

# Requirements Management Interface to Building Product Models

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## Summary

In current AEC practice client requirements are typically recorded in a building program, which, depending on the building type, covers various aspects from the overall goals, activities and spatial needs to very detailed material and condition requirements. This documentation is used as the starting point of the design process, but as the design progresses, it is usually left aside and changes are made incrementally based on the previous design solution. These incremental small changes can lead to a solution that may no longer meet the original requirements. In addition, design is by nature an iterative process and the proposed solutions often also cause evolution in the client requirements. However, the requirements documentation is usually not updated accordingly. Finding the latest updates and evolution of the requirements from the documentation is very difficult, if not impossible. This process can lead to an end result, which is significantly different from the documented requirements. Some important requirements may not be satisfied, and even if the design process was based on agreed-upon changes in the scope and requirements, differences in the requirements documents and in the completed building can lead to well-justified doubts about the quality of the design and construction process.

This paper documents our observations of the requirements management problem and suggests that even a simple active link between the client requirements and design tools can increase the usage of requirements documentation throughout the design and construction process and facilitate necessary updates of the client requirements. The key limitation is the lack of a theory to link the requirements to the design representations used by design tools. We propose to formalize a requirements model linked to product model based design tools to improve the quality of the design process and documentation. The research is a part of CIFE's Virtual Design and Construction (VDC) framework; objects in the requirements model represent Desired Product Forms in the Product-Organization-Process (POP) ontology.

## 1 Requirements Management Problem

### 1.1 Requirements Documentation

A building program specifying a project's goals and requirements for all the spaces is the typical client requirements documentation in building projects, though there are also several other methods to capture client requirements (Kamara et al 2003, Syed et al 2003, Pennanen 2004). Regardless of the capturing method, the requirements, depending on the project type, consist of more or less detailed information about the required properties; net area, activities, connections to other spaces, security, appropriate or desired materials, conditions like daylight, lighting, temperature, noise level, etc. Many requirements also "cascade"; e.g., create additional requirements to bounding elements and systems serving the spaces. Moreover, an important part of the design process is that some requirements can be in conflict; the project team must prioritize and make trade-offs between different requirements, which creates the need to update the requirements, and thus, manage and document the changes to the requirements and the design solution.

In practice several factors make it virtually impossible that all the participants know and remember all the relevant requirements and especially their relationships to each other and to the design solutions:

- The amount and complexity of project information,
- The duration of projects,
- The need for designers to work simultaneously on many projects,
- Changing stakeholders in different project phases, and
- Shifting design focus, e.g., moving from overall problem solving to detailed technical solutions.

## 1.2 AEC Process

The Stanford project guidelines "Heartbeat" (Figure 1) represent a typical description of the design and construction process. Though it is basically correct, it creates an illusion of a sequential process, where the requirements are set in the programming phase and design is just solving the documented needs.

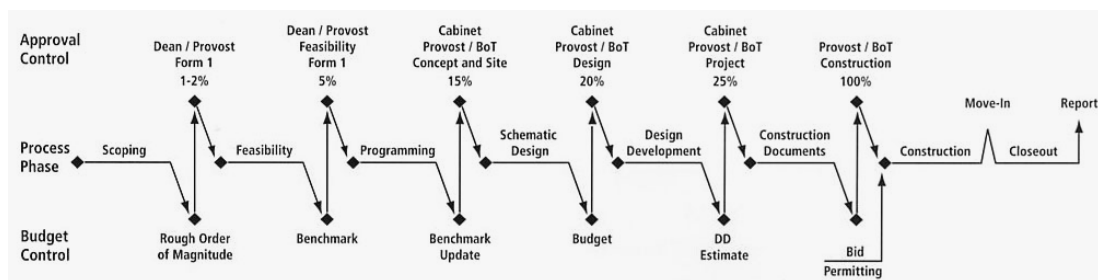


Figure 1: "Heartbeat", the Project Delivery Process at Stanford (Stanford University 2001)

However, this is not the case; design is by nature an iterative process, and the provided design solutions affect also the client expectations, causing evolution of the requirements. Though the intensity of requirements definition and design activities, and the character of the changes, are different in different stages of the process, we argue that the process should be described as parallel activities, including requirements management through the whole process and several stages where local authorities check that the design and construction meet the regulations (Figure 2).

