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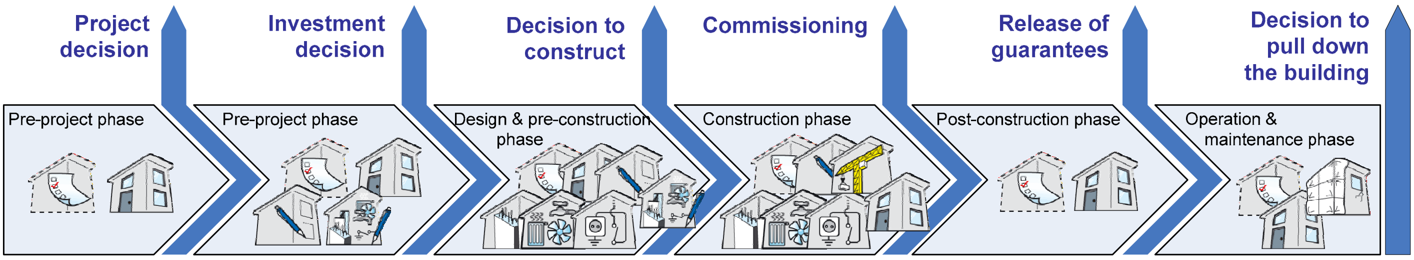

Requirements Management and Critical Decision Points

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Requirements Management and Critical Decision Points

Abstract

In this working paper, a study carried out as part of the second phase of the Virtual Building Environments research and development project is reported. The working paper covers work done to determine the interface between requirements management and critical decision points. The report first defines the processes and critical decision points within building architecture, engineering, construction and operation (AECO) project lifecycle for which users require information exchange. Then, detailed information needs in each critical decision point are specified. Finally, the actors sending and receiving information within the project lifecycle are identified and the associated, required information content of BIMs is determined.

Within this working paper, the life cycle of the building is divided into five phases: pre-project, design & pre-construction, construction, post-construction and operation & maintenance. The actors in the process are the owner, end-users, marketing & sales, project management, designers, constructors, facilities management and authorities. Only "hard gates", critical decisions that involve a permission from the financial authority (the owner) to proceed, are studied in detail. "Soft gates", decisions and selections made by the individual designers or the design team during the process, are not documented. The critical decision points in the process are 1) project decision and investment decision during pre-project phase, 2) decision to construct after design & pre-construction phase, 3) commissioning after construction phase, 4) release of guarantees after post-construction phase, and 5) the decision to demolish the building in the end of the building's life cycle.

Many of the information needs during the process relate back to the project requirements. Requirements set the basis for the design and, throughout the process, the results of the project must be compared with the requirements in order to define the level of requirement fulfilment. This emphasises the importance of capturing and documenting initial requirements and updating the evolving requirements during the process. Current technologies also enable use of more complicated and automated analyses as a basis of more informed decision-making.

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Preface

In 2002 VTT, CIFE/Stanford University and Lawrence Berkeley National Laboratory (LBNL) agreed about the concept of so called Virtual Building Environments (VBE). The basic idea is to provide a collaboration platform for the research, development, implementation and deployment of building product model technologies. The first VBE effort in Finland was done as a collaboration project between VTT and Tampere University of Technology (TUT) in parallel with ProIT project, and it created 1) a framework for development of methods to measure the benefits of the use of interoperable models and data sharing, and 2) identified some bottlenecks in the current processes and technologies. As the result, in August 2005 VTT and TUT started the second phase of VBE project, VBE2, together with 18 leading Finnish companies. In general, VBE2 project’s goal is to make a major contribution by leveraging the use of VBE technologies to the next level by changing the current processes and establishing a critical mass of Finnish organizations that are able to utilize Virtual Building Environment efficiently.

This work is a part of VBE2, Work Package WP3 – Decision Support Technologies. The report covers the work done in Work Package WP 3.5 – Requirements Management and Critical Decision Points.

We thank all parties who have financed the project, been involved with the actual research work, and provided information for the work. We express our gratitude especially to the interviewees, who were willing to devote their valuable time and share their views on the BIM-based construction process and decision points in it.

July 2007
Espoo, Finland

Tiina Koppinen   Arto Kiviniemi

Contents

List of acronyms

2D/3D	2-Dimensional/3-Dimensional
AECO	Architect, Engineer, Construction, Operation
BIM	Building Information Model
CURT	Construction Users Roundtable
HVAC	Heating, Ventilating and Air-Conditioning
IDM	Information Delivery Manual
NBIMS	National BIM Standard
VBE	Virtual Building Environment
WP	Work Package

Definitions

Process	A series of actions, changes, or functions bringing about a result, in this case a building: *the building process.* Here the process is considered from a view point of a building's life cycle. The process starts when a need for a building is determined and ends when the building is demolished as the result of no further need for the building.

1. Introduction

1.1 Background

This work is a part of a project called Virtual Building Environment (VBE2). The report covers the work done in the work package 3.5 – Requirements management and critical decision points. Critical decision points of the BIM-based (Building Information Model) design and construction process are determined, and the relation of associated data and the requirements model is analysed.

The Construction Users Roundtable's (CURT) Architectural/Engineering Productivity Committee concluded in *Collaboration, Integrated Information and the Project Lifecycle in Building Design, Construction and Operation,* "The goal of everyone in the industry should be better, faster, more capable project delivery created by fully integrated, collaborative project teams. Owners must be the ones to drive this change, by leading the creation of collaborative, cross-functional teams comprised of design, construction and facility management professionals" (Fallon and Palmer, 2007). The assumption behind the VBE research is that a significant element of faster, more capable project delivery is through adoption of BIM-based design and construction.

The basic tenets of this BIM-based approach echo the principles of reengineering defined by Hammer and Champy (1993) in *Reengineering the Corporation: A Manifesto for Business Revolution*, particularly:

- **Capture information once; avoid redundant data entry.** The use of the intelligent BIM to provide input to multiple analyses facilitates a higher degree of design optimization by eliminating the need to re-enter the same basic building information into each software. This improves quality by reducing chance of human errors in data entry, accelerates significantly the analyses and ensures that all analyses are performed on the same information.
- **Link parallel activities instead of integrating their results.** The use of 3D review sessions to highlight interferences before components are fabricated reduces the cost and time required for resolution in the field. Some projects using this technique have reported zero change orders due to clashes between building system components encountered in the field (e.g. Barista, 2007).
- **Let one person perform a work process from beginning to end.** Allowing the suppliers and subcontractors who will provide and install the components to actually develop the virtual building components to be included in the construction model gives them the greatest flexibility in meeting requirements and improves the dimensional accuracy of the model.

- **Build control into the process.** Automated clash detection of BIM incorporating multiple building systems allows interference resolution before the components have been fabricated, delivered to the site and erected. This reduces waste, cost and time lost.

1.2 Objectives

The objectives of this work are:

1. Analysis of the critical decision points.
2. Analysis of possibilities to use requirements model in the decision-making process.

This involves following subtasks:

1. Define the processes and decision points within the AECO project lifecycle for which users require information exchange.
2. Specify the information needs at each decision point.
3. Identify the actors sending and receiving information within the process.
4. Describe the results of process execution (domain specific BIMs and the associated analyses).

The deliverable of WP 3.5 is documentation of:

1. Identified critical decision points within a process map (Appendix A).
2. List crucial information for the decision-making in each of these points (Appendix B).
3. The relation of the required information to the requirements model.

2. Decision making levels

According to Kagioglou et al. (1998), the process of design and construction has to cover the whole life of the project from recognition of a need to the operation and maintenance of the finished facility. In these processes, decision points can be divided into two different levels: “soft gates” and “hard gates”. Soft gates enable concurrency in the process whereas hard gates require the temporary overhaul of the project until the decision to proceed is made. Often critical decisions (i.e. hard gates) are perceived to be decisions that involve a permission from the financial authority (e.g. the owner) to proceed. In the process, the intent of each gate is to assure high quality of work performance and adequate information availability during each phase of the project.

Key principles behind the process described in this report are (Kagioglou et al., 1998):

1) Whole project view – The process covers the whole life of the project from recognition of a need to the operation and maintenance of the finished facility. This ensures informed decision-making at the front-end.
2) Progressive design fixity – The BIM process applies a consistent planning and review process throughout the project resulting in progressive fixing of design information. Once certain information according to the information delivery schedule is decided upon, this information can be used as a basis for further, more detailed design.
3) A consistent process – The generic properties of the BIM process will allow a consistent application of the process irrespective of the project at hand. This helps to establish the BIM-based construction process and reduce uncertainty experienced by the participants.
4) Stakeholder involvement/Teamwork – Project success relies upon the right people having the right information at the right time. The process should ensure that the right people are consulted earlier in the process. Also active decision-making is encouraged.
5) Co-ordinator – Effective coordination between the project team members is paramount.
6) Feedback – Success and failure can offer important lessons for the future.

Information needs at the hard gates, also called here critical decision points, was the focus of the research reported in this working paper. The information needs at each point are analysed and the producer of this information is determined. This way it can be ensured that appropriate data is available when needed and in the model where it is supposed to be in. It is also determined which data is related back to the requirements model.

3. Information needs and delivery

3.1 Defining Model Views

An established technique is to define specific workflows and information use cases for model exchange (IAI, 2007). An example of a use case would be the handover of building information to the contractor for cost estimation. Each use case may require multiple information exchanges. For each exchange, it is necessary to detail the information to be exchanged and define the entities in the standard format that are required for the exchange. This creates a Model View.

