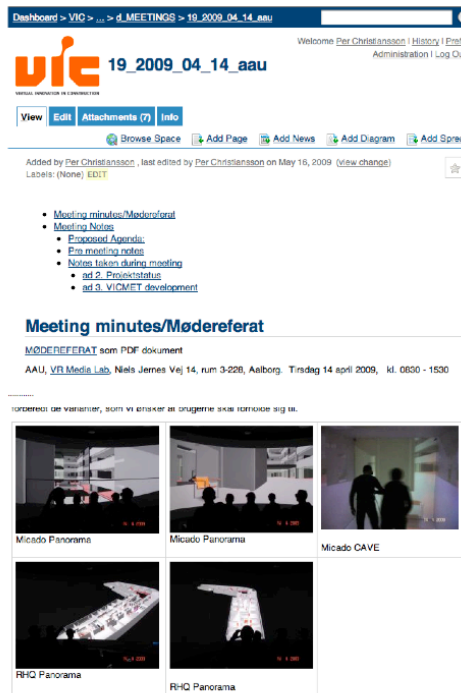


Figure 2. Screen dumps from meeting notes taken during work group meeting in the VIC project. The Confluence enterprise wiki is used for project collaboration support and documentation.

### 5.1 The two headquarter cases

The VICMET is explained and assessed based on a test case 'innovative meeting room design'. Examples are given on collection of contextual inquiry information through for example meta-marking and automatic storing of self observations, work flow models in Contextual Design (Beyer & Holtzblatt, 1998), and questionnaire handling.

Initial needs and requirements on the system are consolidated from Arkitema A/S and Ramboll A/S respective design of their new offices in Copenhagen as well from project participants' general experiences.

### 5.2 VICMET conceptual models

The Contextual Design methodology is partly used in design of the VICMET itself. Figure 3 shows an example of a work flow model during conceptual modeling of VICMET actors information flow and place holders for information banks and meeting places. The model is dynamically documented in the CmapTools, <http://cmap.ihmc.us/download/>, an open source concept-mapping tool running on Windows, Mac and Linux platforms. External elements can be

accessed by clicking concepts for example URL links, videos, and software applications and the whole concept map can be published and accessed from the WWW. An early interactive layout of VICMET according to Figure 3 was for example used in working sessions and also accessible from the WWW.

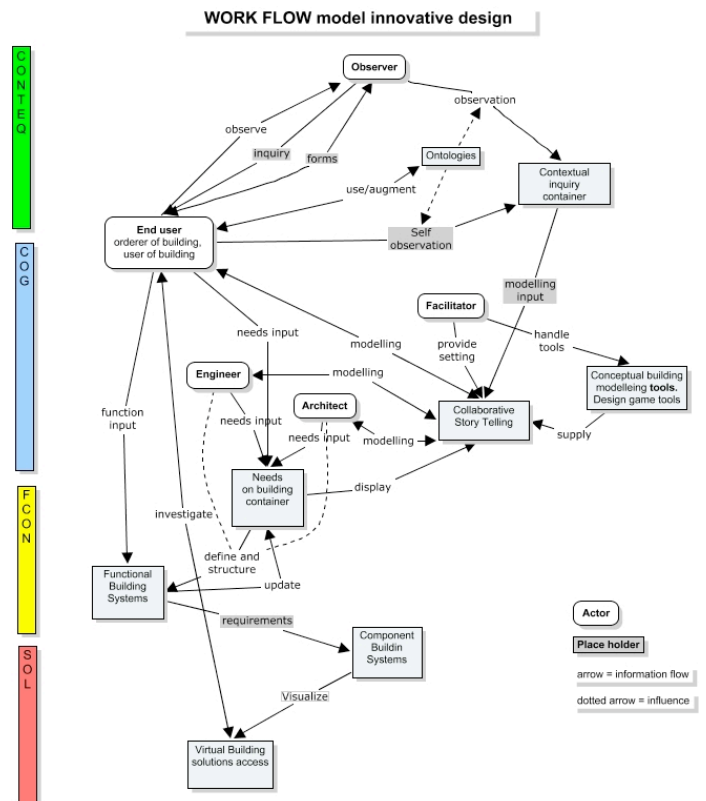


Figure 3. An early work flow model of the VICMET with references to the SOL Solution Space (SOL), FBS (Functional Building Systems) Consolidation Space (FCON), Conceptual Modeling and Game Space (COG), and Contextual Inquiry Space (CONTEQ).

