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Change management during hospital construction projects – a multiple case study

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Abstract

The healthcare facilities in Finland as in many other countries need significant investments during the next decade. The old-fashioned buildings are in many cases not able to answer the demands posed by the evolving medical technology, changes in demographics, care trends, and capacity needs, or political decision-making. However, there is clearly room for improvement with how efficiently the hospital projects are carried out to make the most out of these investments. Hospitals are perceived to have a relatively high number of changes compared to many other types of construction, even in the late project phases, and changes often have negative effects to the project efficiency. Changes are overall known as a significant factor causing cost and schedule overruns in construction projects, while they cause disturbances to the planned workflow and are a primary reason for rework.

This thesis focuses on three question related to project changes: 1) why changes are needed in hospital construction projects, 2) what effects do changes have on the different stakeholders, and 3) how changes could be managed better during the project. A multiple case study of five recent hospital construction projects from Finland, Sweden and the U.S. was conducted with semi-structured interviews.

The findings show that the procurement of medical equipment and extensive user involvement in the design are two important change sources in the hospital construction context, which have not earlier been included in more general change categorizations. Furthermore, the identified change root causes can often be linked to project complexity, mainly in the structural complexity, uncertainty, and socio-political complexity dimensions. This leads to the conclusion that changes are to some extent needed to answer the changing demands inside and outside the project, being necessary to project success. The concept of project flexibility is suggested as an approach to mitigate the negative effects of changes, by allowing for changes later during the project. The thesis has several theoretical implications: new change source categories were created to suit the hospital construction context, construction changes had not previously been linked with project complexity factors, and the use of project flexibility strategies as a change mitigation measures is a new approach compared to the dominant change avoidance. Important managerial results include the practical methods of executing flexibility in projects and the possibility of better collaboration between the owners and contractors through trust and relational project delivery methods.

Keywords Change management, Project management, Construction, Hospitals, Flexibility

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Tiivistelmä

Terveydenhuollon kiinteistöt niin Suomessa kuin ulkomailla tarvitsevat tuntuvia investointeja seuraavan vuosikymmenen aikana. Vanhanaikaiset rakennukset eivät monesti pysty vastaamaan kehittyvän terveydenhuoltoteknologian, muuttuvan väestön, hoitopolkujen ja kapasiteetin, tai poliittisten päätösten asettamiin vaatimuksiin. Sairaalaprojektien toteutuksessa on kuitenkin selviä tehostusmahdollisuuksia investointien hyödyntämiseksi parhaalla tavalla, sillä niissä on huomattu tapahtuvan enemmän muutoksia kuin muissa rakennusprojektityypeissä, jopa myöhäisissä projektin vaiheissa. Muutokset suunnitelmiin tai vaatimuksiin heikentävät usein projektin tehokkuutta ja niiden tiedetään olevan merkittävä syy projektien aikataulun ja kustannusten ylityksiin, koska ne aiheuttavat häiriöitä projektin työjärjestykseen ja ovat yksi pääsyistä työvaiheiden uudelleentyöstämiselle.

Tämä diplomityö keskittyy kolmeen muutoksiin liittyvään kysymykseen: 1) miksi muutoksia tarvitaan sairaalarakennusprojekteissa, 2) mitä vaikutuksia muutoksilla on eri sidosryhmille, ja 3) miten muutoksia voisi hallita paremmin projektin aikana. Tutkimus suoritettiin monitapaustutkimuksena, ja teemahaastatteluja tehtiin viidestä viimeaikaisesta sairaalarakennusprojektista Suomessa, Ruotsissa ja Yhdysvalloissa.

Tulokset osoittavat, että sairaalalaitteiden hankinta sekä laaja käyttäjien osallistaminen suunnittelussa ovat tärkeitä muutoksen lähteitä sairaalarakentamisen yhteydessä, eikä niitä ole aikaisemmin huomioitu yleispätevimmissä muutosluokitteluissa. Lisäksi tunnistetut muutosten juurisyyt yhdistyvät usein projektin kompleksisuuteen, pääosin rakenteellisen kompleksisuuden, epävarmuuden sekä sosiopoliittisen kompleksisuuden kautta. Tästä voidaan päätellä, että muutoksia tarvitaan tietyssä määrin vastaamaan muuttuviin vaatimuksiin projektin sisältä ja ympäristöstä, ja että muutokset ovat välttämättömiä projektin menestykselle. Projektin joustavuuden käsitettä ehdotetaan lähestymistavaksi lieventää muutosten kielteisiä vaikutuksia sallimalla muutoksia myöhemmin projektin aikana. Työllä on monia uutta teoriaa koskevia ehdotuksia: uusia muutoskategorioita luotiin sopimaan sairaalarakennuksen kontekstiin, muutoksia ei ennen ollut yhdistetty projektin kompleksisuuden osa-alueisiin, ja uutta näkökulmaa edusti myös joustavuuden käyttö muutosten vaikutuksen lieventämiseen verrattuna hallitsevaan tapaan vältellä muutoksia. Johtamissuositusten osalta merkittäviä tuloksia ovat tavat toteuttaa joustavuutta käytännössä sekä omistajan ja rakentajan välisen yhteistyön parantaminen luottamuksen ja yhteistyötä palkitsevien projektintoteutusmuotojen kautta.

Avainsanat Muutosten hallinta, Projektinhallinta, Rakentaminen, Sairaalat, Joustavuus

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Anna Särkilahti
Espoo, May 2017

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List of abbreviations

BIM	Building information modeling
BOT	Build-operate-transfer
CM	Construction manager
CT	Computed tomography
DB	Design-build
DBB	Design-bid-build
HVAC	Heating, ventilation, air conditioning
IPD	Integrated project delivery
MEP	Mechanical, electrical, plumbing
MRI	Magnetic Resonance Imaging
OR	Operating room
PET	Positron emission tomography
PFI	Private finance initiative
PPP	Public-private partnership
RFI	Request for information

1 Introduction

1.1 Background and motivation

Hospital construction is currently booming in Finland as well as in other Nordic countries. Many of the existing hospital buildings, built in the 1960s and 70s or even earlier, do not meet the standards of current or future healthcare in their spaces or operational concepts. Considering the large and growing share of healthcare sector in the economy in most developed countries, there seems to be overall a lack of investment in the healthcare infrastructure (Pauget & Wald, 2013). In Finland, hospital construction is also driven by moisture damage and related indoor air quality issues, and the infrastructure repair backlog has been growing for a long time due to a lack of sufficient investment. In many cases, it will be more economical to construct a completely new hospital than to invest in renovating the old and unsuitable spaces. However, while the construction of hospitals is picking up, the knowledge and skills needed for successfully procuring and building a hospital have in many areas been forgotten after years of inactivity in large capital investments.

The overall healthcare sector in Finland is facing large changes in the following years. The planned social and healthcare services reform starting from 2019 onwards will change the organization of healthcare services radically, which will also change how healthcare facilities are managed in Finland. Due to the uncertainty posed by this change, different regions are aiming to secure their status after the reform, which has been one reason for the large number of hospital projects started in recent years. The future model in terms of hospital care will resemble the regional system in use in Sweden, which makes it a good comparison in terms of how the healthcare reform could reflect on hospital construction.

According to The Association of Finnish Local and Regional Authorities, the investments into public hospitals in Finland between 2012–2021 will be over €3bn (Punnonen, 2013). The figure represents solely public spending, and the current economic situation with budget deficits and the growing public debt level is posing increased pressure to save money. Infrastructure investments are no exception to these cost pressures, where even small improvements in the efficiency of the projects can lead to significant financial savings. On the other hand, saving from the wrong places during a project can be extremely harmful if it decreases the quality of planning or functionality, as the construction costs only account for a few years' worth of operating costs of the facilities. The need for more flexibility, innovation and higher environmental standards in hospital construction has been recognized (Pauget & Wald, 2013).

This thesis focuses on the phenomenon of changes during the construction of a new hospital. The choice of topic was based on an observation made by construction professionals that hospital projects seem to be facing more changes than other types of construction, often during the late project phases, and leading to issues in the construction process. The changes were often seen to have a negative effect on project schedule and costs, which raised the question of how to manage them better to avoid these negative consequences. However, before any practical advice on the issue can be given, it was seen that more understanding is needed on why and how changes come about in hospital construction projects and what their broader consequences are.

Although the motivation for the study came from the industry, hospital construction has drawn academic interest, especially from the point of view of flexibility and adaptability of facilities to future needs. However, surprisingly little research exists on hospital construction from the point of view of the actual construction process. This thesis aims to contribute to this research gap. Next, the specific research problem and research questions are presented.

1.2 Research problem and research questions

Changes seem to cause more disruption and inefficiency during hospital projects than other types of construction projects. Overall, changes in construction projects have been recognized a primary cause for cost and schedule overruns as well as a source of dispute between project parties (Love & Edwards, 2004; Olawale & Sun, 2010). The purpose of this thesis is therefore to explore and propose better ways to manage changes during the construction phase of a hospital project.

Change in this thesis is defined as change to project scope, designs, contract requirements or other assumptions which have previously been considered as frozen. The point-of-view is on the relationship and agreements between the owner and the contractors, and how changes appear and are handled in that context, which in practice can be seen through the change order process. Thus, some other types of changes not related to the relationship of the contract parties are not addressed, like changes to the construction process or schedule stemming for instance from internal resourcing changes by the contractors or weather conditions.