The Norwegian buildingSMART initiative and the NBIMS Committee (National BIM Standard, USA) have built upon the use case approach with the Information Delivery Manual (IDM) methodology. The advantage of the IDM methodology is that it accommodates information packages that have multiple sources over time. For example, the designer specifies the performance requirements of building products and systems, while the actual products, their characteristics and their installation and operation are defined in submittals during the construction phase. Both sets of information are required for operations and maintenance. The COBIE initiative has adopted the IDM approach because it simplifies the development of a specification for the collection of incremental, process-based information packages. This allows the data subsets to be captured at the source throughout the design/construction process, rather than recreated at project closeout (Fallon and Palmer, 2007).

IDM and MVD methodologies are used to define the exact information exchange between the parties in a BIM-based construction process. Here, the information delivery is not defined quite at this accuracy and detail, but rather a slightly more generic level is still applied.

3.2 Project Information Handover Plan

The information strategy specifies the information requirements for decision-making, work processes and regulatory compliance. These are called information packages. The information packages are prioritized according to the strategy. At the same time it is identified by whom and when in the facility life cycle these information packages should be created. It is also identified by whom or what process and when in the facility life cycle these information packages are needed and used.

The information handover requirements define, for each information package:

- Content
- Uses
- Preferred form and format
- Metadata requirements
- Retention.

The project information handover plan brings together the information handover content, format and metadata requirements, and the project-specific conditions to ensure that the required information handovers can be executed. In projects, this methodology could also be used to define party specific information packages and potential tool specific format requirements.

3.3 Information needs in the critical decision points

In this report, the information needed in each decision point is determined based on the owner needs: what information is needed in each decision point in order to provide adequate and appropriate information for decision makers. The key components that are within the boundary of information exchange are identified according to the following list:

1. use – which decision is supported by the information;
2. content – what type of information is required;
3. which data (specific pieces of information) enables the creation of the information;
4. which business process produces the data (requirements capturing/ architectural design/structural design/HVAC design/model checking).

In further research, and by application developers, this information could be turned into IDM. The information can also be used to produce project specific information packages.

4. Critical decision points

The critical decision points are depicted in a chart (see Appendix A) where the vertical axis lists “the activity zones”, e.g. levels of decision-making and project working. Each activity zone has a prime responsibility for one or more deliverables in the project. These activity zones are listed below.

- Owner requirements management – determination of the owner’s needs and the owner’s decision-making.
- End-user requirements management – capturing the end-users needs and hand-over to the end-users.
- Marketing and sales – marketing and sales is an activity performed by a department/agent of the owner organisation and responsible for the communication with the end-users.
- Project management – management of the design and construction process. An activity that is responsible for the communication with the owner and making sure that project requirements realize.
- Design – design, production of BIMs and detailed designs, simulations and visualisation. Production of building specifications. Preparations of building permit and call for tender documentations.
- Construction – preparation of as-built BIM(s) and maintenance manual.
- Facilities management – operation and maintenance of finished facilities. Associated requirements and review of design.
- Authority activities – determination of authority requirements. Statutory permitting, inspections and approvals.
- Management of Building life-cycle information – management and archiving of the information (e.g. BIMs created during the process. This activity is not included in the process map.)

In the process chart, the horizontal axis depicts the different phases in the whole life of the project from recognition of a need to the operation and maintenance, and finally disposal of the finished facility. The phases are determined based on the project phases presented by Fallon and Palmer (2007), Kagioglou et al. (1998) and confidential material on investment processes of different Finnish construction and facility owner organisations. As the result of the analysis, the phases of a BIM-based design and construction process are presented in Table 1. This process covers five main phases: pre-project, design & pre-construction, construction, post-construction, operation & maintenance. The main phases are divided into (1–3) sub-phases. Each phase ends up with a decision point, main phases with hard gates (critical decision points), while sub-phases end up with soft gates. The only exception is the sub-phase called “Objectives & requirements & feasibility study” during the pre-project-phase that ends up with a hard gate, i.e. project decision.

The whole design and construction process with the above described phases and zones is presented in Appendix A. The process chart also provides information on BIMs that should be produced in each phase and the analyses/simulations that should be performed in order to produce important data for the critical decision-making. The symbols used throughout the process descriptions are listed in Appendix A. The colour-coding used in the chart is following:

- Green – The BIM and simulation/analysis can be produced with the current technology, and, thus, should be performed.
- Yellow – The BIM and simulation/analysis may not be doable with the current technology, but would be beneficial – OR – the production of the BIM and simulation/analysis should be determined project-specifically. (Thus, the BIM/simulation/analysis is not appropriate or needed in every project).

The phase-specific information requirements at each decision point are listed in the following paragraphs and in Appendix B. Information needs are determined through interviews and literature (e.g. Kujala 1999). The required and specified information should be available in the requirements model, domain specific BIMs, detailed designs/drawings or building specifications. The source of information/data in each decision point will also be discussed in the next paragraph.

Table 1. Project phases and associated decision points. Critical decision points are written in bold text.

Phase	***Description***	***Definition/Associated decision points***
Phase 1. Pre-project Phase		
1.1	Need Determination	Establish the need for a project to satisfy the owners/end-users business requirement. 1.1.1 Start-up decision.
1.2	Objectives, Requirements & Feasibility Study	Identify project objectives and requirements. Identify potential solutions to the need that meet the objectives and requirements. Examine the feasibility of options. **1.2.1 Project decision.**
1.3	Alternatives	Capture end-user requirements. Produce spatial design alternatives that meet the requirements and project objectives. Select the most prominent alternative for further design. 1.3.1 Selection of alternative. **1.3.2 Investment decision.**
Phase 2. Design and Pre-Construction Phase		
2.1	Early Design	Identify major design elements based on the selected alternative. Building permit documentation produced. 2.1.1 Early design approval.
2.2	Detailed Design	Detailed design and all deliverables ready for detailed planning approval. Call for tender documentation produced. 2.2.1 Detailed design approval 2.2.2 Decision to call for tenders.
2.3	Bidding and Procurement	2.3.1 Selection of the contractor. **2.3.2 Decision to construct.**
Phase 3. Construction Phase		
3.1	Construction	Produce a product that satisfies set client requirements. 3.1.1 Change approval **3.1.2b Handover of the building as planned (contractor-perspective).** **3.1.2a Commissioning (owner-perspective).**
Phase 4. Post-construction Phase		
4.1	Operation and maintenance	Operate and maintain the product effectively and efficiently. 4.1.1 Handover to users. **4.1.2 Release of guarantees.**
Phase 5. Operation and Maintenance Phase		
5.1	Operation and maintenance	Operate and maintain the product effectively and efficiently. **5.1.1 Decision to dispose of the building.** Decommission, dismantle and dispose of the components of the project and the project itself according to environmental and health/safety rules.

5. Information sources

5.1 Pre-project phase

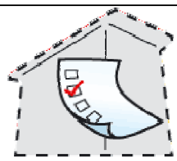
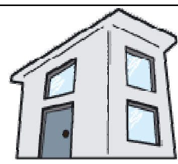
5.1.1 Project decision

The information requirements in different decision points and sources of this information are depicted in the Figures presented in Appendix B. The pre-project phase is divided into three sub-phases: 1.1 need determination, 1.2 objectives requirements & feasibility study, and 1.3 alternatives. Need determination (1.1) defines the basic demand to investigate the need for a new building or for a renovation project of an existing building. Two latter ones (1.2 and 1.3) are concluded with critical decision points. The primary information needs during pre-project phase are defined here in more detail in terms of the information/analysis requirements in these critical decision points: 1.2.1 Project decision and 1.3.2 Investment decision. At the same time sources of the required information are determined and listed in Table 2 and 3.

Determination of project requirements and objectives and feasibility study (sub-phase 1.2) is brought to a close with the project decision – a decision to start the project and gather a project team to manage the project. The information required for this decision covers: target cost, estimated revenues, life-cycle cost of alternative means to meet the need, target schedule, spatial programme, alternative plots of land and available funding. In this phase, most information still relates to the requirements and goal setting and to information on (or BIMs of) similar reference projects. In pre-project phase, the owner and end-user requirements should be determined in the form of Excel workbooks (e.g. spatial programme), as this format would enable utilisation of the data in a later design checking and in verifying the level of requirements fulfilment of the design alternatives.

The owner and end-user requirements and objectives (i.e. needs and wants) may be numerous and sometimes conflicting or impossible within the available budget. Thus, it is important to identify the priorities and mandatory requirements as early as possible. In that way, the documented requirements will be restricted into a relevant starting point for the design (Kiviniemi 2005, Kujala 1999). Early cost estimation helps to demonstrate the price of different factors and enables realistic designs later in the process. Early cost estimation with the most accurate data available at this phase is an important element of efficient risk management. Also, the availability of reference data on similar projects assists in informed decision-making.

Table 2. Information needs and sources in critical decision points during pre-project phase – 1.2.1 Project decision.