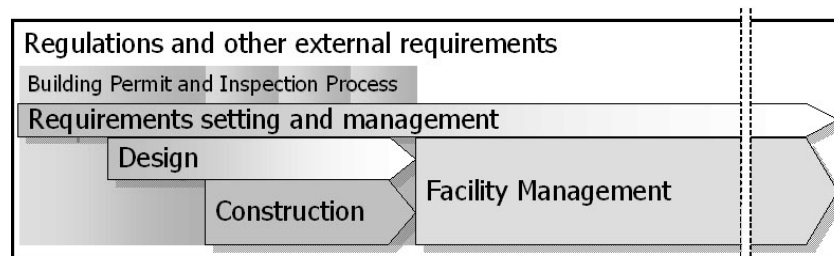


Figure 2: Concurrent design and requirements management processes

The iterative nature of the design process and the usually large number of changes during the process increase the complexity of the problem. Project teams have to make rapid decisions on how to solve a specific issue, and it is often difficult to notice all interdependencies. Thus, a solution, which is meeting one requirement, can have a significant negative effect on another crucial requirement. One trivial example of this is accessibility vs. access control; optimizing the accessibility to the various spaces in a building is in contradiction with access control, which demands as few access points and alternative routes as possible. Our observation is that the current process could improve significantly if:

- The project team could manage and update the evolving requirements, and
- The designers could easily find the detailed requirements related to their current tasks.

Our research focuses on connecting the requirements better to the design process and help designers understand the interactions between the requirements and design solutions (Figure 3).

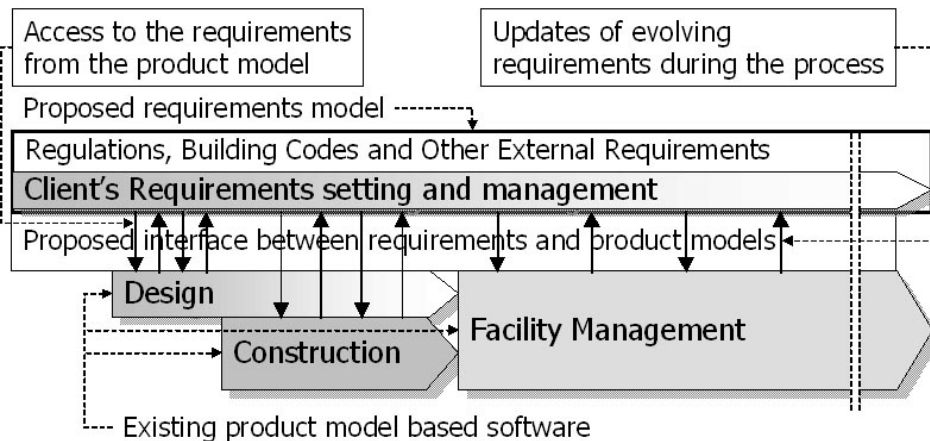


Figure 3: Proposed solution supporting interactions between requirements and solutions

### 1.3 Shifting Focus

After conceptual design the requirements documentation is usually not used actively in today's design process, and often the evolving requirements are not even communicated to the whole project team (Kagioglou et al 1998). Thus, the changes are compared to, and decisions made based on, the previous design solution. The current design tools do not support recording of client requirements or designers' intent in the documents. Thus, the people deciding on the changes do not always even know the original intent, and the solution can "shift away" from the original goal (Figure 4) without actual decisions to change the goal or understanding the contradiction between the proposed design and project goals.

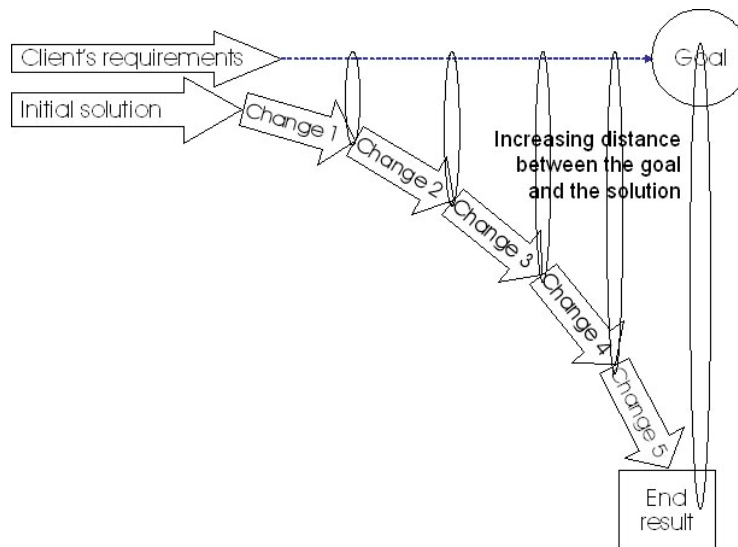


Figure 4: Shifting away from the goal

Our observation, supported by interviews with many industry experts (see 1), is that to some extent this happens on most projects. This does not mean that most buildings are badly designed, or that they do not meet their overall purpose. However, we argue that they often miss some properties, which the end-users might have preferred, and that the changes of requirements are not well documented. This happens because the design tools do not support such documentation, and the design process includes many trade-offs between different requirements. Therefore, we suggest that the approved updates in the requirements should be recorded so that they can be checked and compared easily with the design solution and completed building.