The specific research questions (RQs) of interest are the following:

> **RQ1: What kinds of changes are typical during the construction phase of hospital construction projects and at which point? Why are changes needed?**
>
> **RQ2: How do different types of changes affect the project performance for the users, owner, and contractors?**
>
> **RQ3: How could changes be managed during the construction phase to minimize their negative effect and maximize their positive effect on the project success?**

The first two questions deal with the change causes and effects in the projects, trying to find the underlying reasons why changes happen and how they might be problematic in the project. The data collection and analysis were mainly focused on these two questions. The third question relates to the practical actions that could be taken to address the current issue with changes and represents the overarching goal of the study from a managerial point of view.

The research is focused on changes during the construction phase, which is seen to start after the detailed design phase has been finished and a contractor has been chosen for executing the released drawings. In concurrent design and construction projects, changes happening after the release of the drawings for construction are considered as construction phase changes. In addition, the research is only limited to hospital construction, which is defined as the construction of facilities primarily for centralized secondary and tertiary care by medical specialists, to distinguish from the construction of other types of healthcare facilities. Geographically, the research is limited to Finland, Sweden, and the U.S..

1.3 Research approach and structure of work

An explorative case study research design was chosen for answering the research questions as no suitable theoretical framework was found in the literature to test in an explanatory way. The goal of the study therefore was to develop a good enough understanding to be able to give managerial advice and later formulize hypotheses for further research. The main research method was semi-structured interviews in five case studies on current hospital construction projects, supported by secondary evidence from the cases. The analysis of the data was guided by a literature review on the topics of hospital construction characteristics as the context, change management in construction projects to provide background on the researched phenomenon, and project flexibility as the chosen approach towards change mitigation. These themes also provided linkages with the current research knowledge.

The thesis comprises two main parts. The first part is the literature review, which consists of three themes: overall hospital construction characteristics, construction change literature and flexibility in projects. The second part of the thesis is focused on the empirical research. First the methodology for the empirical part is presented, which is followed by the introduction of the case projects. Main research findings are presented through a cross-case analysis, where the reoccurring themes through the cases are analyzed further. In the final section, the findings are discussed and interpreted in the light of previous research and the research questions, and the limitations of the study are presented.

2 Literature review

The purpose of the literature review is to give an overview of the previous research and frame the field for this research, as well as suggest interesting points of view on the analysis that have not been thoroughly addressed in previous studies. The review is structured in the following way: First, project complexity and hospital construction characteristics are discussed to provide background to the industry and frame the research problem. In the second part, literature on changes and their effects on construction projects is presented to understand how the phenomenon has previously been studied and what kinds of research opportunities still exist. The third chapter focuses on the concept of project flexibility as well as introduces practical methods for exercising flexibility in construction. Flexibility was chosen as a novel way to approach change mitigation mechanisms, with the emphasis on those operational methods for flexibility that could help reduce the negative effects of changes. It has been recognized that contextual factors have a large impact on project planning and change management subjects (Dvir & Lechler, 2004), and thus hospital construction literature is also discussed when available.

2.1 Hospital construction projects as complex, multi-stakeholder endeavors

There are several characteristics in hospital construction which make it different from other types of construction. Challenges include changes in the overall healthcare sector, the large size and changing technical requirements of the buildings, and high level of user involvement in the design phase. These all affect how hospital projects should be managed in general and related to project changes.

Hospital construction is highly dependent on the framework conditions of the healthcare sector where it is happening, like the level of government involvement in healthcare planning and provision (Olsson & Hansen, 2010). The context of healthcare systems is changing frequently due to changes in medicine via new treatments, technology, and care processes; political decisions like healthcare service regulation, organization and funding; as well as population parameters like demographics and morbidity (Barlow & Köberle-Gaiser, 2009; de Neufville, Lee, & Scholtes, 2008; Olsson & Hansen, 2010). Barlow and Köberle-Gaiser (2009) presented the concept of different change cycles of components of a healthcare system, seen in Figure 1. The individual services, comprising of treatment protocols and care pathways are changed on a yearly basis, and technological change happens every few years in medical technology or ICT. The infrastructure, on the other hand, is built or renovated for the time span of more than thirty years.

This dynamic can be realized as a large number of changes in the use and functions of facilities during their lifespan, even during the design and construction project (Sivunen, Kajander, Kiiras, & Toivo, 2014). Kendall (2005) describedd that complex buildings such as hospitals only become whole over time and are actually never finished, and design and construction processes should reflect this incremental process. The possibility of facilities becoming obsolete already shortly after finishing them is a constant concern among hospital projects. Hospital projects tend to be large in size, and they involve a lot of technical systems and coordination (Manning & Messner, 2008). Decouvelaere, Berrard and Fabrega (2007) emphasized the need to leave the possibility to integrate new technology into the facilities until the time of opening, which means balancing between the difficult coordination task and changing demands.

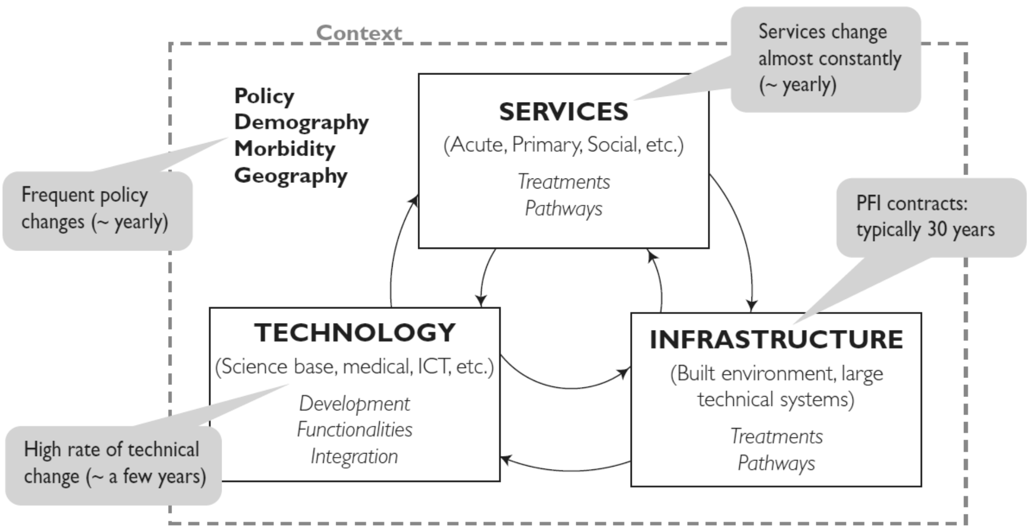

Figure 1: Key elements and dynamics of the healthcare infrastructure system (from Barlow & Köberle-Gaiser (2009))

In hospital buildings, the operational processes and the facilities are tightly interlinked. The physical design of facilities influences the efficiency of operations, life-cycle costs, as well as staff well-being. It is thus possible that the hospital will end up with a suboptimal caregiving plan due to facility constraints (Pati, Harvey, & Cason, 2008). The trends of user involvement in design and patient-centered care have brought the clinical and support staff as well as patients in the center of the operational and facility design. Olsson and Hansen (2010) noted that Norway is at the high end of the spectrum when comparing user involvement in hospital design in European countries. They attribute this to the Scandinavian management tradition with emphasize on user involvement in situations of organizational change, implying a similar culture also in Sweden and Finland.

Next, more theoretical background is given to some of the influencing contextual factors affecting hospital construction. First, the dimensions that form the concept of project complexity are presented. Project success is also discussed to form an understanding of what measures projects can be evaluated against and how these are prioritized among the project parties. Stakeholders and their roles in hospital construction are also addressed, and lastly, some attention is paid to how hospital projects are procured.

2.1.1 Project complexity

There has been a shift in recent decades away from seeing project success merely as conformance to plans but as primarily delivering customer value (Hellström & Wikström, 2005). This means that projects should not be considered as closed but dynamic and open systems, where success should also take into account the expectations of the customer. The dynamism and uncertainty stemming from the project context challenges the traditional pursuit of stability in project management (Olsson, 2006). Classical project management techniques are in many ways not suitable to deal with this kind of goal uncertainty (Williams, 1999), and "one-size-fits-all" type of approaches are not able to match the varieties of contexts where projects are carried out (Maylor, Vidgen, & Carver, 2008; Shenhar & Dvir, 1996).

Project complexity is a term traditionally used when referring to large or technologically advanced projects, but it has to be noted that project management literature has not yet agreed on a common definition of the concept. Maylor et al. (2008) highlighted that consideration has to be given to the complexity of the management task at hand, which includes foremost the subjective perception of project managers and is not just derived from the technical definition of the project. Some characteristics found common to different definitions of project complexity include the interdependency of elements, non-linear and networked causality, and dynamic and emergent behavior (Bakhshi, Ireland, & Gorod, 2016).

In attempts to operationalize the concept of project complexity, typologies of which dimensions or characteristics should be included in the concept have been suggested. *Structural complexity* represents maybe the most traditional way of perceiving complexity, and is used widely when describing different types of engineering products (Jarratt, Eckert, Caldwell, & Clarkson, 2011). Williams (1999) combined previous literature by proposing two dimensions of project complexity: structural complexity stemming from the number of elements and their interdependency, and *uncertainty* either in project goals or methods of achieving those goals. A similar conceptual model was earlier proposed by Shenhar and Dvir (1996), and their two-dimensional typology matches quite accurately the dimensions proposed by Williams (1999): Their first dimension of "system scope" is comparable to structural complexity, and the second dimension of "technological uncertainty" can be seen as a subset of uncertainty.