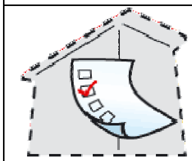
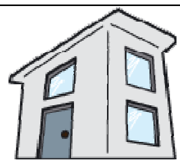
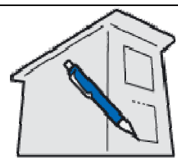
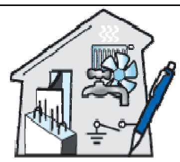
Information required in 1.2.1 Project decision	**Sources of information/data**		
			Other sources of information
• Target Cost • Estimated revenues • Life-cycle costs of alternatives • Target schedule • Spatial programme o Programme area o Rentable/saleable area o Different operative areas • Plot of land • Availability of funding • Risk level	• Owner/end-user needs • Spatial programme (area, quality-level, use, HVAC-requirements, special purpose spaces etc.) • Spatial target cost • Estimated construction time • Target ratios • Site requirements • Building requirements • Storey requirements • Statutory requirements • Financiers' requirements	• Cost estimate based on utilisation/repair of existing structures • Spatial cost based on reference projects (realised cost per area/volume) • Revenue based on reference projects (price) • LCC cost based on reference projects (energy consumption, operation, maintenance, etc. costs per area/ volume) • Operative areas based on reference projects • Current site & zoning • Building rights • Risks realized in reference projects	• Availability of funding o Equity o Potential financiers o Cost of financing • Estimated revenue based on location/ use/area/end-user/ quality-level, etc. • Market analysis (existence of capable/available resources, market price, etc.) • Work-place assessment • Guidelines on operative areas (best practice) • Available sites & zoning, building rights

5.1.2 Investment decision

The project is started by producing alternative (sub-phase 1.3) spatial models (spatial BIMs) that should contain the spaces specified by the spatial programme. These alternatives are compared based on their investment and life-cycle cost, level of requirements fulfilment, effectiveness, functionality, usability, etc. Once one design alternative is selected as the basis for the further design, the investment decision may be made. The investment decision is based on following information: spatial cost estimate/target cost, revenue estimate, life-cycle cost, investment schedule, functionality, usability, utilisation of old structures, effectiveness of the design (ratios), level of requirements fulfilment, project plan and pre-contracts. The sources of this information are listed in Table 3.

In alternative phase spatial design is made based on the requirements and goal setting. The design is produced in the format of a spatial BIM. The design is checked against the requirements. If existing structures are to be utilised, BIM of these should be produced as a basis for the designs and cost estimation. In a project with very demanding structures or HVAC-systems, structural or HVAC engineer may participate in the alternative design. Use of BIMs enables earlier and more accurate analyses of e.g. energy consumption and life-cycle cost. Potential early involvement of structural and HVAC engineers can also improve the quality of the designs and reduce the number and extent of design changes in the later project phases.

Table 3. Information needs and sources in critical decision points during pre-project phase – 1.3.2 Investment decision.

Information required in 1.3.2 Investment decision	**Sources of information/data**				
					Other sources of information
• Target cost • Revenue estimate • Life-cycle cost • Investment schedule • Usability • Functionality • Utilisation of old structures • Effectiveness ratios • Realisation of requirements • Space types and areas • Area of shell • Total volume • Project plan • Pre-contracts	• Spatial programme • Space types • Programme areas • Quality-level • Use • Life • Project requirements (owner/end-user) • Building requirements • Site • Statutory requirements • Schedule • Budget • Target ratios	• Space types • Spatial areas • Retained/ Repaired/ Modified/ Demolished structures • Use of spaces • Relationship between new & existing spaces • Visualisation • Quality-level • Rentable/ saleable area • Facades • Roof • Building geometry + volume • Energy simulation • Location/ Direction on site	• Space types • Spatial areas • Quality-level • Spatial cost estimate • Rentable/ saleable area • Facade • Roof • Building geometry + volume • Architecture • Functionality • Energy simulation • Estimated construction time • Relationships between spaces • Location/ Direction on site • Traffic schema • Visualisation • Area calculation rules	• Model checking • Calculation of ratios • Comparison between requirements model/spatial programme and BIM	• Cost/m^2 of different spaces • Market prices • Site location • Micro environment • Weather information • Reference projects • Availability of funding • Work-place assessment • Neighbouring sites and their use • Best practice • Project team • Procurement method

Generally, the later in the process the investment decision may be made, the more accurate the data is on which the decision is based, and, thus, less risk is experienced. As the result, the investment decision may be delayed all the way to the decision to start construction, if the owner's investment process allows this.

In summary, in pre-project phase a lot of the information relates back to the requirements models and spatial programme (Kiviniemi 2005). Often this phase is managed without BIMs even though production of spatial, architectural BIM and visualisation would enable more informed decision-making, as a more thorough and automated analysis of effectiveness ratios would be possible. Also more advanced criteria (e.g. life cycle cost) could be used to assess alternatives with only minimal amounts of additional work. Production of structural, HVAC and electrical BIMs would be beneficial especially in complicated and/or large projects. However, determination of associated space or structural requirements early in the process could reduce complications later in the process in many projects.

5.2 Design & pre-construction phase

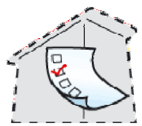
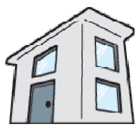
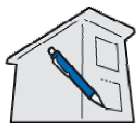
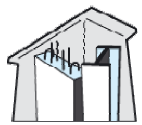
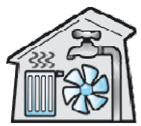
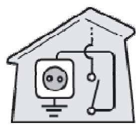
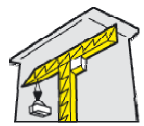
The design & pre-construction phase is also divided into three sub-phases: 2.1 early design, 2.2 detailed design and 2.3 bidding and procurement. Once both early and detailed designs are approved, the decision may be made to call for tenders. Based on tenders received the contractor is selected. Now the decision to construct (2.3.2) may be made. The information requirements and sources of information in this critical decision point are listed in Table 4. Decision to construct is based on: contract price, estimated cost of operation, life-cycle cost, construction schedule and level of requirements fulfilment.

The information dealt with in this phase is created by performing different analyses (cost, energy simulation, indoor environment, lighting, fire and visualisation) on domain specific BIMs: architectural, structural, HVAC and electrical. The results of the analyses are compared to the requirements and targets. It is paramount to ensure that the project scope does not grow unduly or without a reason during the process. Thus, comparison between the requirements and the design is essential. As the requirements model is the basis for comparisons, it is important to update the requirements model and spatial programme during the process if necessary. Also, the decisions preceding the changes should be documented.

Another very important purpose of the analyses is to resolve on-site clashes already during the design process. This is done with the help of the integrated BIM. As the result of the clash checking several percent of the capital value of a typical project may be saved.

The contractor also utilises the domain specific BIMs in developing a tender. This involves use of 4D-scheduling, calculation of quantities, and procurement. Use of BIMs reduces the contractor’s risks as the quantities and resource needs may be determined more accurately. As the result, risk premium in the tender should be reduced.

Table 4. Information needs and sources in critical decision points during design & pre-construction phase – 2.3.2 Decision to construct.

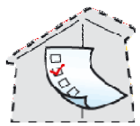
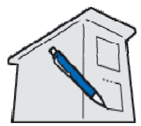
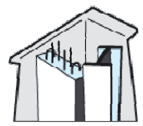
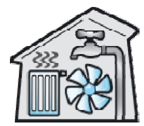
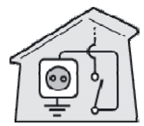
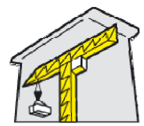
Information required in 2.3.2 Decision to construct	**Sources of information/data**								
									Other sources of information
• Contract price • Cost of operation • Life-cycle cost (= investment + operation cost) • Construction schedule • Level of requirements fulfilment	• Target cost • Spatial programme • Quality-level • Other owner/ end-user requirements • Schedule requirements • Target ratios	• Retained/ repaired/ modified spaces & areas/volumes • Expected maintenance activities and intervals	• Spaces (areas, heights, volumes) • Building geometry • Relationships • Surface materials • Windows & doors • Quality-level • Resource-based cost estimation • Energy simulation with structural information • Area/volume calculation rules	• Structural system • Construction materials & methods • Construction components • Work packages (procurement) • Resource-based cost estimation • Expected maintenance activities and intervals	• HVAC systems • Work packages (procurement) • Resource-based cost estimation • Indoor environment • Energy consumption • Expected maintenance activities and intervals	• Electrical systems • Lighting systems • Work packages (procurement) • Resource-based cost estimation • Energy consumption • Functionality • Expected maintenance activities and intervals	• Procurement planning • 4D-scheduling • Work planning	• Model checking • Clash checking • Comparison of requirements and BIMs • Calculation rules	• Building specification • Work description • Call for tender documentation • Tenders • Selection of contractor • Cost of energy • Cost of water • Cost of services • Building specification • Work description • Procurement

5.3 Construction phase

The construction phase involves production of a construction/production BIM which is utilised for scheduling, work-planning, procurement and logistics. This phase is concluded with the commissioning (3.1.2a). The information requirements and sources of information in the critical decision point are listed in Table 5. The commissioning is based on: realised project cost and schedule, changes, acceptance inspections, maintenance manual, and as-built BIM.

During the construction phase, the importance of the requirements model is reduced since it may be assumed that the design is produced appropriately based on the requirements. The results of the construction are compared to the designs (domain specific BIMs and descriptions) and the contract/tender documentation. The domain specific BIMs should be updated, if changes to the designs are made during the construction. Also, the effect of changes on maintenance manual should be noted and changes made accordingly. When design changes are made, these should be compared to the requirements in order to avoid disadvantageous and unnecessary changes.