## 1.4 POP, FFB and VDC Framework

The Center for Integrated Facility Engineering (CIFE) at Stanford University has introduced the concepts of Product-Organization-Process (POP) and Form–Function–Behavior (FFB) modeling for Virtual Design and Construction (VDC). This framework enables integration of different models, which are often seen as separate entities. Each of the POP elements consists of all three FFB elements, which are divided to three sub-elements; Desired, Predicted and Observed (Figure 5). This structure provides a conceptual framework for a project ontology connecting the different views to the information. Our proposed requirements model represents Desired Product Form connected to the Predicted Product Form (design model) in the POP ontology.

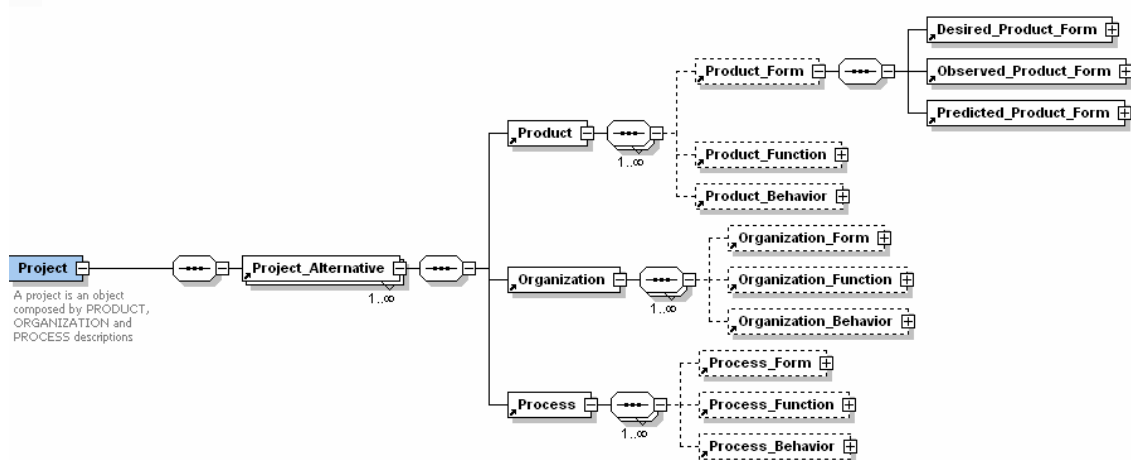


Figure 5: POP Ontology [Garcia et al, 2003]

## 2 Case Studies

To test the existing problems and possible solutions we studied the building programs of two projects; the ICL Headquarters project in Helsinki built in 1994-1996 and the on-going Lucas Center Expansion at Stanford University. We selected these two projects to test the generality of the problem and potential solution, because their characteristics are very different. The ICL Headquarters is a large office building consisting mainly of standard office rooms, but including also some special rooms and requirements. The Lucas Center Expansion is a small special laboratory consisting mainly of unique rooms with very little repetition. In the test cases the research concentrated on room related client requirements only, external requirements were not in the scope at this stage.

### 2.1 ICL Headquarters, Helsinki

The case, which suggested the idea for the potential solution, is the ICL Headquarters project designed and built in Helsinki, Finland from April 1994 – June 1996. The project is a large office building for ~1,000 employees, including space for an extensive computer service and delivery center. The net area in the building program is ~20,000 m<sup>2</sup>, consisting of ~800 rooms. The project's room program was done entirely in MS Excel based on a simple room type classification. In the design phase, MS Excel data was linked to AutoCAD, where rooms were represented using simple objects consisting of polylines and extended data linking the rooms in the drawings and the area requirements in the MS Excel spreadsheet. During the entire design process, design and target values were observed almost in real time, at least once a week, by exporting the actual areas into MS Excel (Figure 6) and comparing them to the target values. However, client requirements other than area were not linked and observed using this method.