In later studies, further dimensions of complexity have been included in the concept. Geraldi, Maylor, & Williams (2011) added dynamics, pace, and socio-political dimensions to the previously mentioned two categories. *Dynamics* refers to changes happening in some of the other dimensions of complexity, such as "dynamic structural complexity" from changes in scope or "dynamic uncertainty" from the emergence of new technology during the project. Dynamics is thus also linked to the uncertainty dimension. *Pace* is the temporal aspect of complexity. Tight timeframes intensify other types of complexities, for example by requiring new types of processes such as concurrent design, increasing ties between project components and thus increasing the structural complexity. *Socio-political complexity* arises from stakeholders, the people who influence and carry out the project, representing how their interaction, joint sense-making process and establishment of common goals play out. It also adds more emphasis on the human dimension in project management. The different factors and examples of corresponding complexity indicators are found in Figure 2.

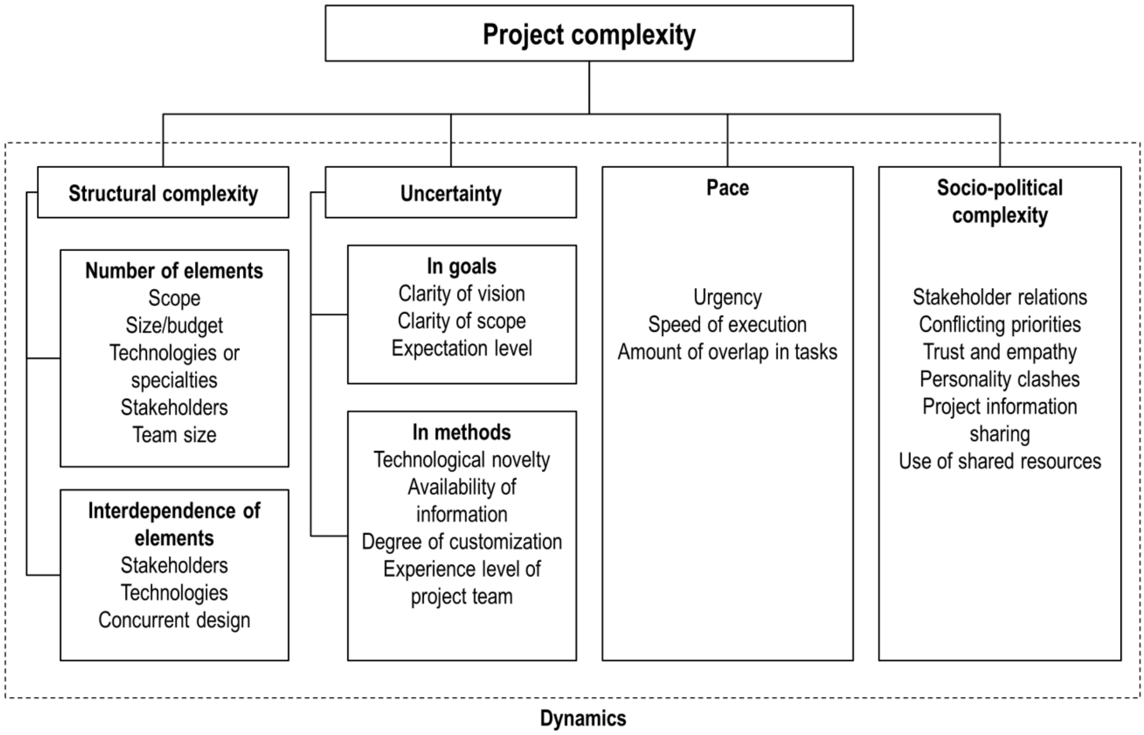

Figure 2: Project complexity dimensions and indicators according to Geraldi et al. (2011)

Other, competing typologies of project complexities exist. Bakhshi et al. (2016) developed a slightly different categorization of project complexity factors, integrating three separate views on complexity found from a systematic literature review. The seven elements in their model included project context, connectivity, diversity, emergence, project size, autonomy and belonging. Maylor et al. (2008) presented the managerial complexity dimensions of mission, organization, delivery, stakeholders, and team. The latter division presents complexities through the project components or functionalities it concerns, whereas the others focus more on different types of complexities that can affect many parts in the project. Despite the different categorizations, a majority of the lower-level factors in both are the same as proposed for example in Geraldi et al. (2011).

The concept of complexity is not always used when discussing related issues. For example Love et al. (2002) used the concepts of attended and unattended dynamics from system dynamics literature, dividing the latter to internal and external uncertainties. Clearly these are complementary and overlapping concepts to some of the complexity features discussed here. Overall, the dynamic qualities of complexity have gained a lot of attention lately (Maylor et al., 2008). Williams (1999) already noted that the suggested types of complexities also feed on each other: if there is uncertainty in the requirements and they are not frozen or have to be changed later on, this can have unexpected results that lead to cross-impacts between tasks, feedback loops and rework. Changes and rework might add more structural complexity, so in time the complexity of the project would increase. Most typologies acknowledge that the complexity dimensions proposed are not independent but impact each other (e.g. Geraldi et al., 2011), which implies that the understanding about the complexity construct in projects is still insufficient.

As it is possible to see from the number of competing typologies of complexity dimensions, the view on complexity will change and be complemented in the future. In this thesis, the division from Geraldi et al. (2011) presented in Figure 2 is used for operationalizing the concept in a way that helps interpreting the empirical evidence. Hospital construction projects are typically described as complex projects, but the linkage to complexity literature has not thoroughly been made to evaluate how the different complexity factors affect hospital construction or specifically changes in them. By comparing the hospital construction characteristics presented earlier with these complexity dimensions, it can be noted that many of the typical hospital project characteristics are possible sources of project complexity. However, the level of complexity can vary according to the unique project circumstances.

2.1.2 Project success

To answer questions related to project success, it is necessary to first clear out what is meant by it. Here, a distinction between two components of project success is made. Firstly, *project management success* is used when referring to the success of the project process, and for example how the traditional cost, schedule, and quality goals are met. Project management success is thus an internal measure, and is mainly concerned with conformance to the project plans. *Product success* on the other hand relates to the longer term effects that the final product has in fulfilling its purpose, and could be seen as an external measure of success. (Baccarini, 1999)

The two success dimensions are also linked to project efficiency and effectiveness. While *efficiency* is a concern for achieving project management success, *effectiveness* contributes to the ultimate product success. This division explains why there might exist a disparity between different stakeholders on how flexibility and design changes are perceived. The project owner or end user are more likely to see changes as positive and contributing to the project goal and purpose through promoting better effectiveness. However, on the execution side where most of the costs and also responsibility for project management success lie, the view on changes is much more negative as they compromise the efficiency of the implementation and reaching their contractual obligations. (Olsson, 2006)

The division of interests is of course a simplification, because most owners are also concerned about project efficiency issues while cost, schedule and quality pose significant risks to them too. Baccarini (1999) made an important observation about the hierarchy of the project objectives. Product success is a higher-level and thus ultimately more important success measure as it defines how the project will contribute to the strategic goals of the organization and fulfilling user needs. Product management success which deals with the process of turning inputs to outputs efficiently, with quality, and in the agreed limits of time and budget, is usually of interest during the project but loses significance shortly afterwards. However, during the project, the internal project management success measures can take over and lead to sub-optimal decisions from product success point of view, if the project teams both from client and contractor sides are evaluated with the project management measures (Andersen, Olsson, Onsoyen, & Spjelkavik, 2011).

Figure 3 depicts this hierarchy and sets examples of the different levels of project objectives in the domain of hospital construction. When success is defined this way, the same project can be a product success but a project management failure or vice versa. Balancing between what makes the product better but considering at the same time the effects to project management success is at the core of the change management dilemma in hospitals as in other complex projects.

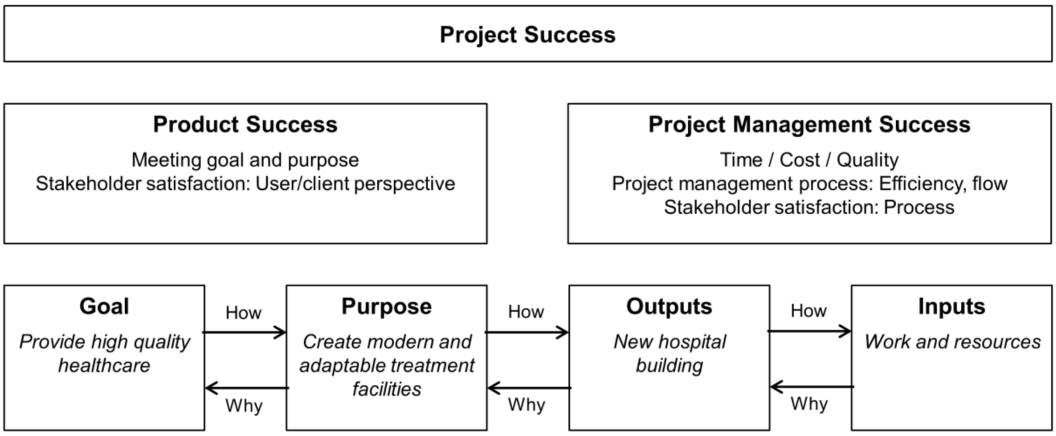

Figure 3: Definition of project success and the relationship of success components to project objectives (adapted from Baccarini (1999))

2.1.3 Stakeholders in hospital construction projects

Stakeholders that are of interest to project management purposes are those entities who are able to affect the project progress or outcomes (Ward & Chapman, 2008). *Internal stakeholders* include the owner of the project as well as all other parties with contractual relationships to them. The temporary organization created by the internal stakeholders, including the relationships within and between the different internal stakeholder groups and individuals can be called a *project network* (Pauget & Wald, 2013). External stakeholders such as regulators and local communities can influence the project from outside (Ward & Chapman, 2008).