Table 5. Information needs and sources in critical decision points during construction phase – 3.1.2a Commissioning.

Information required in 3.1.2 Commissioning	**Sources of information/data**							
								Other sources of information
• Realised cost • Realised Schedule • Changes • Acceptance inspection • Maintenance manual • As built-BIMs	• Target cost • Schedule • Owner/end-user requirements • Quality-level	• As--built BIM • Format and content according to contract	• Updated architectural BIM • Visualisation • Format and content according to contract	• Updated structural BIM • Format and content according to contract	• Updated HVAC BIM • Format and content according to contract	• Updated electrical BIM • Format and content according to contract	• Procurement planning • 4D-scheduling • Work planning	• Tender • Accounting • Cost control • Work descriptions • Updated building specifications • Updated maintenance manual • Inspection minutes • Owner/end-user operation briefing • Delivery of commissioning materials in acceptable format • Archiving

5.4 Post-construction phase

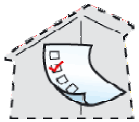
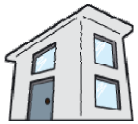
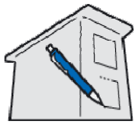
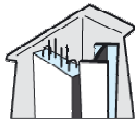
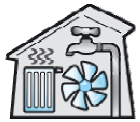
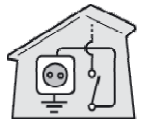
During the post-construction phase the building is taken into use. The building's functionality and usability become apparent. At the same time, the appropriateness of the initial requirements and realised characteristics of the building may be assessed. The phase is concluded with the release of guarantees (4.1.2). The information requirements and sources of information in this critical decision point are listed in Table 6. The release of guarantees involves: guarantee inspection, realised cost of operation and the level of requirements fulfilment in terms of operative characteristics.

The realised energy consumption, lighting, indoor environment, functionality and usability may be assessed by comparing the building and its systems to both requirements and designs. This type of analysis is very beneficial especially for professional owners, organisations that own and operate multiple buildings and frequently go through the building process. If the building is produced according to the designs, but the expected or required environment is not produced, the design was imperfect. If the required environment is produced, but this does not provide adequate functionality or usability, the initial requirements and goal setting was imperfect. This type of analysis is very important for organisational learning in order to enable and ensure more effective and needs oriented project delivery in the future. Currently the post-occupancy assessment is seldom performed and documented in a systematic and detailed way. In addition, very few organisations have established a formal process to deliver the assessment results to the department responsible of their future projects. Thus, the information often stays in the Facility Management department and never reaches the people responsible for the delivery of the next buildings.

5.5 Operation and maintenance phase

During the operation and maintenance phase, the pre-described process from need determination (1.1) to post-construction phase (4) will be repeated several times in each new renovation project. The operation and maintenance phase finally ends up with the critical decision point 5.1.1, Decision to demolish the building. This decision is preceded by an assessment of the facilities and determination of current and future end-user needs. If the potential of the existing facilities does not meet the needs, and the reconstruction or required modifications are considered uneconomical, the decision may be made up to demolish the building or, at the minimum, to relinquish the premises. As the information required for the decision-making is very case-specific and comes mainly from other sources than the domain specific BIMs, this critical decision point is not looked at in more detail.

Table 6. Information needs and sources in critical decision points during post-construction phase – 4.1.2 Release of guarantees.

Information required in 4.1.2 Release of guarantees	**Sources of information/data**						
							Other sources of information
• Guarantee inspection • Realised cost of operation • Level of requirements fulfilment • Energy consumption • Indoor environment • Functionality • Usability	• Owner/end-user requirements • Initial targets	• Updated As-built BIM • Design values	• Updated As-built BIM • Design values	• Updated As-built BIM • Design values	• Updated As-built BIM • Design values	• Updated As-built BIM • Design values	• Energy & indoor environment follow-up • Updated maintenance manual • Inspection minutes • Cost of services • Cost of energy • Cost of water • Accounting & cost control

6. Conclusions

Many of the information needs during the process relate back to the project requirements. Basically, the quality of a building may not be verified without a well-defined goal. The requirements set the basis for the design and the results of the project must be compared with the requirements in order to define the level of requirements fulfilment. This emphasises the importance of capturing and documenting initial requirements and updating of the evolving requirements during the process (Kiviniemi 2005).

Even though multiple issues are assessed at the critical decision points, the main emphasis has long been on the investment cost (Kujala 1999). One reason for emphasising investment cost is the ability to assess it relatively reliably. However, the use of more advanced simulation technologies and BIMs enables more complicated, and yet reliable analyses of life-cycle costs. Having this type of information earlier in the process is an effective risk management tool end ensures more informed decision-making. For example, the owner's environmental goals may be achieved with increased certainty once energy and other environmentally important simulations are performed before a design alternative is selected and the investment decision made. BIMs also enable (semi-)automated calculation of different ratios that may guide the decisions towards more optimal solutions.

Even though the decision-making will, and should, involve assessment of multiple variables, the cost (whether investment or life-cycle) and its accuracy will still remain important factors. In order to determine the cost as accurately as possible in each project phase, different information is needed based on the degree of readiness and accuracy of the design and BIMs. In the beginning of the process, the data required mainly relates to spaces, uses, areas, and quality-levels. If life-cycle cost is assessed, historic information on reference projects is needed to derive appropriate estimates of these costs for certain types of solutions. Further in the process the cost may be determined based on material types and quantities, and required resources. Once contracted, the realized costs may be compared with the earlier estimates and targets in order to verify the accuracy of estimates and to assess the effectiveness and success of the project management. This is important for the learning process.

7. Summary

The study reported in this working paper is part of a research and development project called Virtual Building Environment (VBE2). The working paper covers research carried out to determine the interface between requirements management and critical decision points. First, the processes and critical decision points within the AECO project lifecycle for which users require information exchange are defined. Then, detailed information needs in each critical decision point are specified. Finally, the actors sending and receiving information within the process are identified and the associated, required information content of the BIMs is determined.

Here the life cycle of the building is divided into five phases: Pre-project, design & pre-construction, construction, post-construction and operation & maintenance. The actors in the process are the client, end-users, marketing & sales department/agent, project manager, designers, constructors, facilities managers and authorities. Even though the process goes through multiple decision points (soft gates), only hard gates or critical decisions which are perceived to be decisions that involve a permission from the financial authority (the owner) to proceed are studied in more detail. The critical decision points in the process are: the project decision and investment decision during the pre-project phase; the decision to construct after the design and pre-construction phase; the commissioning after the construction phase; the release of guarantees after the post-construction phase; and the decision to demolish the building in the end of the building's life cycle.

The decision-making in each phase involves the assessment of multiple variables. These variables include factors like target cost, expected revenues, life-cycle cost, schedule, usability, functionality, different ratios, realisation of requirements, etc. However, cost (whether investment or life-cycle) and its accuracy is emphasised throughout the process. Use of BIMs enables earlier and more accurate analyses of e.g. energy consumption and thus life-cycle cost. This facilitates truly informed decision-making and reduces project risks experienced by the owner.

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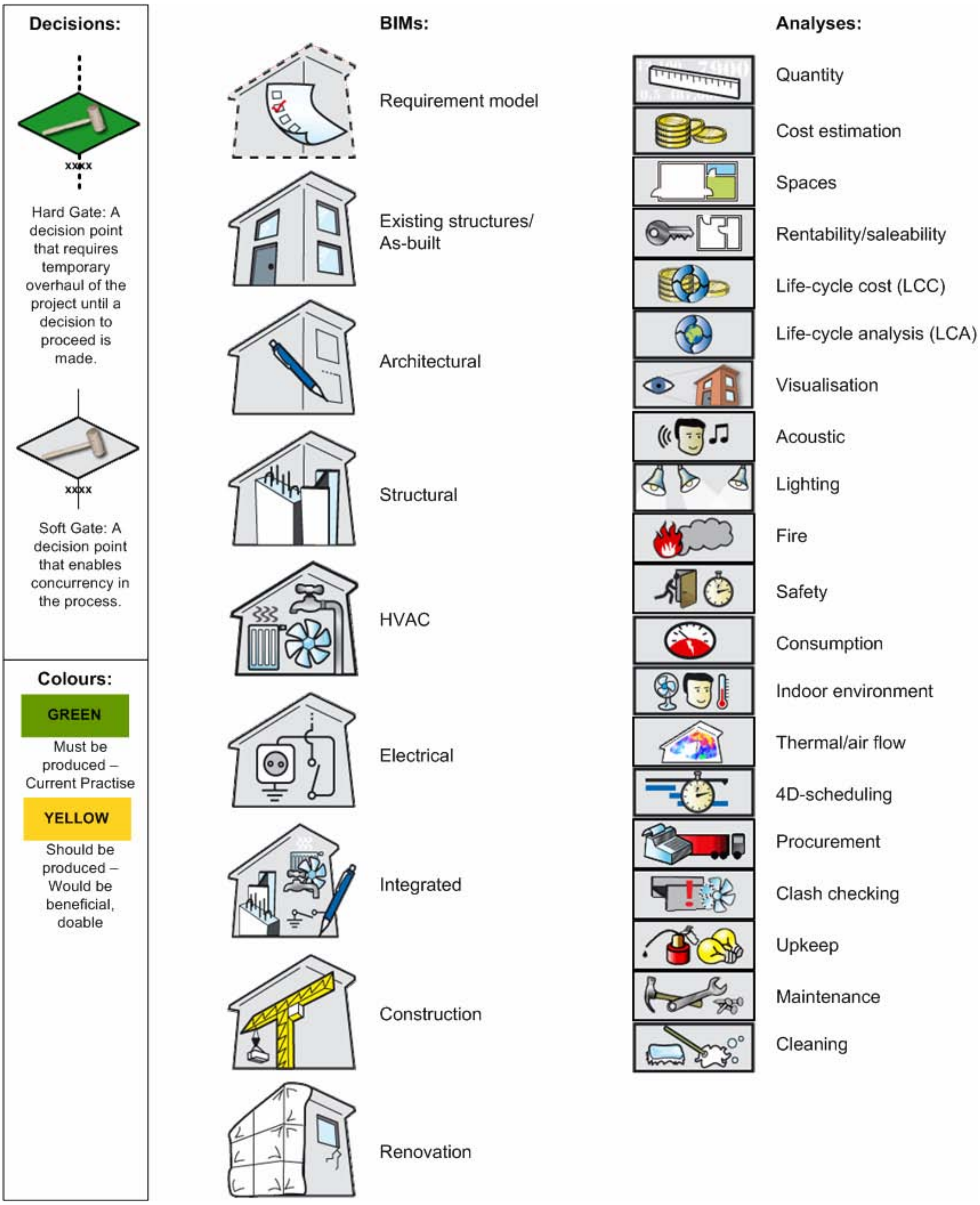
Senaatti-kiinteistöt. BIM requirements (2007):