### 5.3 Ontologies

What is an ontology? "Within knowledge engineering the term has been widely discussed in the 1990's (Guarino 1996). Guarino argues that Tom Gruber's definition is the best known (Gruber 1993): "An ontology is an explicit specification of a conceptualization." For use within IT in construction the similar but more detailed definition by DLI Glossary (1998) is also a good definition: "An ontology is an explicit formal specification of how to represent the objects, concepts, and other entities that are assumed to exist in some area of interest and the relationships that hold among them." (Sørensen et al. 2008a).

Figure 4 presents the upper general ontology used in the VICMET. The IntelliGrid Ontology Framework (Gehre et al. 2006) also describes a meta ontology and four independent but inter-related ontologies that can be further specialized in an



extensible set of domain-specific ontologies serving particular industry purposes.

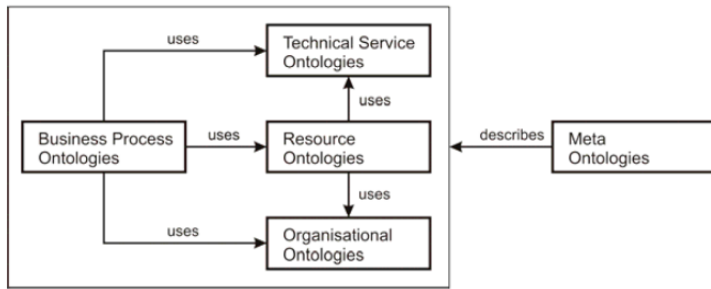


Figure 4. Overview of ontology domains and their relations. From (Sørensen et al., 2008a)

A meta level VICMET ontology was presented in (Christiansson et al. 2008).

Business process ontologies cover areas such as end-user needs, and Functional Building Systems (FBS). Organizational ontologies cover areas such as actor roles, company organizations and interrelations, design paradigms, and building project organization. The Resource Ontologies cover areas such as VICMET tools, Component Building Systems (CBS), and Virtual Building models. Technical service ontologies describes services enabling data communication through heterogeneous networks and also standardized use of hardware and software from different suppliers.

## 6 VIC METHODOLOGY

### 6.1 The VIC Method

VICMET can be used in connection with design of new buildings or refurbishment of old ones in different phases of a project and with different focus areas. VICMET has a formalized approach adapting to design context with selection of appropriate tools to support end-user participation in the creative and innovative design process.

VICMET has four spaces for user involvement: (Figure 5)

- 1) The Contextual Inquiry Space
- 2) The Conceptual Modeling and Game Space
- 3) The Functional Building Systems (FBS) Consolidation Space
- 4) The Solution Space.

In addition to these spaces there are supporting artifacts like Idea Bank and Good Story/Best Practice bank, Ontology containers and access to Communities of Practice and Interest.

VICMET is implemented in the so-called VIC-SPACE mainly residing on the WWW and accessed as an innovative/creative design tool aid under the working name VICCI.

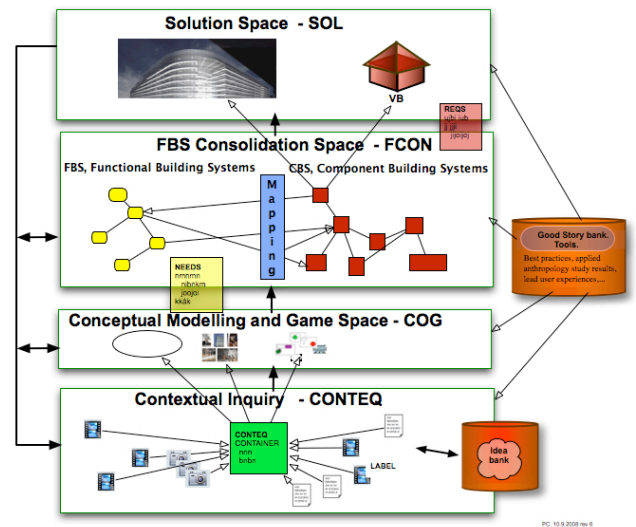


Figure 5. The main working spaces in the VICMET supporting creative and innovative building design.