The most central players in a hospital construction project are the owner of the hospital (typically either alone or with the help of consultants) acting as the developer of the project, designers responsible turning requirements into a functioning design, and the general contractor as the primary network coordinator during construction, responsible for managing the efforts of suppliers and subcontractors. A special characteristic of hospital projects compared to other types of construction is that users, i.e. the hospital staff, have traditionally been involved extensively in the design process. Thus, they could be seen as an internal stakeholder group as well, being a part of or at least contractually dependent on the owner organization, however they do not necessarily have a financial stake in the project. In recent years, the introduction of patient-centered care has brought the patients to the core of the design. Still, the patient view is typically represented indirectly through the work of associations or expert opinions, and patients themselves could be considered more as an external stakeholder group during the project.

The inherent complexity of hospital construction projects leads to increasing needs of information sharing and coordination between the stakeholders (Pauget & Wald, 2013). In addition, stakeholders are a major source of project complexity themselves (Maylor et al., 2008). The number of different actors in the project network and their heterogeneity in terms of culture, knowledge and tasks increase the project complexity in the structural and socio-political complexity dimensions (Geraldi et al., 2011). Stakeholders in the project network take different roles, depending on the contract set-up and how the formal project organization is formed, but also outside their "set" roles. In an article about a French hospital construction project by Pauget and Wald (2013), three different types of network roles were recognized: coordinator, gatekeeper, and mediator. The coordinators usually have a central role in the network and organize the action between different project parties. Gatekeepers regulate the information flow between the project and the external environment. Mediators work as translators between the differing culture and values of the project actors. Thinking about stakeholders through these roles could lead to important insights in terms of project success and change management. For example, a lack of certain roles like mediators between the users and the designers could lead to adverse effects on the project through late design changes. In addition, some individuals can prove to be more influential than their formal role would suggest. An example of such stakeholders could be a top surgeon, who may have a disproportionally large influence on the design of the facilities.

2.1.4 Typical project delivery methods and contract types for hospitals

The ultimate goal of providing better healthcare and the servitization trend in the construction industry has led to a situation where rather than procuring a complex building, hospital owners are instead faced with the task of procuring complex performance (Caldwell, Roehrich, & Davies, 2009). The traditional project delivery methods have been challenged by new models that question the division of the construction process to distinct phases of design, construction, and operations. Trends have been towards more integrated forms of project delivery, where contractors provide services, knowledge and support to the client in addition to the actual construction activities (Lahdenperä, 2012).

Different project delivery methods, funding models, and contract types have varying effects on the distribution of risk and reward, the communication methods used, and the involvement and roles of project stakeholders in different phases. Drivers including project schedule, flexibility and preconstruction service needs, as well as the owner's skill level and risk preferences determine which project delivery methods would be most suitable (Gordon, 1994).

As mentioned, formal contract ties have a strong influence on how the project network forms and which players will take a central role in managing the project (Pauget & Wald, 2013). Especially in projects with the client from the public sector written contracts are seen as very important, and a lot of time is put into perfecting the paper work due to pressures of transparency and politics (Caldwell et al., 2009). Contracts are a means to reduce the uncertainty between the client and contractor by laying out the responsibilities of the parties. A lot of uncertainty might remain regardless of a carefully written contract, due to asymmetric information and unforeseen circumstances. Possible problems include intentionally or unintentionally biased estimates about project budget or schedule, and principal-agent issues (Ward & Chapman, 2008). In addition, a large part of the collaboration, such as informal communication needed to successfully deliver a project, cannot be specified in the contract, but rather is dependent on the personal relationships between the individuals in the project (Caldwell et al., 2009).

The specific project delivery and contract types differ in their emphasis between formal and informal control mechanisms that are used for supervising the project delivery: formal mechanisms rely on contract clauses whereas informal mechanisms are based on mutual trust and commitment (Caldwell et al., 2009). Eriksson and Laan (2007) divided control mechanisms into three distinct categories: output or price focus, authority and process control focus, and trust and self-control focus. The two first control categories rely more on formal control mechanisms and the last to informal mechanisms. Other project characteristics associated with the distinct categories include the way the bid is evaluated, the means of specifying the solution to be executed, compensation models, collaboration, and performance evaluation. The three different categories of project control mechanisms can be seen in Table 1, with examples of project delivery types that most correspond to the specific control mechanisms.

There is emerging literature on how the selected project delivery type can affect the project performance. Suprapto et al. (2016) found that partnering and alliancing contracts seem to perform better on average, with better relational attitudes and teamworking quality as the explaining mechanisms. It is not given that projects with relational project delivery methods would always perform better than other methods, but it might be easier to establish a better owner-contractor relationship in that setting than with other set-ups. Next, the most typical project delivery methods and associated contract types used in hospital projects are introduced more specifically. They vary substantially in terms of the differentiation of design and construction activities, risk allocation, project organization and other details.

Table 1: Procurement effects of control types and governance mechanisms (adapted from Eriksson and Laan (2007), author additions marked with *)

Buying stage	Price focus through output control	Authority focus through process control	Trust focus through social control
Specification	Spec. by client	Spec. by contractor	Joint spec.
Bid invitation	Open bid procedure	Limited bid invitation	Limited bid invitation
Bid evaluation	Focus on tender price	Focus on authority-based soft parameters	Focus on trust-based soft parameters
Contract formalization	Formal, comprehensive contracts	Formal, comprehensive contracts	Informal and incomplete contracts
Type of compensation	Fixed price	Reimbursements	Including incentives
Collaborative tools	Low usage	Low usage	High usage
Performance evaluation	Output control by client	Process control by client	Self-control by contractor
Division between design and construction stages*	Strict division	Loose division	No division
Project delivery methods*	DBB	CM, DB, (BOT)	Alliancing, Project partnering, IPD

Design-bid-build (DBB) and multiple prime

A design-bid-build type of delivery is the most traditional way of procuring hospitals and is still used quite frequently for example in the Nordics, especially in the public sector, as it ideally has many advantages for the owner. They have control over the design and are able to fix the total price before the start of construction. It is most suitable in projects where the goal is clearly defined, the design is complete, and changes are unlikely to happen during construction (Gordon, 1994), as the procurement method requires very comprehensive contracts. Typically, it is combined with a lump sum contract, where the contractor carries most of the risks in the project in terms of schedule or budget overruns (Ibbs, Kwak, Ng, & Odabasi, 2003). The selection of the contractors is in most cases done through the lowest bid, focusing on the tender price.

Multiple prime is a similar contracting type but with the difference that all the trade contractors are under separate contracts with the owner of the project, providing each specific parts of the project (Gordon, 1994). The trade's work is either coordinated by the owner or subordinated to the general contractor. It is a more fragmented project type compared to the original DBB setting.

While lump-sum contracts assume a higher level of certainty about the project scope, disputes about the original scope and the effect of change orders and additional work to the construction are typical in these types of projects. Lack of teamwork and an adversarial relationship between the design and construction parties are frequent problems, and there is little incentive for the contractor to look for cost savings for the owner (Gordon, 1994).

Construction Manager (CM)

The construction manager contract appoints an entity to work as the project manager and consultant for the owner, typically providing preconstruction services in the design phase (Mesa, Molenaar, & Alarcón, 2016). In the construction phase, they usually handle to role of the general contractor, contracting and coordinating the work of subcontractors. A CM contractor can also be used in case of multiple prime contracts as the coordinator of work if the owner does not have the resources to coordinate the work themselves (Al Khalil, 2002).

A CM type contract is typically procured as a cost-plus contract, where the contractor is reimbursed for all variable costs and either a fixed amount or a percentage-based fee to cover their margin and fixed costs. Guaranteed maximum price (GMP) is a way of limiting the owner risks in a cost-plus contract by setting the maximum amount they will have to pay for the project (Gordon, 1994), where the CM is responsible for costs above the GMP. The role of the CM should be an advocate for the owner, and incentives are in place for them to limit the costs and staying under the GMP. However, the procurement relationship still relies heavily on comprehensive contracts.

Design-build (DB)

In a design-build (DB) contract, the general contractor is also responsible for at least a portion of the design work. This includes gathering a team of designers and subcontractors to conduct the work (Ibbs et al., 2003). As the contract scope might not be clear at the stage when a contractor is chosen, the selection method might be at least partly qualifications-based, a so called best-value method, taking into account qualitative criteria like experience, plans for executing the project, track record, and team member credentials in addition to price (Mesa et al., 2016), named “authority-based soft criteria” by Eriksson and Laan (2007). Both lump sum or cost-plus contracts with GMP can be used with DB.

In a design-build setting, the design and construction activities can be conducted concurrently, decreasing project duration, and the design can be detailed much later. Early involvement of the contractor allows constructability issues to be addressed in the design (Gordon, 1994). The client is usually more involved during the whole construction project because their input is needed for finalizing the design and ensuring that the project will be executed to their needs by monitoring the delivery process of the DB contractor. The client might, however, have a more limited influence on the design decisions under a DB contract than under contracts with separate design and construction parties (Al Khalil, 2002).