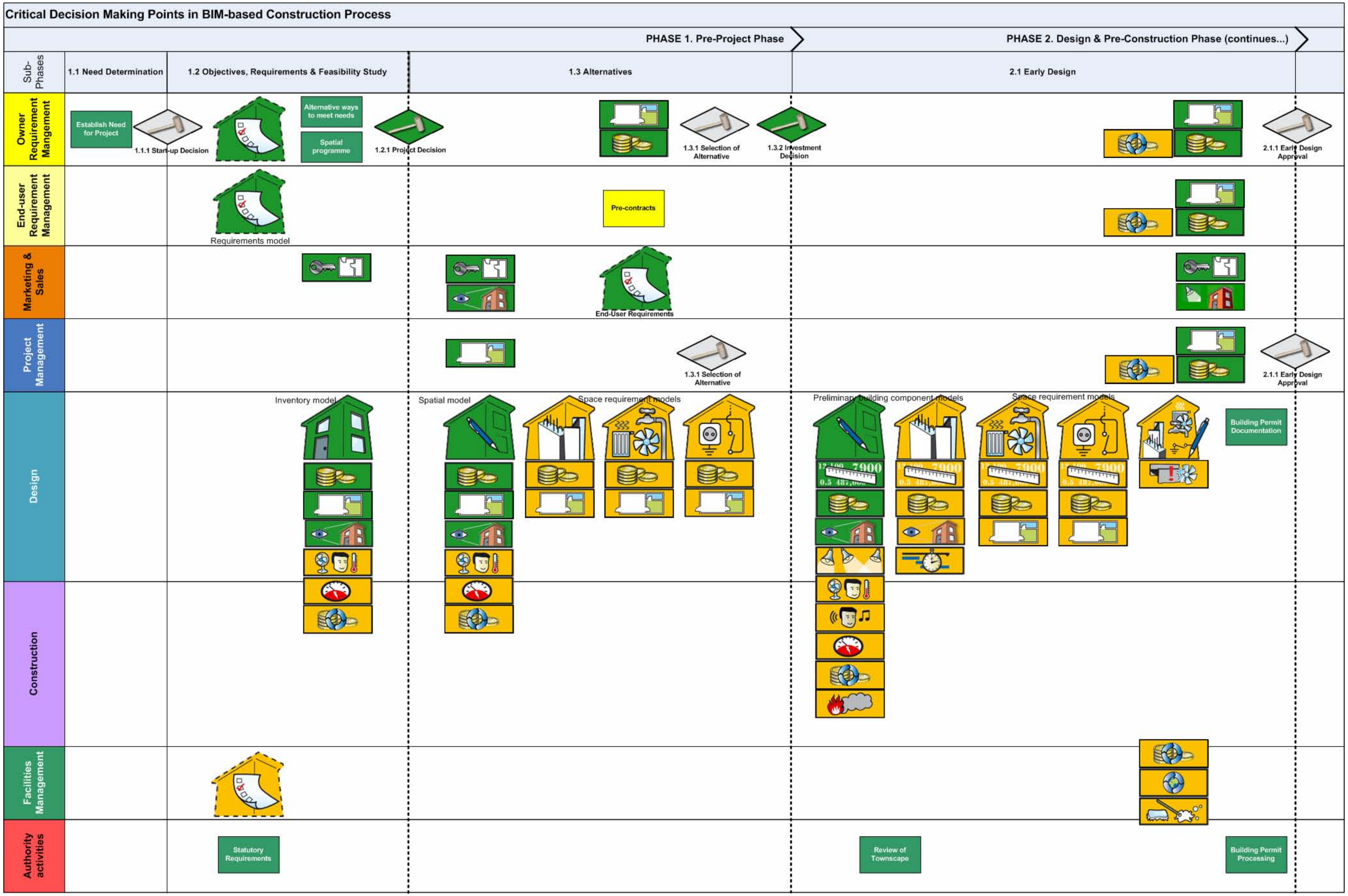
- Inventory BIM
- Architectural BIM
- Structural BIM
- HVAC BIM
- BIM quality assurance

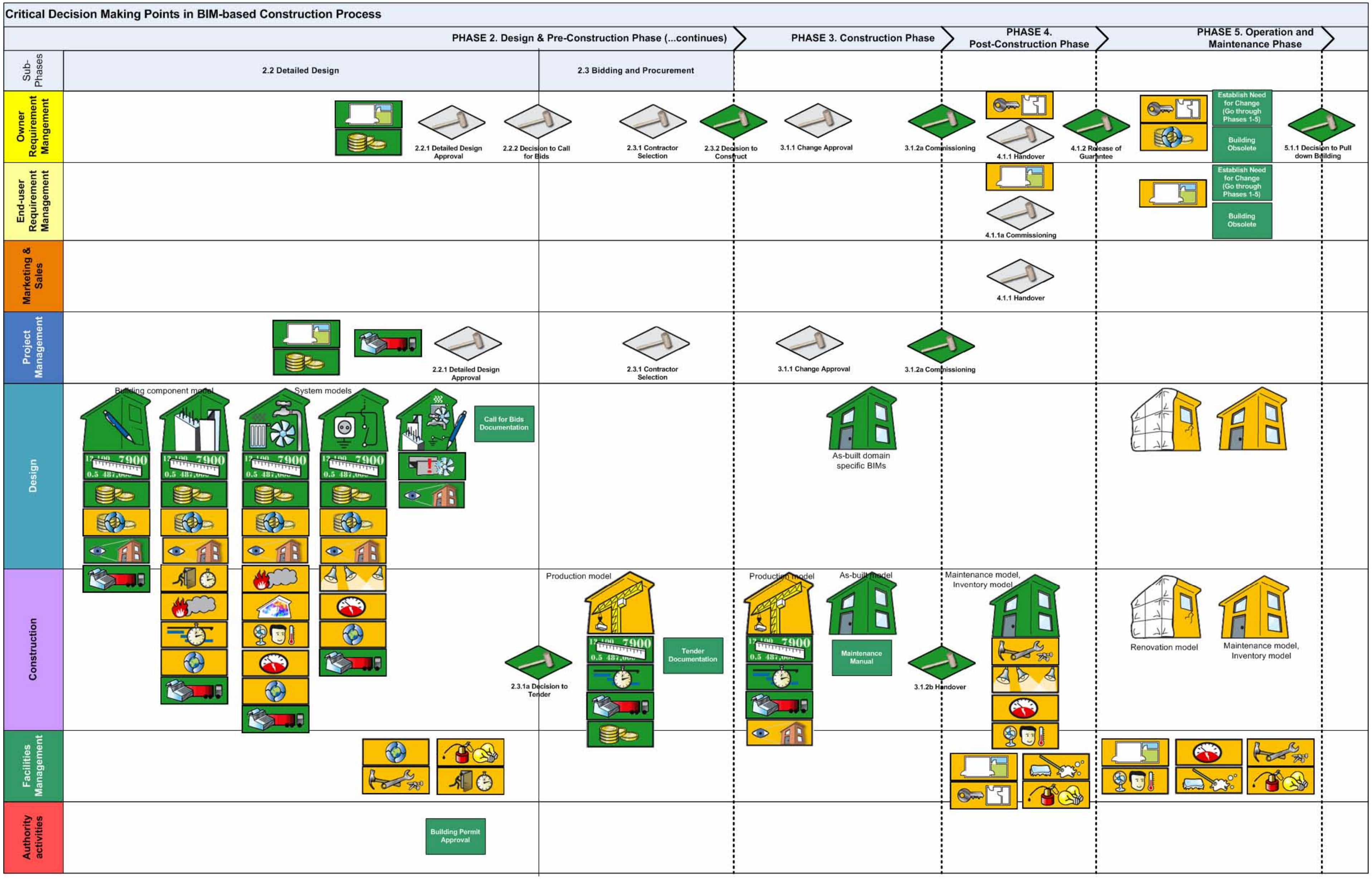
Additionally:
Investment processes of different Finnish construction and owner organisations.