The VICMET follows 8 steps according to the list below;

1. *Formulate Design/Innovation domain*
2. *Set up design theme*  
include end-users). Identify/allocate resources such as Idea bank, Best practice, Contextual Inquiry Bank
3. *Contextual Inquiry* (in CONTEQ)  
Where, how, who, when, methods support
4. *Conceptual Modeling and Gaming* (in COG)  
Modeling support (Contextual design methodology).  
Functional Building Systems specification.  
Creative/Innovative design.
5. *Consolidation and Value formulation* (in COG)  
Collaborative Story telling.  
Needs weighing and listing.
6. *Component Building System* (in FCON)  
CBS modeling.  
Functional Building Systems and Component Building Systems mapping.
7. *Solution* (in SOL)  
3D virtual building modeling of (alternative) solutions.
8. *Evaluation of solutions* (in SOL)
9. goto 3

The VICMET is through a scenario 'Innovative ICT supported Design in the year 2015' - described below.

### 6.2 VICMET scenario

'Innovative ICT supported Design in the year 2015'

#### 6.2.1 Formulate Design Domain

An architect has the first meeting with a new client. A meeting that concerns design of a new headquarters for the client's knowledge based company. During the meeting they have discussed possibilities in building a new innovative and flexible headquarter.

ters but also the difficulties in satisfying the employees during times with reduced employment. The architect used the first meeting to understand the new costumer and their organization as well as what initialized the idea of building a new headquarters. During the meeting the architect and client cooperatively sketch early concept maps (Novak & Cañas, 2008) of the ideas and the organization to define the design domain in the web-based design and collaboration tool VICCI. It helps to create a shared understanding of the task at hand between the architect and client and to later help them remember all the input from the inspiring discussion.

### 6.2.2 Set up design team

The architect returns to the office and access VICCI where she enters a few more details to the concept maps, and observes that the Idea Bank widget running in the corner of the VICCI interface presents inspiration from similar projects and some of the highest ranked office space solutions earlier designed for knowledge companies.

VICCI provides an overview of the available resources within the organization and collaborators in their network. A suggestion of the best team for the task, based on personality profiles, is also presented to the architect to ensure the right mix and availability of social as well as AEC professional competences within the estimated 6 months design. The architect now sends an invitation to the suggested two engineers, the virtual modeling expert and the architect to participate in the project and sign up in VICCI. Similar work is done at the client organization to establish a user group.

### 6.2.3 Contextual inquiry

The contextual inquiry is to high extent a highly iterative activity and the design team uses interviews, workshops, collaborative story telling, commented virtual building model walkthroughs, and observations of the knowledge workers in their actual working environment to get an understanding of the business problems that the new building must support. The architect has focus on the observations at the work place because his experience proves that it will ensure capture of the real business practice and daily activities and not just self-reported issues and company policies. See also (Christiansson et al. 2008). Self-observations are also documented during this phase, see figure 6.

### 6.2.4 Conceptual modeling and gaming

After a broad understanding of the users' contexts in the new building is it time to enter the conceptual modeling and game space so the users can express and discover their actual needs, behaviors and functional requirements on the new building (including what is prescribed in norms and regulations).