Alliancing, project partnering and integrated project delivery (IPD)

Alliancing and project partnering are relatively recent developments in the procurement of large infrastructure projects. Integrated project delivery (IPD) was initially developed for the purposes of large scale construction projects to help the project parties together to cut waste and manage costs (Ilozor & Kelly, 2012), and it has been applied most in building construction and especially in healthcare projects. All three belong under the concept of *relational project* *delivery methods*, which emphasize trust and informal control mechanisms in the project as opposed to the typical transactional view. As these contracting methods are constantly evolving, their definitions seem to differ between individual arrangements. The terms of partnering and alliancing are sometimes used interchangeably, and while all three methods are preferred in different geographical areas, they do also adopt practices from each other. (Lahdenperä, 2012)

Similar practical arrangements are used in all the different relational contraction methods. Cooperative and open working culture, early involvement of key players, shared risks and rewards through a multi-party agreement, an emphasis on team building and planning activities as well as team co-location are features more or less related to all of the relational project types with some different focus areas (Lahdenperä, 2012). For example IPD emphasizes the early involvement of key contractors and suppliers, which helps them contribute to the design choice while gathering the whole team to a "Big Room" to ease the communication (Ilozor & Kelly, 2012). In terms of contracts used, it could be stated that project alliancing goes the furthest in integrating different organizations and their goals under one contract and team while project partnering is based on more conservative and traditional contracting methods with the addition of extra partnering clauses (Lahdenperä, 2012). IPD is less precise in its definitions, but could be seen as falling somewhere between the other two, emphasizing more the informal integration than the exact project form. Relational project delivery methods need to use qualifications-based tendering while the parties will form the target price later together.

Build-operate-transfer (BOT) and public-private partnerships (PPP)

In a build-operate-transfer contract, the funding, design, construction, and operating of the facilities have all been combined under one contract. In public hospital construction in the UK, the dominant project delivery method has been the Private Finance Initiative (PFI), which is a form of a public-private partnership (PPP). A PPP contract involves a consortium of private-sector partners that makes a long-term contract with the hospital trust to provide the infrastructure and related services in exchange for regular payments. Typical contract lengths are for around thirty years, after which the ownership of the facilities will be transferred back to the client.

The purpose of these contracts has mainly been to avoid large, one-off investments in the public sector and to shift some risk of the construction and operating costs from the public sector to the contractor. Other benefits aimed for have been better communication and transparency as well as increased innovativeness compared to traditional contracts (Barlow & Köberle-Gaiser, 2009). It seems, however, that at least the PFI model of PPP's has not been able to deliver all the benefits it was supposed to. In a hospital project under PFI there have been reports of a lot of variations to the contract in very late phases of the project or even during early use (Caldwell et al., 2009), and the projects have not actually reached the desired innovation level in terms of adaptability of the facilities (Barlow & Köberle-Gaiser, 2009). One issue with the project type has been that there has not really been a "systems integrator", a party that would see the project and its different stakeholders as one entity (Barlow & Köberle-Gaiser, 2009; Caldwell et al., 2009), and the multi-layered management structure involved has complicated the communication between project parties.

2.2 Changes and their effects in complex construction projects

Multiple different types of changes happen all the time in construction: the schedule is modified, there might be changes to the design, the work cannot be done in a certain way because of unexpected circumstances, a subcontractor is behind in their work, which influences the other contractors, and the list could go on. This section introduces how changes have been approached in project and construction literature. It includes how changes are perceived and categorized, what causes changes to happen, what kinds of effects they have, and how these effects are mitigated.

2.2.1 Different types of changes during construction projects

There are various ways to define and classify changes in projects. Dvir and Lechler (2004) divided project changes into two categories: goal changes and plan changes. *Goal changes* are related to the project end goals and customer requirements, the "what" of the project, while *plan changes* are changes to the process of reaching those goals or the "how", which can result from unexpected environmental factors like poor weather or delay in deliveries. Therefore, goal changes are clearly linked to product success and plan changes to project management success. It has also been noted that goal changes usually lead to plan changes through which they are implemented. Other types of descriptive categorizations of changes are to emergent or anticipated, radical or gradual, elective or required (Sun, Fleming, Senaratne, Motawa, & Yeoh, 2006), proactive or reactive (Motawa, Anumba, Lee, & Peña-Mora, 2007), or are based on the timing of the change during design development or construction.

One clear type of change when talking about physical products like buildings is *design change*, which has been frequently used in construction context. Siddiqi et al. (2011) presented it as a change to something in the design that had been considered completed or frozen. Akinsola et al. (1997) used the term variation to mean those modifications or changes to design that happen after signing the contract. This is a practical way of measuring changes in design-bid-build projects, where the design and construction activities have been divided to separate phases. In other types of projects with a less clear-cut contract form, design sign-offs or even assumptions of the final design could work as the basis against which the design change is happening. The idea of changes after the release of drawings or start of production coincides with the view of what constitutes an "engineering change" according to Jarratt et al. (2011).

A common and important finding from these definitions is that for a change to happen, there must have been some kind of earlier released design to make the distinction between a design iteration and a design change (Siddiqi et al., 2011). Not all research papers however use this kind of separation between design and other types of change (e.g. Dvir & Lechler, 2004; Hanna, Camlic, Peterson, & Nordheim, 2002). Mejlænder-Larsen (2017) included also process changes by defining change as any "unplanned, out-of-sequence design development or alteration to execution method/sequence". Plan changes according to Dvir and Lechler (2004) can be seen as any adjustment to the budget, sequence, schedule or other parts of the project plan. The problem with these extremely broad definitions is that on a very low level of examination, the number of changes becomes very high, as plan changes are a natural and continuous part of construction. Defining the baseline level relative to which changes are evaluated and analyzing them in a meaningful way thus becomes very difficult.

Based on searches on change literature in hospital construction, there seems to be a lot of focus on how the initial design process preceding construction could be executed more efficiently and how to minimize unnecessary iterations due to changes in requirements (e.g. Feng & Tommelein, 2009; Sivunen et al., 2014). The design process is, however, significantly different from the construction process as it contains such a significant number of coupled tasks that feed information to each other, while construction usually has more sequential dependencies but also costs of rework are higher. Changes in the later phases of a construction project have been reported having a larger impact on productivity than if happening in earlier phases (Ibbs, 1997). Thus, there is a significant difference between the effects of a "pre-fixity" or design development change and a "post-fixity" change during construction (Motawa et al., 2007), and it is relevant to separately study changes happening after the construction has already started, when they have a direct effect to the construction process. For example, Cox et al. (1999) researched changes that occurred after the construction contract award when the contractors were already involved in the project. These types of changes affecting the contractual relationship between the client and the contractors are relatively easy to recognize as projects have formal processes to approve and keep track of changes for compliance and contract enforcement reasons.

2.2.2 Change orders and change management processes

Change orders (also called change notices or variation orders) are official documents that are used for implementing changes to the initial contract scope and design in construction projects. When a change order is accepted, the new design will become a part of the project scope. As such, they are important documents to reinforce the initial contract in almost all project delivery forms and a tool to manage the design over time. Change orders are a tangible representation of an otherwise vague concept of change in construction projects, and project teams systematically collect a database of certain attributes of these types of changes like their cost. For these reasons, change orders have been the focus of analysis in many research papers concerning construction changes (e.g. Cox et al., 1999; Siddiqi et al., 2011). In addition to the contractual meaning, change orders and requests for information (RFIs) work as communication tools, sometimes referred to as boundary objects, a common language between different stakeholders for evaluating change effects and a basis for client decisions of whether to accept or deny the change (Shipton, Hughes, & Tutt, 2014).

Change orders are strongly linked to the formal change management process in place in all construction projects. Typical change order process models contain similar stages of identification, evaluation, approval, implementation and review (Ibbs, Wong, & Kwak, 2001; Mejlænder-Larsen, 2017). The evaluation phase where the estimated costs and benefits of the change are weighted against each other has been highlighted in these sources. However, in practice, there have been great difficulties in determining change impacts beforehand. Increased use of IT tools and building information modeling (BIM) to assist in the change management processes will help to automate and identify downstream effects has been suggested for more accurate evaluation of changes (Mejlænder-Larsen, 2017).

Shipton et al. (2014) observed in their ethnographic study of a hospital project in the UK that the emphasis in the change order process was mostly on proving the compliance and accountability to formal rules and less on reflecting on the content or necessity of the change, which should be an essential part of the change management processes. The contractor team in the study showed a lack of interest on implications of change outside of direct cost impacts that they are obliged to report to the client as a part of the formal change management procedure. This highlights a larger problem among the industry, as change orders processed without an understanding of their purpose seem like a non-value adding but compulsory part of a project for the contractors. It also explains the traditional emphasis of the literature to minimize and control changes.

The review or learning phase of the change management processes has sometimes been overlooked, although it could be valuable information for developing the other steps of the change management process. Senaratne and Sexton (2009) researched how knowledge about unexpected change situations is captured and shared after the event. They found that knowledge about the change events stays mainly as tacit knowledge among the team members and is shared through socialization activities rather than explicitly codified and stored. As a result, knowledge is mainly internalized inside the project team and carried with the individuals to the next projects. Their findings challenge the typical knowledge sharing practices through IT systems and emphasize more support to softer strategies through social interaction. IT-based change tracking could still enable a more thorough analysis of past data and root cause identification (Cox et al., 1999), in addition to the project members having more knowledge and a proactive approach to changes in following projects (Ibbs et al., 2001).