Appendix A: Critical decision points in BIM-based construction process

List of symbols used in the process map:




Critical Decision Making Points in BIM-based Construction Process
PHASE 1. Pre-Project Phase
PHASE 2. Design & Pre-Construction Phase (continues...)
Sub-Phases
1.1 Need Determination
1.2 Objectives, Requirements & Feasibility Study
1.3 Alternatives
2.1 Early Design
Owner Requirement Mangement
End-user Requirement Management
Marketing & Sales
Project Management
Design
Construction
Facilities Management
Authority activities
Establish Need for Project
1.1.1 Start-up Decision
Alternative ways to meet needs
Spatial programme
1.2.1 Project Decision
1.3.1 Selection of Alternative
1.3.2 Investment Decision
2.1.1 Early Design Approval
Requirements model
Pre-contracts
End-User Requirements
Inventory model
Spatial model
Space requirement models
Preliminary building component models
Space requirement models
Building Permit Documentation
Statutory Requirements
Review of Townscape
Building Permit Processing


Critical Decision Making Points in BIM-based Construction Process
PHASE 2. Design & Pre-Construction Phase (...continues)
PHASE 3. Construction Phase
PHASE 4. Post-Construction Phase
PHASE 5. Operation and Maintenance Phase
Sub-Phases
2.2 Detailed Design
2.3 Bidding and Procurement
Owner Requirement Mangement
End-user Requirement Management
Marketing & Sales
Project Management
Design
Construction
Facilities Management
Authority activities
2.2.1 Detailed Design Approval
2.2.2 Decision to Call for Bids
2.3.1 Contractor Selection
2.3.2 Decision to Construct
3.1.1 Change Approval
3.1.2a Commissioning
4.1.1 Handover
4.1.2 Release of Guarantee
Establish Need for Change (Go through Phases 1-5)
Building Obsolete
5.1.1 Decision to Pull down Building
4.1.1a Commissioning
4.1.1 Handover
2.2.1 Detailed Design Approval
2.3.1 Contractor Selection
3.1.1 Change Approval
3.1.2a Commissioning
Building component model
System models
Call for Bids Documentation
As-built domain specific BIMs
Production model
Tender Documentation
2.3.1a Decision to Tender
Production model
As-built model
Maintenance Manual
3.1.2b Handover
Maintenance model, Inventory model
Renovation model
Maintenance model, Inventory model
Building Permit Approval

Appendix B: Information needs at the critical decision points

Here the information needs in the critical decision points are depicted from a broader process viewpoint. The aim is to show how the decisions relate to other project tasks and deliverables. The critical decision points depicted are:

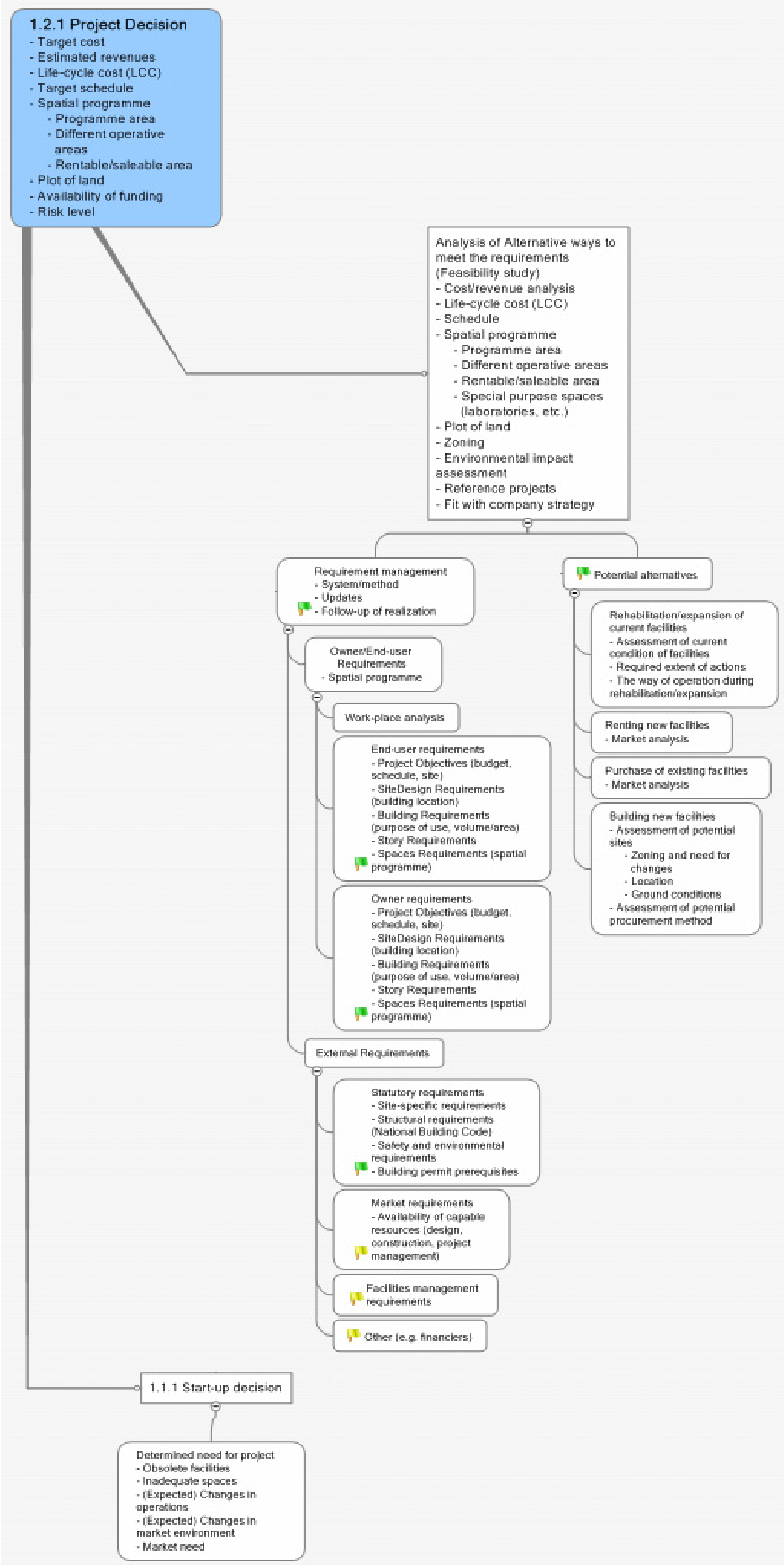
1.2.1 Project decision

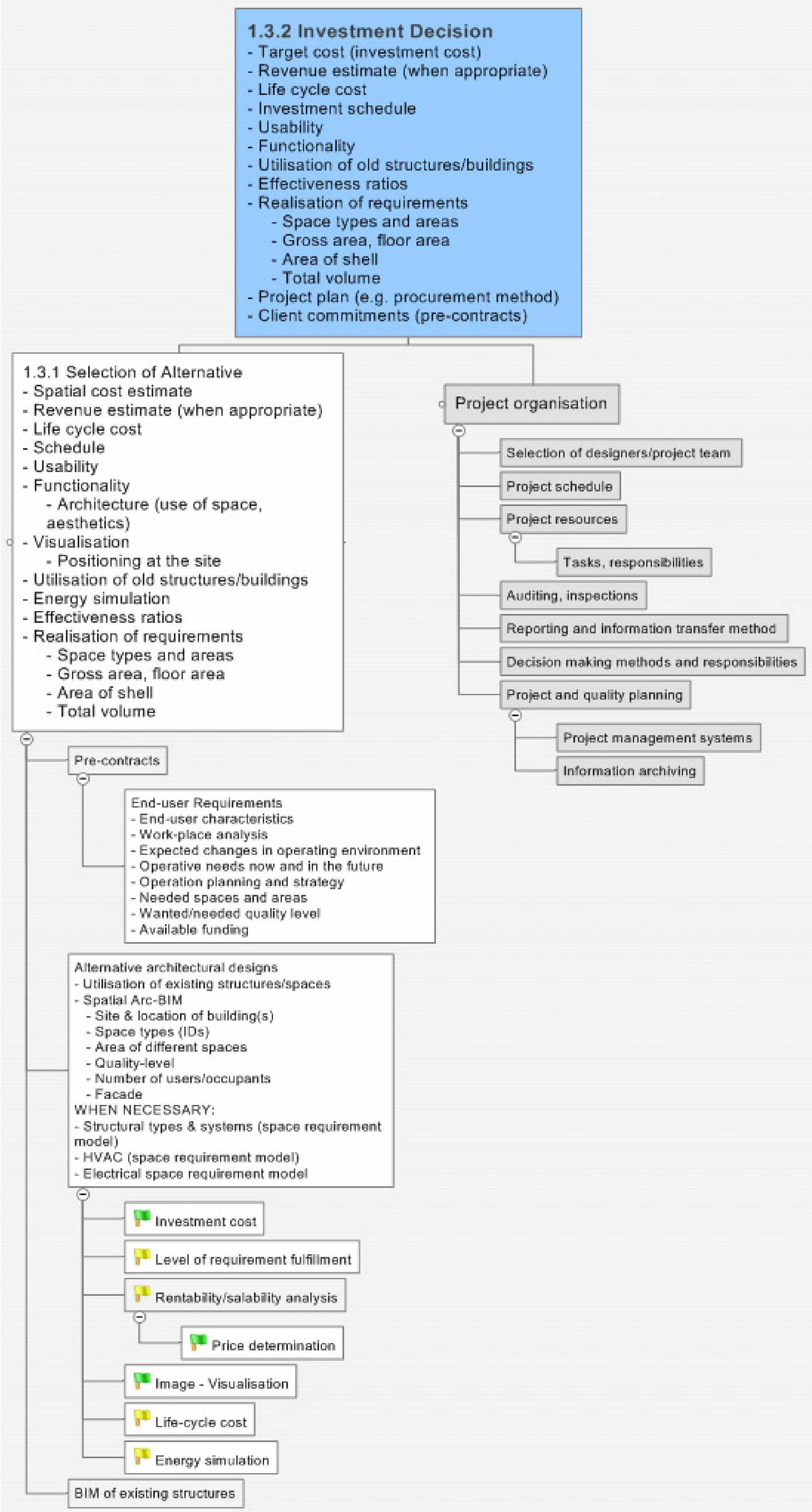
1.3.2 Investment decision

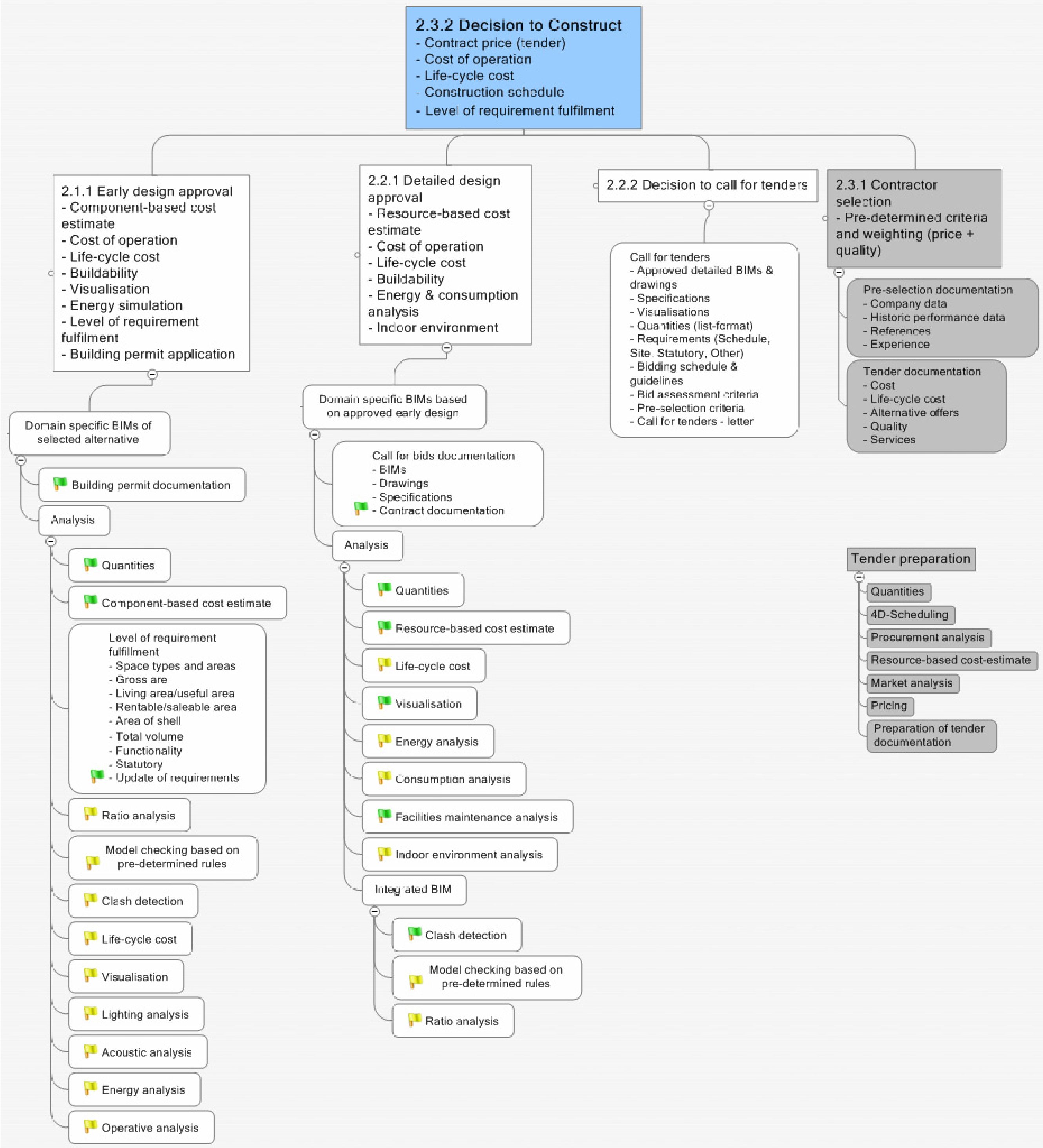
2.3.2 Decision to construct

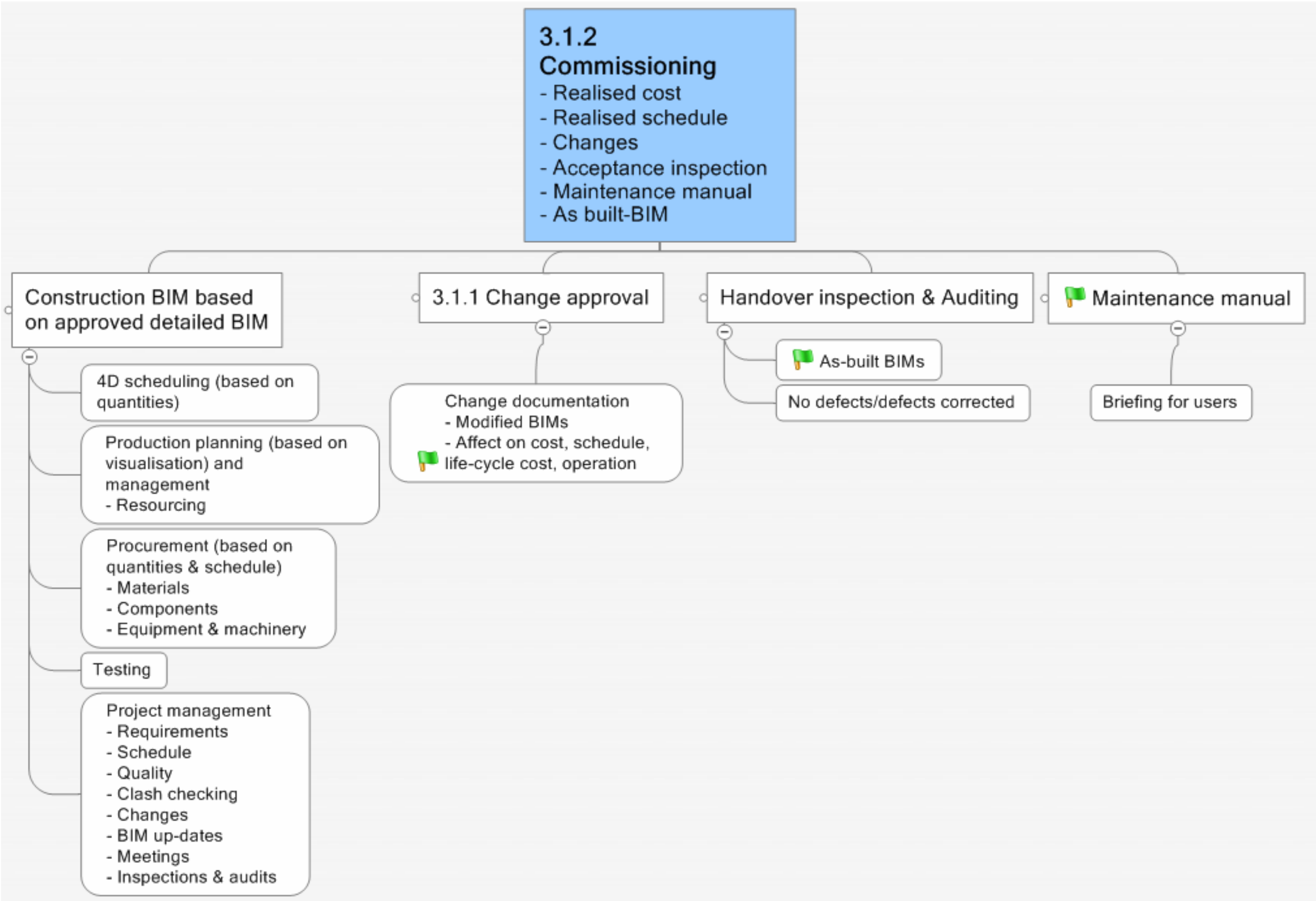
3.1.2 Commissioning

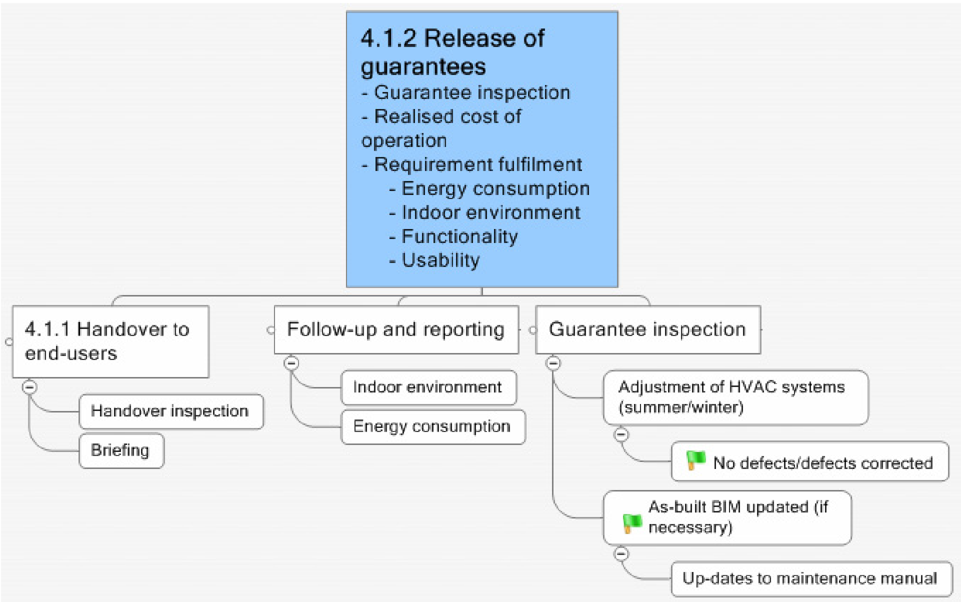
4.1.2 Release of guarantees


1.2.1 Project Decision
- Target cost
- Estimated revenues
- Life-cycle cost (LCC)
- Target schedule
- Spatial programme
- Programme area
- Different operative areas
- Rentable/saleable area
- Plot of land
- Availability of funding
- Risk level
Analysis of Alternative ways to meet the requirements (Feasibility study)
- Cost/revenue analysis
- Life-cycle cost (LCC)
- Schedule
- Spatial programme
- Programme area
- Different operative areas
- Rentable/saleable area
- Special purpose spaces (laboratories, etc.)
- Plot of land
- Zoning
- Environmental impact assessment
- Reference projects
- Fit with company strategy
Requirement management
- System/method
- Updates
- Follow-up of realization
Potential alternatives
Rehabilitation/expansion of current facilities
- Assessment of current condition of facilities
- Required extent of actions
- The way of operation during rehabilitation/expansion
Renting new facilities
- Market analysis
Purchase of existing facilities
- Market analysis
Building new facilities
- Assessment of potential sites
- Zoning and need for changes
- Location
- Ground conditions
- Assessment of potential procurement method
Owner/End-user Requirements
- Spatial programme
Work-place analysis
End-user requirements
- Project Objectives (budget, schedule, site)
- SiteDesign Requirements (building location)
- Building Requirements (purpose of use, volume/area)
- Story Requirements
- Spaces Requirements (spatial programme)
Owner requirements
- Project Objectives (budget, schedule, site)
- SiteDesign Requirements (building location)
- Building Requirements (purpose of use, volume/area)
- Story Requirements
- Spaces Requirements (spatial programme)
External Requirements
Statutory requirements
- Site-specific requirements
- Structural requirements (National Building Code)
- Safety and environmental requirements
- Building permit prerequisites
Market requirements
- Availability of capable resources (design, construction, project management)
Facilities management requirements
Other (e.g. financiers)
1.1.1 Start-up decision
Determined need for project
- Obsolete facilities
- Inadequate spaces
- (Expected) Changes in operations
- (Expected) Changes in market environment
- Market need


1.3.2 Investment Decision
- Target cost (investment cost)
- Revenue estimate (when appropriate)
- Life cycle cost
- Investment schedule
- Usability
- Functionality
- Utilisation of old structures/buildings
- Effectiveness ratios
- Realisation of requirements
- Space types and areas
- Gross area, floor area
- Area of shell
- Total volume
- Project plan (e.g. procurement method)
- Client commitments (pre-contracts)
1.3.1 Selection of Alternative
- Spatial cost estimate
- Revenue estimate (when appropriate)
- Life cycle cost
- Schedule
- Usability
- Functionality
- Architecture (use of space, aesthetics)
- Visualisation
- Positioning at the site
- Utilisation of old structures/buildings
- Energy simulation
- Effectiveness ratios
- Realisation of requirements
- Space types and areas
- Gross area, floor area
- Area of shell
- Total volume
Project organisation
Selection of designers/project team
Project schedule
Project resources
Tasks, responsibilities
Auditing, inspections
Reporting and information transfer method
Decision making methods and responsibilities
Project and quality planning
Project management systems
Information archiving
Pre-contracts
End-user Requirements
- End-user characteristics
- Work-place analysis
- Expected changes in operating environment
- Operative needs now and in the future
- Operation planning and strategy
- Needed spaces and areas
- Wanted/needed quality level
- Available funding
Alternative architectural designs
- Utilisation of existing structures/spaces
- Spatial Arc-BIM
- Site & location of building(s)
- Space types (IDs)
- Area of different spaces
- Quality-level
- Number of users/occupants
- Facade
WHEN NECESSARY:
- Structural types & systems (space requirement model)
- HVAC (space requirement model)
- Electrical space requirement model
Investment cost
Level of requirement fulfillment
Rentability/salability analysis
Price determination
Image - Visualisation
Life-cycle cost
Energy simulation
BIM of existing structures


2.3.2 Decision to Construct
- Contract price (tender)
- Cost of operation