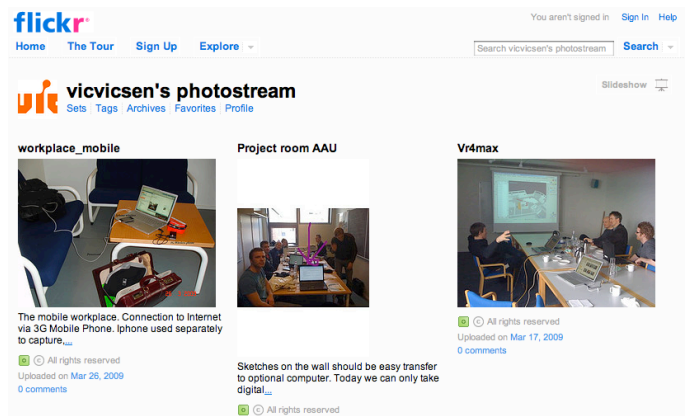


Figure 6. Example on used self-observation methodology. The self observations in this case are captured on an Apple iPhone where they are immediately meta-marked and then automatically uploaded and stored on flickr, <http://www.flickr.com/>, on the WWW.

During workshops the client and the architects collaborate in making conceptual models such as work flow models, cultural models and the physical environment models on multi-touch display on the table (Microsoft, 2009). The tool palette in VICCI supports this by a set of predefined game editing tools as well as free hand sketching. Their modeling work ends up with a functional building system diagram describing the functions to be supported by the new building, how they are related, and their properties and artifacts.

### 6.2.5 Consolidation and value formulation

The budget is tight and therefore prioritizing of the clients needs to the new building is required. A set of functional prioritization criteria is created in collaboration between the design team and the client. Based on the inquiry and the conceptual modeling each member in the design team creates lists of needs related to the functional building systems. The lists are then mapped to the prioritization criteria in a consolidation matrix to support the decision making process.

An important part of this collaborative work is also the formulation of the vision for the building project. This vision is important to bridge the gap between the design team involved in the early phases of the project and the designers responsible for the detailed design. See also Figure 7.

### 6.2.6 Component Building System

The functionality of the building from end-user perspective is more or less formalized in the Functional Building System (FBS) and linked to the building elements represented in the so called Component Building System (CBS), which in the Solution space can be implemented in an IFC model server or traditional CAD system. The virtual modeling expert creates a mapping scheme between the functional building system and the overall component building system based on a national building

classification system. This mapping is used in the design process whenever information about the user needs is needed.

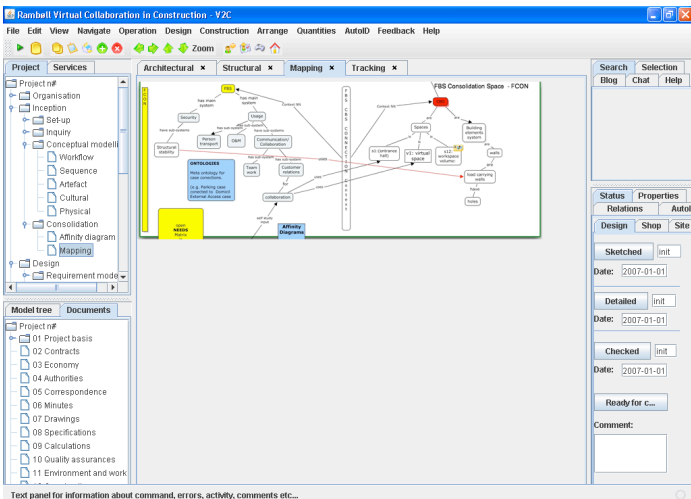


Figure 7. Prototype, where the mapping functionality from the Functional Building System to the Component Building System is illustrated in a virtual collaboration tool for construction. The prototype illustrates an implementation in a desktop application.

#### 6.2.7 Solution

The virtual building (VB) plays a central role when we simulate, test, evaluate and refine services during building design. A VB may be defined as “a formalized digital description of an existing or planned building which can be used to fully simulate and communicate the behavior of the real building in its expected con-texts” (Christiansson 1999).