2.2.3 Classification of change causes

As changes have been found as a problematic area in construction projects, their causes have been extensively studied. The goal of finding change causes is typically to predict, proactively manage, and prevent changes from happening (Sun & Meng, 2009; Zhao, Lv, Zuo, & Zillante, 2010). The most used methods for researching change causes have been surveys, project record research, and case studies, all having their own strengths (Sun & Meng, 2009).

Change causes can be dealt with on very different levels: while survey type research covers a larger set of projects and causes, they are rarely capable of providing more in-depth explanations apart from a sorted list of the found causes. For example, Ibbs (1997) used the division to design errors and omissions, design changes, and external causes. On the other hand, case studies or studies on project records are typically limited to a few projects, and thus do not provide a comprehensive set of causes but could potentially include some more in-depth analysis. For instance, Cox et al. (1999) listed designer omissions in tender documents, coordination defects, shop drawing coordination, change of client requirements or new information on site conditions to be the most mentioned among various other change reasons for the three case studies on different types of construction projects. No further commonalities in change causes could be found between the cases in this small sample, highlighting the difficulty of comparing and drawing conclusions between different project contexts in case studies. Additionally, there was no attempt to make root cause analysis or categorize the changes. By means of researching project records, Siddiqi et al. (2011) organized change orders to different categories based on the system or subsystem in question, and plotted information about them by timing, cost and initiator in their case study from an oil and gas sector project. The data was then used to recognize some change "hotspots", either from different technical fields or temporally during the project, but due to the single case study research method, the results lack generalizability to other projects and especially to other project types.

What are perceived as the most influential change causes in terms of frequency and effects tend to vary between different studies. Hsieh, Lu, and Wu (2004) contributed most changes to problems in design and planning activities, such as mistakes and omissions, among the researched building and civil construction projects in Taiwan, while Burati Jr., Farrington, and Ledbetter (1992) found design changes based on technical advancement, operational process changes in the use of building, and client-initiated changes to be more significant when studying changes with data from 9 industrial construction projects. In their literature review, Sun and Meng (2009) consolidated previous research findings on change causes into five cause categories: project-related, client-related, design-related, and contractor-related causes, and external factors. They introduced their own three-level, generic taxonomy with slightly different categorization. The taxonomy presented is as follows (examples of factors in brackets):

Project external causes affecting the project from outside are:

- Environmental factors (conservation restrictions, weather and geological conditions)
- Political factors (government policies and planning permissions)
- Social factors (demographic changes, skill shortages and neighboring communities)
- Economic factors (economic cycle, inflation and market situation)
- Technological factors (new materials, construction methods and technological complexity)

Project internal causes relate to the specific project and are the following:

- Client generated (requirement change, funding, decision making)
- Design consultant generated (incomplete documentation, errors and omissions)
- Contractor/subcontractor generated (poor plan/schedule, delays, productivity issues)
- Others (poor communication, team instability, inappropriate organizational structure)

Organizational causes, which can be interpreted as embedded in the above-mentioned stakeholders are:

- Process related (business strategy and procedures)
- People related (competence, skills, culture and ethics)
- Technology related (IT and communication systems, technical support)

When Zhao et al. (2010) modelled change effects, they also made assumptions about the underlying change root causes, naming them non-activity-based factors. One factor could have effects on creating multiple actual change causes which then subsequently affect one or multiple activities. They did not themselves try to identify those non-activity-based factors contributing to the change causes, and it is unclear whether there even exists a general set of factors suitable to be evaluated in different types of construction projects. One possible hindrance in developing an overarching change cause typology or model are the specific contextual factors present in different types of projects, which might call for more specific tools to produce useful findings in practice. The need to empirically study influencing factors and change causes further, especially from a social perspective, has been recognized also in other studies (Dvir & Lechler, 2004; Sun et al., 2006). To really understand change root causes, it is important to also consider the people, their motives and the decision process influencing changes. It has also been noted that in reality a single change can stem from a variety of factors, direct or indirect, and thus any simplified categorization will lack this complexity (Sun & Meng, 2009).

2.2.4 Change effects

Change orders are regarded as the most common reason for disruption and delay in large and complex construction projects. While change orders used to be a profitable business for construction companies, the true costs of them in a complex environment might be very hard to estimate. Contingencies are left in case of disruptions and delays to the project budgets and schedules, but these are often underestimated. One reason for this are the feedback dynamics which refers to a change in one task having an impact on other tasks or the tasks of subcontractors, as well as the unpredictable combined effects of multiple changes and changes to come. Even small individual changes can incrementally build up and have unforeseen combined effects. The effects can many times reveal themselves only much later from the initial change, making it hard for either the contractor or the client to point out the initial reason for the delay. (Eden, Williams, Ackermann, & Howick, 2000)

The discussion on changes is typically combined with several other themes in construction such as rework, time and cost overruns, and there seems to be a consensus about what negative effects changes can cause in a project. Love and Edwards (2004) determined client-initiated changes as the most significant cause for rework in building construction, and that they have a negative effect on productivity and performance, and create a source of conflict. Olawale and Sun (2010) found that design changes were estimated in a survey of construction professionals to be the most important reason for difficulty in time and cost control in construction projects. Cox et al. (1999) estimated that in their researched case studies changes accounted for an increase of 5–8% of the project cost, and those projects were all considered to be well-managed and successful, and not thus reflecting the reality of typical projects.

It has been recognized that the absolute cost of changes increases with project size and complexity (Akinsola et al., 1997), which can be intuitively understood. Hanna et al. (2002) researched factors that would imply that the project is “impacted by change orders”, which mixed independent explanatory variables like the size of the project and the number and value of change orders with causal effects like longer processing time of change orders, overtime, absenteeism and staff turnover, and higher manpower ratios suggesting worse productivity in the project. Human factors like demotivation and lack of productivity could be easily forgotten if change effects are only calculated with mechanistic tools like the critical path method (Eden et al., 2000). In addition to the often mentioned time, cost and productivity effects, Sun and Meng (2009) recognized also risk-related and other effects in their comprehensive literature review. The second order effects leading to further disruption as well as the loss of schedule buffers increase project risk significantly. Other effects combined a set of miscellaneous, difficult to quantify effects such as quality, reputation, disputes, and a loss of morale.

The dynamic nature of changes, including second and higher order effects, has been widely recognized among researchers, and the suggested solution to include them has usually been system dynamics -modeling which can take feedback loops into account (Love et al., 2002; Motawa et al., 2007; Williams, 1999). Figure 4 presents an example of the possible feedback loops starting when there is a need to accelerate the project in case of a disruption. Vicious circles, where the attempt to accelerate leads to more delays, can be traced back to the lower productivity levels of employees and unforeseen influences between tasks on and off the project critical path, such as resource dependencies (Eden et al., 2000). Zhao et al. (2010) created a modelling technique using an activity-based design structure matrix that describes the interdependencies between different construction activities as well as external influences to the activities to model change effects. Motawa et al. (2007) used a fuzzy logic system to predict the stability meaning the likelihood of changes of different construction tasks, and took this information to a dynamic model of the iterative cycles that changes cause. The problem with these types of simulation models seems to be that the needed parameters are to a large extent project-dependent which reduces the practical usefulness of the models without extensive testing. As such, the systemic models serve rather as intellectual tools for understanding the complexities and interrelationships between different factors than automated change effect prediction methods. All systems models do not try to quantify the different effects but visualize the system and found influences, like Love et al. (2002) did in their causal loop model of a project management system or Isaac and Navon (2013) in their graph-based model.

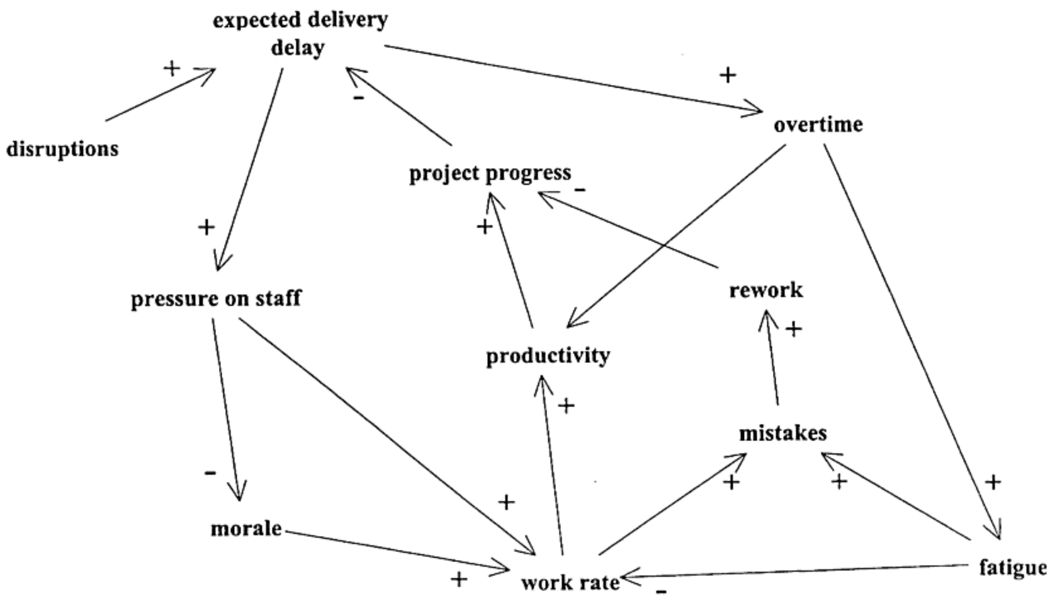

Figure 4: Influence diagram showing some of the feedback loops deriving from managerial action taken in response to disruptions (from Eden et al. (2000))

An interesting perspective to the change effect literature is to study what happens if changes are not implemented during the project. Andersen et al. (2011) saw that changes after the official project end are typical in almost all building projects, and that a tighter schedule and budget might feed on incentives to shortsightedly postpone changes that would have actually been less costly and disturbing to implement already during the project. Also in cases where some functionality had been removed for cost reasons during the project, it typically needed to be added back after the project to sufficiently reach the project goal, showing a similar tendency to sub-optimize. Motawa et al. (2007) also paid attention to what happens to change orders that are rejected during the project. Some of them are rejected permanently, but others can remain in the background as latent changes that could surface later, for example as post-project changes. The human factor in initiating, approving and implementing changes has overall been mentioned as an area of further exploration in change analyses (Siddiqi et al., 2011).