| A  | B                              | C    | D          | E          | F   | G  | H     | I     | J | K | L   |
|----|--------------------------------|------|------------|------------|-----|----|-------|-------|---|---|---|
| 1  | Toiminta                       |      |            |            |     |    |       |       |   |   | HUOM  |
| 2  | Name                           |      |            |            |     |    |       |       |   |   | Comments  |
| 3  |                                |      |            |            |     |    |       |       |   |   | or special  |
| 4  | ICL KOKONAISTILAOHJE           | Type | Total area | Total area |     |    |       |       |   |   | requirements                                      |
| 5  | ESIKUNTA- JA PALVELUYKSIKÖT    |      |            |            |     |    |       |       |   |   | Sijainti vesiseinien, voi sijaita eri kerroksissa |
| 6  | työnommainen työhuone          | O1   | 14         | 10         | 140 | 17 | 182.5 | +42.5 |   |   | huoneessa 1-2 henkeä                              |
| 7  | työnommainen työhuone          | O2   | 6          | 20         | 120 | 8  | 167.5 | +47.5 |   |   |   |
| 8  | maiseimatoinnisto              | O3   | 20         | 12         | 240 | 22 | 246.0 | +6.0  |   |   |   |
| 9  | huonekoko / korjausmaa         |      |            |            |     |    |       |       |   |   |   |
| 10 | Yht.                           |      | 40         |            | 500 | 47 | 596.0 | +96.0 |   |   | xx) vert yhteiskäyttötilat                        |
| 11 |                                |      |            |            |     |    |       |       |   |   | ksi 17 muuta työntek.                             |
| 12 | Työn aputilat                  |      |            |            |     |    |       |       |   |   |   |
| 13 | toimistovarasto, kirjasto, tms | A1   | 2          | 20         | 40  |    | 38.5  | -1.5  |   |   | sis kassakaapit 9 kpl                             |
| 14 | komponentti-varasto, tms       | A2   |            |            |     |    |       |       |   |   |   |
| 15 | lahiarkisto                    |      |            |            |     |    |       |       |   |   | 20 jm   |
| 16 | lahiarkisto                    |      |            |            |     |    |       |       |   |   | 60 jm   |
| 17 | lahiarkisto                    | A3   | 2          | 35         | 70  | 1  | 11.5  | -58.5 |   |   | palkka-asiat, n. 420 jm                           |
| 18 | lahiarkisto                    | A3   | 1          | 10         | 10  | 1  | 8.5   | -1.5  |   |   | sairasasiat, n. 60 jm                             |
| 19 | kopiointi, printeri, fax, yms  | A4   | 2          | 12         |     |    |       |       |   |   |   |
| 20 | Yht.                           |      |            |            |     |    |       |       |   |   |   |
| 21 |                                |      |            |            |     |    |       |       |   |   |   |
| 22 |                                |      |            |            |     |    |       |       |   |   |   |
| 23 |                                |      |            |            |     |    |       |       |   |   |   |
| 24 | Tekniset aputilat              |      |            |            |     |    |       |       |   |   |   |
| 25 | konesali                       | T1   |            |            |     |    |       |       |   |   |   |
| 26 | testi- ja laitehuone / jäähd.  | T2   |            |            |     |    |       |       |   |   |   |
| 27 | testi- ja laitehuone           | T3   |            |            |     |    |       |       |   |   |   |
| 28 | projektihuone                  | T4   |            |            |     |    |       |       |   |   |   |
| 29 | Yht.                           |      |            |            |     |    |       |       |   |   |   |
| 30 |                                |      |            |            |     |    |       |       |   |   |   |
| 31 | Kokous, opetus, näyttely       |      |            |            |     |    |       |       |   |   |   |
| 32 | kokoustila                     |      |            |            |     |    |       |       |   |   |   |
| 33 | ny                             |      |            |            |     |    |       |       |   |   |   |
| 34 | iso                            |      |            |            |     |    |       |       |   |   |   |
| 35 | ATK-luokkia                    |      |            |            |     |    |       |       |   |   |   |
| 36 | demotilat, näyttely            |      |            |            |     |    |       |       |   |   |   |
| 37 | Yht.                           |      |            |            |     |    |       |       |   |   |   |

| Floors                            | Room area | Traffic area | Permit area | Gross area |
|-----------------------------------|-----------|--------------|-------------|------------|
| 2 ICL LAUOUSTARINASTELU 22.5.1985 |           |              |             |            |
| 3                                 |           |              |             |            |
| 4                                 |           |              |             |            |
| 5                                 |           |              |             |            |
| 6 ALAKELLARI                      | 349.5     | 402.0        | 50.0        | 60.5       |
| 7 KELLARIKERROS                   | 3 710.0   | 4 110.0      | 679.0       | 3 010.0    |
| 8 1.KERROS                        | 4 210.5   | 4 455.0      | 433.0       | 71.0       |
| 9 2.KERROS                        | 2 864.5   | 2 539.5      | 512.0       | -8.5       |
| 10 3.KERROS                       | 2 142.5   | 2 509.5      | 482.5       | 88.5       |
| 11 4.KERROS                       | 1 932.0   | 2 509.5      | 620.5       | 88.5       |
| 12 5.KERROS                       | 1 618.0   | 2 509.5      | 411.5       | 343.5      |
| 13 6.KERROS                       | 0.0       | 0.0          | 38.5        | 923.0      |
| 14 7.KERROS                       | 0.0       | 0.0          | 0.0         | 1 038.5    |
| 15 KATTOKERROS                    |           |              |             |            |
| 16 YHTEENSÄ                       | 20 181.0  | 24 175.0     | 4 177.5     | 2 232.5    |
| 17                                |           |              |             |            |
| 18 Poikkeama tavoitteesta         | +963.0    |              |             |            |
| 19 Muutos edelliseen (2.2.)       | -333.5    |              |             |            |
| 20                                |           |              |             |            |
| 21                                |           |              |             |            |
| 22                                |           |              |             |            |
| 23                                |           |              |             |            |
| 24                                |           |              |             |            |
| 25                                |           |              |             |            |
| 26                                |           |              |             |            |
| 27                                |           |              |             |            |
| 28                                |           |              |             |            |
| 29                                |           |              |             |            |
| 30                                |           |              |             |            |
| 31                                |           |              |             |            |
| 32                                |           |              |             |            |
| 33                                |           |              |             |            |
| 34                                |           |              |             |            |
| 35                                |           |              |             |            |
| 36                                |           |              |             |            |
| 37                                |           |              |             |            |