The virtual modeling expert supports the architects and engineers in creating virtual building (VB) prototypes of design proposals. The VB prototypes are supplemented with requirement models and physical mock-ups of parts of the solution to provide the client with the best possible basis for decision. The VB prototypes are synchronized with VICCI and shared among the project participants. VICCI also stores the design history to an overview of design rationale. The engineers and virtual modeling expert are not co-located and they therefore collaborate in synchronous as well as asynchronous mode through VICCI.

#### 6.2.8 Evaluation of solutions

Solutions are evaluated against needs and requirements. The developed solution proposals are evaluated in VICCI and with the users in a number of ways. In VICCI the automatic design checker gives the first proposal a functional system bronze score, a LEED silver (Leadership in Energy and Environmental Design - Green Building Rating System) and a long list of soft as well as hard clashes. The virtual prototypes are further evaluated with the client during workshops in the engineers’ virtual reality environment. The interactive virtual model viewer in VICCI is used to evaluate the minor revisions

to get continuous feedback from the client. The design team and client are not satisfied with the functional system and LEED scores. Therefore refined solutions are needed.

The components are continuously annotated with the incoming comments through the whole evaluation process. The previously created mapping between the component building system and the functional building system enables the designers to overview incoming feedback and quickly provide new refined design proposals.

This iterative user involvement process continues from step 3 and runs until a satisfactory solution proposal is achieved. New ideas are captured during evaluation and stored in the Idea bank.

## 7 VICMET EVALUATION

VICMET is evaluated in praxis using the Ramboll and Arkitema headquarters under design and construction. In the Ramboll case the process in many cases take point of departure in the SOL space where possible solutions are analyzed. Arkitema strives to start at a conceptual level in the COG space not to restrain creative thinking.

Previous experiences show that knowledge acquired on needs, common values, overall views, was often lost due to participants entering (often too late) and leaving the process. This was valid for both formally expressed and tacit knowledge (i.e. beyond formally documented during process). Arkitema emphasize that they would have needed a more structured way to handle the consolidation and optimization of needs in the innovative design of their new office. VICMET will help solve these problems.

Different VICMET tools are evaluated for each step in VICMET. Example on VICMET tools is outlined in table 1.

VICMET step (see Chapter 5.1)	Tools used in VICMET (examples)
Step 1	Concept Map tool
Step 2	Belbin personality test
Step 3	Interviews, Questionnaire, Appreciative inquiry, Focus groups, Self Observation , workshops, Confluence distributed workshops, brainstorm, Scenario writing, Lead user involvement, Behavioral mapping, Communities of interest, Commented VB walkthroughs, Contextual Design
Step 4	Collaborative story telling, Contextual Design, Game Cards, Design games
Step 5	Consolidation matrix, prioritization criteria, Story boarding,
Step 6	Concept mapping, Building Classifications,
Step 7	3D authoring (Tekla etc.), Crysis game engine, conversion to 3D Studio Max, ,
Step 8	VR4Max, workshops in Virtual Reality lab, Solibri Model checker, Annotations of model by users



## 8 DISCUSSION

The project has so far validated the need for enhanced methods to involve end-users of buildings in a collaborative/participative creative and innovative building design process. The AEC professionals also appreciate development, enhancement and to some extent formalization of existing methods for user involvement in the building process.

We envision and contribute in the project to a change of the design process. The driving forces for these changes are also reflected in the society in general with new views and values on competences collaboration, knowledge handling, cross company innovation processes, company long term strategic planning, and innovation diffusion.

The Virtual Innovation in Construction Methodology (VICMET) is still under development. Different parts of the method are evaluated in real ongoing building projects. The final version of VICMET can be implemented and optimized for different usage contexts and availability of ICT tools.

## 9 ACKNOWLEDGEMENTS

Results reported derive from the on-going project User Involvement in Construction - Virtual Innovation in Construction, VIC, financed by the Danish Enterprise and Construction Authority (EBST) the Programme for User Driven Innovation. The project is to 50% financed by the participating two main architecture and engineering companies in Denmark, Arkitema A/S and Ramboll A/S, and 30% by Aalborg University, Civil Engineering department.

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