As can be seen from the presented research results, there is a lack of consideration of the positive effects of changes in the literature, and evaluation can be biased towards short term, often negative effects. The dominant approach in researching design changes during construction seems to focus mainly on negative effects of changes which seems to be the traditional attitude of the efficiency-oriented contractor side (Shipton et al., 2014). Even if the positive sides would be briefly mentioned (e.g. Dvir & Lechler, 2004), the focus of the research quickly turns to the negative. As Andersen et al. (2011) pointed out, the positive effect appears mainly through better project deliverables, when they better fulfil the project goal and purpose. The strong negative bias shows, for example, in the work of Ibbs et al. (2001) where they suggested going forward with elective changes only if the perceived benefits seem to overweight the cost very significantly. This could be sound advice for the contractors that usually carry most of the risks of delay and disruption, while many clients are skeptical about their claims for more compensation with costs and time. Often clients can, for example, demand scope increases without a corresponding increase in project time, and few contractors want to jeopardize the client relationship by asking for too much (Eden et al., 2000). To conclude, both clients and contractors would benefit from better understanding of both the negative and positive sides of design changes to find the balance in implementing the right changes. Addressing changes in a timely manner would also be less disruptive and costly for projects as a whole (Ibbs, 1997).

2.2.5 Mitigation of changes

Two main strategies have been suggested to manage changes, either 1) try to avoid or prevent them or 2) try to mitigate their negative impact to project efficiency (Olsson, 2006). Balancing between these strategies returns to the difference between plan and goal changes: goal changes can be weighed up against the pros and cons before taking action, with the possibility to reject changes or negotiate their content, while plan changes, as they appear, just have to be taken into account and dealt with as efficiently as possible (Dvir & Lechler, 2004). In the study by Dvir and Lechler (2004), better quality of planning was statistically significant only for reducing goal changes. The third point of interest in the literature is the evaluation of change effects of these goal changes beforehand. As goal changes can also be seen as positive to the project success through the improvement of the end product, there should be a way to estimate the reduction in efficiency and rise in effectiveness as well as a better way to deal with the issue of who is responsible for the losses in efficiency (Olsson, 2006).

As already mentioned, many of the articles concentrating on change or rework causes name the goal to be subsequently able to prevent some of the changes from happening (Hanna et al., 2002; Love & Edwards, 2004), implying that many changes would be in fact avoidable. Andersen et al. (2011) suggested better engineering, user involvement for accurately capturing requirements, and flexible design and execution model for reducing changes occurring after the project, but the same advice could apply to changes already during construction. Other general advice has been to freeze the design as early as possible, but being at the same time cautious that it does not lead to second thoughts among unexperienced clients or be in conflict with achieving client requirements (Dvir & Lechler, 2004; Love & Edwards, 2004).

Other articles like Isaac and Navon (2013) presented ways of better predicting change effects for more accurate evaluation of changes before implementation. Sun et al. (2006) prototyped a toolkit for predicting changes as well as assisting with workflow rescheduling after changes happen, but they notice that the systems would need a lot of manual input and are not yet integrated enough to be used in practice. Olawale and Sun (2010) constructed a list of 18 mitigation measures towards design changes, but it is more of a checklist for setting up an efficient change management process rather practically mitigating the effects of changes. Complexity is addressed as a separate issue in their paper, adding another 20 measures to deal with project complexities. Some of those measures are also suitable for change mitigation purposes, such as allocating enough resources to deal with complexity, hiring a project manager with experience on the type of complexity and using 4D modeling. While many projects possess dynamic and complex features, continuous control mechanisms are suggested by Love et al. (2002) for preventing the unattended negative dynamics of changes to escalate.

In conclusion, most mitigation efforts concentrate on preventing changes by better engineering and planning, subsequently freezing the design earlier, or predicting where most changes could happen and creating strategies for avoiding them. After a possible change emerges, the focus is on determining the effects as accurately as possible in order to make a decision if it should be implemented. Sun and Meng (2009) stated that although a lot of literature on construction project change exists, it tends to be repetitive and not build upon the previous research. There has not been a lot of practical implementation and empirical testing done based on the results of the existing research, which seems to be the case especially with the models and tool prototypes that have been developed. The change management process literature outlines the desired decision process steps needed but there is little advice on how to make it easier then to implement the needed changes in the project, not to mention the benefits of preparing for certain types of changes beforehand. In the next section, methods to enable projects to be more flexible towards changes are explored. Flexibility has not been previously connected with construction changes, but this thesis approaches it as a very potential remedy against them.

2.3 Flexibility as a means to manage changes in construction projects

Flexibility is a term used to describe the ability to allow more and later changes and thus reduce the project's sensitivity to changes (Gil, Tommelein, Stout, & Garrett, 2005). Olsson (2006) used another definition of flexibility as the capability to adjust the project to meet demands that stem from uncertain circumstances of the project, linking flexibility to the themes of uncertainty and complexity. Flexibility is thus a way of balancing between the amount of information available to design and the need for information to be able to construct. Flexibility has also been associated with the concepts of agility and responsiveness that refer to the capability to be customer-driven, identify when changes are required, and to respond to them effectively and fast (Walker & Shen, 2002).

According to Gil et al. (2005), the concept of flexibility in projects can be divided into two distinct types, product and process flexibility, which can be used separately or in combination to achieve project flexibility. *Product flexibility* means the ability of the product to adjust to changes even after the design is frozen, either by accommodating multiple uses without changes or by incorporating options for easier modification in the future. It is necessary in order to make commitments early, even in uncertain situations. *Process flexibility* on the other hand allows for late changes without leaving such performance allowances in the product design, for example by delaying the necessary construction tasks until a final design decision has been made. Thus, process flexibility requires the design decision process and the construction process to be synced to reach the desired effects. Olsson (2006) used a similar division when he researched how the flexibility in the product and the process interacted in 18 infrastructure projects in Norway. He created a matrix, revised in Hansen and Olsson (2011), indicating the different strategies that could be taken by combining these two dimensions, presented in Figure 5. They named late scope locking or design freeze as the most important ways to conduct process flexibility along with contingency planning, under the heading of "incremental decisions". Product flexibility was reached through what was called "robust concept", which prepares for changes in requirements or use through generality and flexibility of the product itself. The combination of the two strategies was named as "flexibility maximization" and simply stated to combine the methods in product and process flexibility. In the so called "stable environment" situation, no preparations for flexibility are taken.

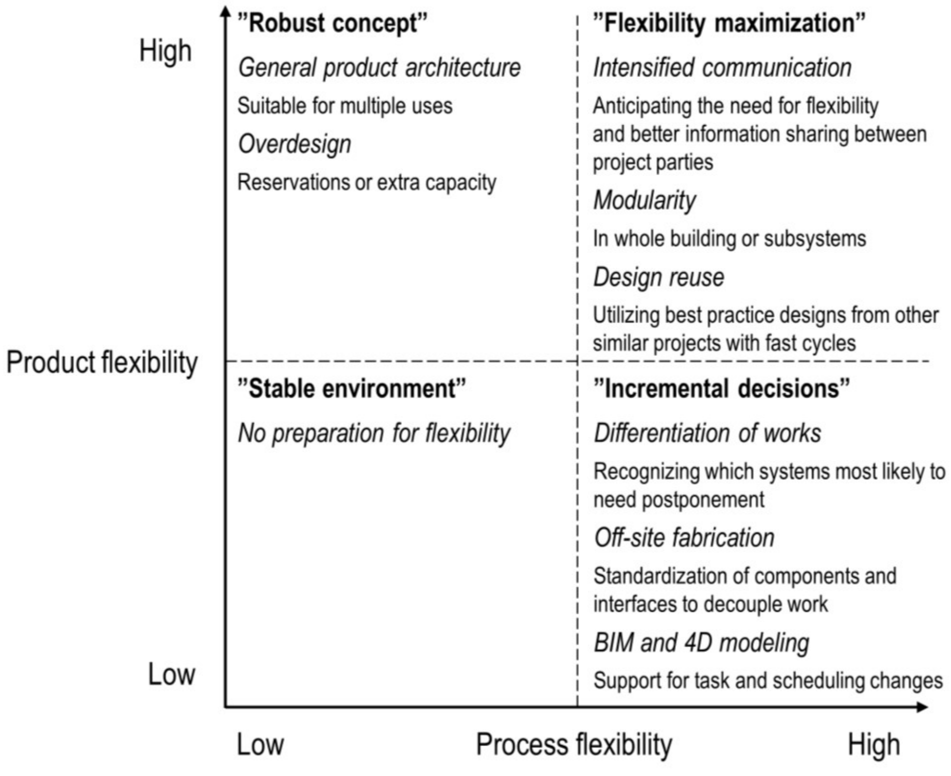

Figure 5: Project flexibility types (adapted from Olsson (2006) and Hansen & Olsson (2011)), and execution strategies (based on Gil et al. (2005))

Gil et al. (2005) researched semiconductor fabrication plant (fab) construction projects, where the main contextual factors like complex design, fast development, changes in design due to technical requirements, and the need for cost control are similar to the challenges in hospital construction. Their main findings were that in that environment, different operational strategies were already used to allow for product and process flexibility. The strategies included overdesigning and leaving allowances to the facilities, postponement of works for some change critical systems, off-site fabrication and modular systems, computer modeling, and intensified communication on critical phases of the project. Their results do not provide an exhaustive listing of flexibility strategies, but serve as a good and grounded base for understanding how flexibility works in practice during a complex construction project. The strategies concern both design and the construction activities. In Figure 5, the individual strategies based on the analysis of Gil et al. (2005) have been placed under the quadrants of the product-process flexibility matrix.