Figure 6: ICL room program and summary page

The ICL Headquarters' room program was one document. The required areas were constantly compared to actual design solutions, and the requirements file was constantly updated during the design process. The requirements documentation with respect to required room areas and identification was coherent and there were no typical problems of mismatched requirements and design solutions.

## 2.2 Lucas Center Expansion, Stanford University

The structure and size of the building program of the Lucas Center Expansion project is very different compared to the ICL Headquarters. The Lucas Center Expansion (LCE) is a small special laboratory for Cyclotron and 7T magnetron laboratories for Stanford University. The net area is 480 m<sup>2</sup> including 23 rooms in the first room program (February 2002), and 1,300 m<sup>2</sup> including 43 rooms in the latest documents (October 2002). Available project documentation consists of a set of design sketches, drawings and MS Excel spreadsheets of different project stages, the architect's requirements database (Claris Filemaker), meeting minutes, and technical specifications. During the research period (November 2003), the project was in the early construction stage. The final design documentation was also available, but because it contained only design solutions, it was not relevant for this research.

LCE's Project Manager and MBT Architecture's Project Architect provided some insight on the project. The basic conclusion based on these interviews is that Stanford's projects are generally well-managed and have clearly defined processes for different stages (Figure 1). However, as is typical in the AEC industry, the requirements capturing process is somewhat fuzzy, based strongly on meetings, where end-users and the project team are interacting trying to find solutions to specific problems. The decisions are recorded in the meeting minutes, and the room areas of each design stage are documented in MS Excel spreadsheets. The reasoning behind the changes and proposed solution becomes tacit knowledge and is "stored" only in the minds of the participants.

### 2.2.1 Detailed Findings and Problems for the LCE project

The Lucas Center Expansion is a small project, and the available documentation was not comprehensive, but still there were several errors and incomplete information in the requirements documentation. The main problems were related to the use of two different sources of information, the Project Manager’s MS Excel spreadsheets and the Project Architect’s requirements database (Claris Filemaker), and their different and partly inconsistent content. In addition, the MS Excel sheets for different stages were in separate files and the development history or reasons were not recorded even for large changes. For example, the changes of the net area in different stages were very large (242-1076%, Table 1). In fact, only the first version (February 2002) presents the actual client requirements; later versions summarize rather the design status in different stages.

|                         | <i>Feb 02</i> | <i>Apr 02</i> | $\delta$    | <i>Sep 02</i> | $\delta$    | <i>Oct 02</i> | $\delta$    | <i>Nov 02</i> | $\delta$    | Total $\delta$ |
|-------------------------|---------------|---------------|-------------|---------------|-------------|---------------|-------------|---------------|-------------|----------------|
| 7T MR                   | 2 380         | 1 680         | 71%         | 1 736         | 103%        | 1 802         | 104%        | 2 011         | 112%        | 84%            |
| Cyclotron               | 1 050         | 1 034         | 98%         | 997           | 96%         | 1 005         | 101%        | 2 536         | 252%        | 242%           |
| Hot Lab                 | 1 020         | 690           | 68%         | 1 288         | 187%        | 1 120         | 87%         |               | 0%          | 0%             |
| Wet Labs                |               | 3 550         | 1076%       | 3 252         | 92%         | 4 326         | 133%        | 4 505         | 104%        | 442%           |
| <b>Lab subtotal</b>     | <b>4 450</b>  | <b>6 954</b>  | <b>156%</b> | <b>7 273</b>  | <b>105%</b> | <b>8 253</b>  | <b>113%</b> | <b>9 052</b>  | <b>110%</b> | <b>203%</b>    |
| Admin & Support         | 750           | 750           | 100%        | 750           | 100%        | 2 856         | 381%        | 4 926         | 172%        | 657%           |
| <b>Total</b>            | <b>5 200</b>  | <b>7 704</b>  | <b>148%</b> | <b>8 023</b>  | <b>104%</b> | <b>11 109</b> | <b>138%</b> | <b>13 978</b> | <b>126%</b> | <b>269%</b>    |
| Technical spaces        |               | 771           |             | 1 150         | 149%        | 1 162         | 101%        | 1 196         | 103%        | 155%           |
| Unassigned spaces       |               | 5 195         |             | 5 234         | 101%        | 5 895         | 113%        | 5 895         | 100%        | 113%           |
| <b>Gross area</b>       | <b>10 400</b> | <b>13 670</b> | <b>131%</b> | <b>14 407</b> | <b>105%</b> | <b>18 166</b> | <b>126%</b> | <b>21 069</b> | <b>116%</b> | <b>203%</b>    |
| <i>Efficiency, real</i> | 50%           | 56%           |             | 56%           |             | 61%           |             | 66%           |             |                |
|                         | 100%          | 131%          |             | 139%          |             | 175%          |             | 203%          |             |                |