- Life-cycle cost
- Construction schedule
- Level of requirement fulfilment
2.1.1 Early design approval
- Component-based cost estimate
- Cost of operation
- Life-cycle cost
- Buildability
- Visualisation
- Energy simulation
- Level of requirement fulfilment
- Building permit application
Domain specific BIMs of selected alternative
Building permit documentation
Analysis
Quantities
Component-based cost estimate
Level of requirement fulfillment
- Space types and areas
- Gross are
- Living area/useful area
- Rentable/saleable area
- Area of shell
- Total volume
- Functionality
- Statutory
- Update of requirements
Ratio analysis
Model checking based on pre-determined rules
Clash detection
Life-cycle cost
Visualisation
Lighting analysis
Acoustic analysis
Energy analysis
Operative analysis
2.2.1 Detailed design approval
- Resource-based cost estimate
- Cost of operation
- Life-cycle cost
- Buildability
- Energy & consumption analysis
- Indoor environment
Domain specific BIMs based on approved early design
Call for bids documentation
- BIMs
- Drawings
- Specifications
- Contract documentation
Analysis
Quantities
Resource-based cost estimate
Life-cycle cost
Visualisation
Energy analysis
Consumption analysis
Facilities maintenance analysis
Indoor environment analysis
Integrated BIM
Clash detection
Model checking based on pre-determined rules
Ratio analysis
2.2.2 Decision to call for tenders
Call for tenders
- Approved detailed BIMs & drawings
- Specifications
- Visualisations
- Quantities (list-format)
- Requirements (Schedule, Site, Statutory, Other)
- Bidding schedule & guidelines
- Bid assessment criteria
- Pre-selection criteria
- Call for tenders - letter
2.3.1 Contractor selection
- Pre-determined criteria and weighting (price + quality)
Pre-selection documentation
- Company data
- Historic performance data
- References
- Experience
Tender documentation
- Cost
- Life-cycle cost
- Alternative offers
- Quality
- Services
Tender preparation
Quantities
4D-Scheduling
Procurement analysis
Resource-based cost-estimate
Market analysis
Pricing
Preparation of tender documentation


3.1.2 Commissioning
- Realised cost
- Realised schedule
- Changes
- Acceptance inspection
- Maintenance manual
- As built-BIM
Construction BIM based on approved detailed BIM
4D scheduling (based on quantities)
Production planning (based on visualisation) and management
- Resourcing
Procurement (based on quantities & schedule)
- Materials
- Components
- Equipment & machinery
Testing
Project management
- Requirements
- Schedule
- Quality
- Clash checking
- Changes
- BIM up-dates
- Meetings
- Inspections & audits
3.1.1 Change approval
Change documentation
- Modified BIMs
- Affect on cost, schedule, life-cycle cost, operation
Handover inspection & Auditing
As-built BIMs
No defects/defects corrected
Maintenance manual
Briefing for users


4.1.2 Release of guarantees
- Guarantee inspection
- Realised cost of operation
- Requirement fulfilment
- Energy consumption
- Indoor environment
- Functionality
- Usability
4.1.1 Handover to end-users
Handover inspection
Briefing
Follow-up and reporting
Indoor environment
Energy consumption
Guarantee inspection
Adjustment of HVAC systems (summer/winter)
No defects/defects corrected
As-built BIM updated (if necessary)
Up-dates to maintenance manual

Research carried out to determine the interface between requirements management and critical decision points is reported in this working paper. First the processes and critical decision points within the AECO project lifecycle for which users require information exchange are defined. Then, detailed information needs in each critical decision point are specified. Finally, the actors sending and receiving information within the process are identified and the associated information content of BIMs is determined. Even though the process goes through multiple decision points, only critical decisions which are decisions that involve a permission from the owner to proceed are studied in more detail.

Many of the information needs during the process relate back to the project requirements. Requirements set the basis for the design. Accordingly, the results of the project must be compared with the requirements in order to define the level of requirements fulfilment. This emphasises the importance of initial requirement determination, and updating of the requirements during the process if initial requirements change. Current technologies also enable use of more complicated and automated analyses as a basis of more informed decision-making.

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