Table 1: Changes of the building program summary of Lucas Center Expansion

More complex technical specifications, like MEP (mechanical, electrical, piping) descriptions, have no relation to the PM’s or PA’s requirements documentation. The “MEP Utility Planning and System Description” document specifies clearly the requirements for the two main spaces, 7T MR and Cyclotron, but the required properties for the other rooms are not easy to interpret. However, because the actual MEP systems are out of the scope for this research this was not studied in detail. It indicates though, that this problem is also related to other design areas.

The main problem categories in the requirements documentation for the LCE project were:

- Lacking or different identifications of the rooms,
- Contradictions in the content of different documents,
- Incoherent way to describe the same requirements,
- Wrong or missing information, and
- Instead of requirements the documents recorded the areas of the design solution.

Furthermore, more complex technical specifications, like MEP (mechanical, electrical, piping) descriptions, have no relation to the PM’s or PA’s room related requirements documentation. The “MEP Utility Planning and System Description” document specifies clearly the requirements for the two main spaces, 7T MR and Cyclotron, but the required properties for the other rooms are not easy to interpret. However, because the actual MEP systems are out of the scope for this research this was not studied in detail. It indicates though, that this problem is also related to other design areas.

### 2.3 Conclusions from the Case Studies

Though many of the mistakes in the LCE project were small, and probably caused little, if any, real problems to the people, who have been involved in the project all the time, they are a clear indication of the general requirements management problem in the current process. To anyone, who joins the project later, it is very difficult and time consuming, sometimes impossible, to find out which requirements are correct and still relevant. Furthermore, someone who wonders about the growth in the size of the project will have great difficulty finding an answer in the project documents.

Though only the required area information of the ICL Headquarters project was linked with the design solution, it provided some benefits. ICL's Project Manager states: "Still today, over 9 years later, ICL Headquarters is the only project, where I got practically real time information comparing actual areas to the building program on a detailed level, and was able to follow constantly that the project design stayed within the allocated limits." In addition, despite the simple approach taken in the ICL project to only link the requirements and the design information for comparing required and real areas, the coherent requirements information suggests that a link between requirements and design tools and the constant use of requirements information in the process could improve requirements management.

## **2.4 Identified Main Problems**

The main conclusions from the two pilot projects are that the client requirements are not well documented and managed during the design process, and an active link between the client requirements and design tools could improve the process. The identified main problems are:

### **2.4.1 No connection between requirements and design documents**

The current design tools do not support documentation of the reasons behind the design solutions. As described earlier, the requirements documentation is used usually only in the early design stages. Later in the process the changes are made based on the previous solution. This leads to the two main problems described above: The design can shift away from the original goal, and the evolving requirements are not updated in the requirements documents.

### **2.4.2 The impact of project personnel changes and project duration**

In the current process the requirements changes are not updated coherently and in an easily accessible format. In the best case, they are stored in the meeting minutes, but often only in the minds of the project team as tacit and implicit knowledge. Even if the changes are documented in the minutes, they are scattered and difficult to find, especially for people, who do not know exactly what and where to look for. This situation leads to significant loss of requirements knowledge if some key persons leave the design team. Long project durations not only increase these personnel changes, but also human difficulties to remember details.

### **2.4.3 Impact of "middle-men" in the process**

The actual end-users are not always closely involved in the design and construction process. Thus, they may lack means to follow and control what happens to their demands in the process. This emphasizes the need to have requirements actively linked to the process, because it would help the designer to find the relevant requirements more easily themselves. In addition, because of described inadequate documentation of the requirements changes, it is difficult to find the approved requirements changes and the end-users may compare the building to the original, outdated requirements.

### **2.4.4 Indirect requirements**

Most client requirements are related to spaces and in current practice recorded in the building program. However, these requirements often aggregate requirements to the bounding elements and technical systems. Bounding elements, e.g., walls, windows, doors and slabs, can have requirements, like, for example, sound or thermal insulation, security, load bearing requirements, etc., inherited from the space requirements. Likewise, technical systems, like mechanical, electrical and plumbing (MEP) systems or information and communication networks, can inherit requirements from the space requirements. These indirect requirements can be difficult to notice or remember, because the detailed design related to them happens late in the process, and is often done by people who were not involved in the early stages when these requirements were defined, and the design documentation does not include the requirements information.

Our observation is that the effect of these factors could decrease if the requirements would be easily available and actively linked to the design solutions. Another important part of a good solution is the appropriate level of detail; i.e., to find exactly the relevant information for the on-going design task from the project data. This need also creates the demand to link the direct and indirect requirements, so that for example the wall requirements caused by the related space requirements can be easily found.

The existing, structured requirements documentation in the beginning of the process provides a potentially usable starting point. The key limitation is the lack of a theory to link the requirements to the product model based design systems. The key elements missing are:

- Lack of a formal specification of the link between requirements and product model, and
- Lack of formal specification to aggregate requirements for bounding elements and technical systems (indirect requirements) from client requirements (direct requirements).

### **3 Point of Departure**

There is no single theory, which would provide the basis to link requirements to the product model. Our proposal is based on five main points of departure:

- Design as an information process,
- Existing client requirements documentation,
- Lawrence Berkeley National Laboratory's (LBNL) Design Intent tools
- Existing IFC product model structure and implementation, and
- Building Lifecycle Interoperable Software (BLIS) views and product model servers.

A detailed description of the point of departure is not possible in this context, but it is documented in a CIFE Working Paper (Kiviniemi and Fischer 2004). The following paragraph is a very brief description of the principle and main information sources.

Design as an information process justifies why the client requirements and their management should be linked to the design process (Froese 2002, Kamara et al 2003, Eastham 2002, Confederation of Finnish Construction Industries 2002). Existing client requirements provide the basic content for the requirements model, i.e., what should be linked (Kamara et al 2003, Syed et al 2003). LBNL's Design Intent and BLISS tools are a reference for requirements management in the MEP area (Hitchcock 1995 and 2003, LBNL 1997-2004). The existing IFC product model structure describes what is available and what is missing in the product model based design software; to which requirements can be linked (IAI 1996-2004, SPADEX 2002, Kam and Fischer 2002). The existing implementations, BLIS views and product model servers provide the technical platform for establishing the link (BLIS 1999-2004, Hietanen 2002, IAI ISG 1999-2004, Adachi 2002, Hemiö 2002, SABLE 2003, IMSvr 2002, Eurostep 2002, EPM Technology 2003). The existing elements are client requirements documents and product model based design software, the main limitation is the lack of a method to link these and handle the relation between direct and indirect requirements.

Thus, the points of departure for a technical solution to address the identified issues are:

- The room related client requirements are defined and documented in the beginning of the process,
- The existing IFC product model contains the necessary elements to link room related client requirements to the building product model,
- The existing IFC product model provides a connection between the rooms and bounding elements, and
- The existing IFC implementations provide a platform, which can be used as a technical basis for the pilot implementation to test my proposed solution.



To explore the possible solutions for requirements management, we used rapid prototyping and implemented some different database structures to find a usable solution to document the client requirements in a structure, which:

- Provides solutions to the problems identified in the LCE project,
- Supports inheritance of the room type requirements (abstract requirement entities, ARqE) to rooms (instantiable requirement entities, IRqE, Figure 8), and
- Enables in the next phase of our research a link between the requirements database and the product model (Figure 8).

The database structure and detailed findings of the pilot implementations will be presented in GCADS'04 conference paper (Kiviniemi and Fischer 2004), and naturally also in the final dissertation document.

#### 4 Proposed Concept

To address the identified limitations, we propose a concept that divides a project's information model into four separate models (Figure 7):

1. Requirements Model
2. Design Model(s)
3. Production Model(s)
4. Maintenance Model

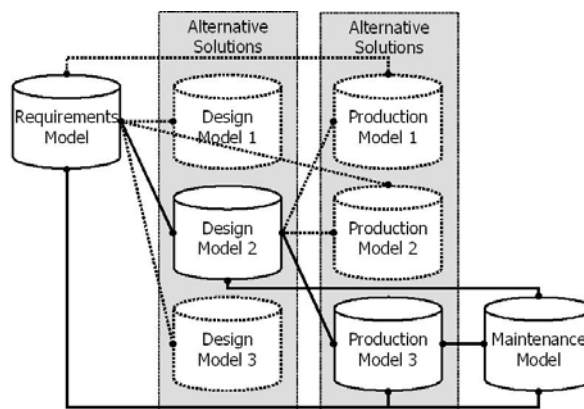


Figure 7: Proposed Model Hierarchy and Connections

There are several reasons for this proposed separation:

- Typically the design team produces several alternative design proposals, which all are expected to meet the defined requirements. Thus, having one requirements model linked to the alternative design models is a logical structure instead of multiplying the requirements to different design alternatives, which would easily lead to requirements management problems. Similarly there can be several alternative production models and finally a separate maintenance model. All these four models should be connected, so that it is possible to access the content of the different models and compare the alternatives at any stage of the process. Our research focuses on the requirements model and its connection to the design model(s).
- One “requirements instance”, IRqE, can relate to a number of separate instances with identical requirements in the product model (Figure 8).
- The existing product model standard, Industry Foundation Classes (IFC) has been developed to describe mainly design solutions, and its current structure does not support requirements management well. The internal structure of existing design software suffers from the same limitation.
- The flexibility of the requirements structure is greater if the two models are separated and connected with a “thin” link. For example, in the case of room related requirements the only property needed for the link is the ID in the space objects, which is supported by almost any design software. For indirect requirements the functional demand is to recognize the

connection between bounding elements and spaces, which is supported by some commercially available product model based software.

- Another reason for the separation is to make the distinction between requirements and properties clear. For example, sound insulation is a requirement between spaces in the requirements database and a property of the bounding elements in the product model.

An important issue is also that the “requirements instances” in the requirements database have no physical locations, i.e., the requirements for bounding elements can relate to one space only. In the product model the bounding elements are always either between two spaces or as a part of the building envelope. This means that the requirements for the bounding elements must be aggregated from the requirements of the related spaces; they cannot be defined directly for the elements in the same manner as the space requirements relate to the spaces.

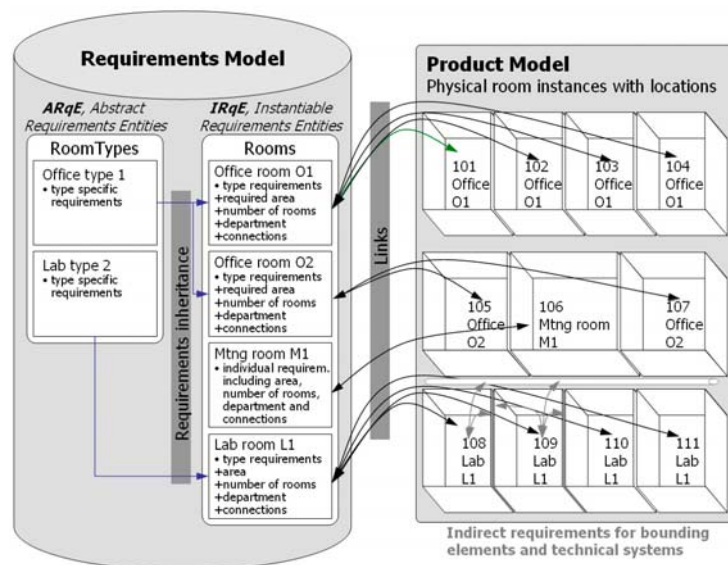


Figure 8: Proposed concept to link detailed spatial requirements to a product model: Relations between requirements types, requirements instances, physical room instances and indirect requirements

## 5 Future Work

In the next phase the main focus of our research will be to further specify this conceptual requirements model and its connection to the design process and to design representations. We will test several building programs to determine commonalities between requirements to establish a requirements management framework for some building types, though we believe that on a detailed level the requirement attributes cannot be fully standardized. The framework, i.e., the requirements model definition, must be project independent, but the project requirements database based on the model can have project specific requirement attributes.

The goal of our research is to develop and test a method to create an active link between requirements and product model based design tools. The anticipated future contributions are:

- Specification of a conceptual requirements model based on our analysis of five building programs of different building types and owners,
- Specification for a link between client requirements and product model objects,
- Specification for the aggregation of indirect requirements from the direct requirements, and
- Extended view “Room Program -> Architectural Design” for the IFC product model implementation.

We expect that our research is also creating a basis for many interesting future research topics, like, for example:

- Different building types and process phases: The scope of our research covers a few building types only. Our intuition is that the same conceptual model could be applied to most buildings, but because of the different requirements the database and UI implementation might be different. In addition, our research covers only design, a short period of the process, the use of the requirements model in other parts of the process, like, construction, FM, etc., is not covered in detail, though same principles are possibly applicable.
- Technical systems and other design areas: The designers' role in defining detailed technical requirements for technical systems is more dominant than in the architectural design, and LBNL's research in this area provides another view on building requirements management. However, there is no link between the technical requirements for systems and the building product model. Our research identifies some connections to technical systems, but the formal link between these two requirements views will need further research, as do requirements link and management in other design areas, like structural engineering.
- Requirements history: One interesting related research area is the requirements history; how the requirements evolve during the process. Our research proposes a conceptual model for requirements, which will provide a conceptual basis to store all the requirements changes during the process in the database. How to implement such a historic perspective of requirements management in detail and which functionalities the UI would need, could be interesting areas for further development.
- Verification: Some requirements are "fuzzy", verbal or otherwise only human interpretable descriptions, but some have an exact content. The possibility to use the exact requirements for automated verification, i.e., how well the design meets the requirements, is a potential usage of the requirements model. Verification of the "fuzzy" requirements must include designers' interaction, but the designer's or project manager's confirmation that the requirements are met, could be part of the database and serve as a formal project history. Solibri Model Checker (Solibri 2004) is one example of commercial tools for such verification, which could readily utilize the requirements model if it were available.

## 6 Endnotes

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