The use of flexibility strategies is however not without tradeoffs: for example overdesign might end up being just extra cost if the flexibility in the product is not needed after all, or if the designed flexibility was of different type that would have actually been needed (Gil et al., 2005). Process strategies, like postponement, are often related to performance tradeoffs through the reduction in efficiency (Gil et al., 2005). Not all researchers have accepted the view that flexibility inevitably increases costs, at least when taken a life-cycle view. Slaughter (2001) argued that using flexible solutions in the design has many times little or no impact to the short-term costs, and even if extra costs incur, they will be compensated already during the first round of modifications. The focus of the article is more on the renovation of facilities, but many of the same methods are usable already for changes during the construction phase. She introduces several design approaches, defined as general goals for the facility design, as well as design strategies, which are the specific means to get to those goals. The general design approaches to reach flexibility suggested by Slaughter (2001) are similar as discussed in Gil et al. (2005) and Olsson (2006), for example separating the major building systems implying the use of modularity, prefabrication of major system components, and designing for overcapacity.

Still, the existence of tradeoffs and the question of who will bear the extra costs are important considerations when thinking about the practical implementation of the strategies. In a hospital setting the client is in many cases a public player and very price sensitive. Therefore everything that could risk incurring more costs in the short term is not looked upon favorably, including possible overhead for flexibility (Barlow & Köberle-Gaiser, 2009). The contractor in the typical project setting is mainly concerned with the project efficiency, so they are focused on minimizing their exposure to risk and less focused on enabling changes in the process. A good example of the practical hindrances of using flexibility can be found from an Australian case study by Walker and Shen (2002). In a hospital construction project they researched, client-initiated variations were ranked as the most important reason for delays and clearly signaling the need for flexibility from the client side. Even when the construction management team in the project had the capability to use flexibility in the process, the rigid contractual situation did not motivate them to act accordingly or even allow them to address problems by solving them together with the design team. Their results imply that not only is the ability to use flexibility important but the willingness to do so also affects the realized level of flexibility. This is in line with the views that relational contracting methods of project partnering or alliancing are seen to allow more process flexibility in the face of unforeseen events (Lahdenperä, 2012).

During the project life-cycle, flexibility has traditionally been seen valuable mostly in the front-end or planning phase of the project, but avoidable in the execution phase (Olsson, 2006). Interestingly, Olsson (2006) saw that although flexibility was not planned for in many of the projects researched, it was still used even at late stages of the project, proving the "stable environment" assumption wrong. This was especially true for those projects which had significant user influence on the end result. Love and Edwards (2004) found that early design freezing combined with inexperienced clients led to more changes, as they felt intimidated about the reduction in decision-making flexibility on a large investment. These results imply that the use of flexibility will be even more costly in terms of efficiency if it is not planned for, and thus a more active approach in identifying flexibility needs already in the beginning of the project would be beneficial (Olsson, 2006).

To conclude, flexibility has been suggested as a way to cope with uncertainty in project goals. Problems with the use of flexibility are related to the uncertain benefits, predicting those aspects in the project where flexibility would be needed, and how the costs of flexibility will be allocated in the short term. In practice, flexibility can be practiced through many different operational strategies embedded in the product, process or both. Next some of those operational strategies are discussed in more detail according to the framework in Figure 5.

2.3.1 Flexibility in the product: Robust concept

Product flexibility prepares the product to be suitable for a number of alternative uses, and thus reduces the amount of information needed about the future to fix the design. The need to provide flexibility in hospital buildings and other healthcare facilities has been widely acknowledged among hospital design literature, and has been a topic of discussion since the 1960s (Carthey, Chow, Jung, & Mills, 2011). The most important reasons for the needed flexibility are the fast development of technology and service processes, uncertain future demand, and changing organizations as well as policy changes (Astley, Capolongo, Gola, & Tartaglia, 2015), and the change pace seems to be increasing all the time. This makes it more important than ever for the infrastructure to be adaptable and flexible towards changes for "future-proofing" and avoiding early obsolescence (Carthey et al., 2011).

There is a lot of confusion and variation around concepts used to describe flexibility in construction. Especially flexibility and adaptability are sometimes used synonymously, or with adaptability seen as a method of reaching flexibility (Pinder, Schmidt, Austin, Gibb, & Saker, 2017). Commonly the literature relates these concepts to enabling changes in use, layout, and size (Pinder et al., 2017). In the domain of healthcare, it seems that flexibility is the most commonly used term to describe the overall ability to adapt to changes, like used in Carthey et al. (2011), and will also be used in this thesis as an umbrella term for the topic.

According to Saleh, Mark, and Jordan (2009), flexibility in engineering systems can be seen for example from the point of view of decision theory and real options. Flexibility in this sense means that there remain more choices after first commitment with the design is made, which could be seen as an antidote to the obsolescence problem. However, they argue that it is important to present operational strategies to practically implement flexibility in the given context, as well as quantify the value of flexibility. Concerning general engineering products, Jarratt et al. (2011) evaluated the pros and cons of three different strategies on how a product can be designed for the future. First of all, designing based only on the current requirements and leaving no room to maneuver can be risky in a changing environment but is also the cheapest alternative. Another strategy is to design based on the prediction of what requirements will be until the end of the product life cycle. However, the reliability of predictions in the long term might be low. A third strategy is to make the product easy to update to meet future needs, which has been difficult to implement in practice. Next, some methods of implementing flexibility in healthcare facilities are presented.

Flexibility in healthcare facilities

Based on a systematic literature review, Carthey et al. (2011) combined different managerial considerations, functional requirements, and building systems to a three-level hierarchy of flexibility in healthcare facility design. Table 2 well depicts how flexibility can be implemented with very different time frames and scopes in mind.

Table 2: Definitions of different levels of flexibility, from Carthey et al. (2011)

Focus	Managerial Considerations	Functional Requirement	Building System
Micro	**Operational** Easy to reconfigure, low impact on time and cost (e.g., furniture and interior spaces)	**Adaptability** Ability to adapt existing space to operational changes (e.g., workplace practices)	**Tertiary** 5–10-year lifespan, no structural implications (e.g., furniture)
	Tactical Involves commitment of capital expenditure; changes not easy to undo (e.g., design of operating rooms, provision of interstitial floors)	**Convertibility** Ability to convert rooms to different functions	**Secondary** 15–50-year lifespan (e.g., walls and ceilings, building services capacity)
Macro	**Strategic** Substantial increase in the lifetime of the infrastructure (e.g., long-term expansion plans, future conversion to other functions)	**Expandability** Ability to expand (or contract) the building envelope and increase/decrease capacity for specific hospital functions	**Primary** 50–100-year lifespan (e.g., building shell)
Source	de Neufville et al. (2008)	Pati et al. (2008)	Kendall (2005)

On the operational level, adaptability is used for reconfigurations due to smaller changes in for example operational practices. This can be achieved through standardized rooms which can facilitate multiple functionalities without physical changes, like examination rooms which can act as offices or patient rooms which are universal or acuity-adaptable (Astley et al., 2015; Carthey et al., 2011; Pati et al., 2008). Also Hansen and Olsson (2011) suggested standardizing rooms in terms of functionality, equipment and layout, while it gives flexibility in terms of locating different wards for instance. Adaptability happens primarily on room-level, and could involve changing furniture or other interior solutions but without affecting the technical systems or other main infrastructure.

On a tactical level, more radical changes can be made to functional units, which need reconfiguring in the mid-term. This typically involves capital investments to implement and might involve a number of technical systems. Convertibility to a different type of operation is enabled by reserving surplus capacity in the mechanical, electrical and plumbing (MEP) systems, interstitial technical floors, zoning and decentralization in building systems, and by reserving softer spaces around the main functionalities, which can then be used for expanding the core functions if they need more space (Carthey et al., 2011). A flexible layout with minimal amount of walls with MEP elements facilitate rearranging sections, with minimum disruption to other systems (Pati et al., 2008). Movable partition walls are a possibility for modifying spaces, if sound insulation is not critical (Astley et al., 2015).

On the long term, the whole building shell might need to be modified to allow for expansion. Open-ended corridors and reserving extra space to the same site would allow an extension to be built (Carthey et al., 2011). These types of radical changes seem unlikely to be needed during the construction project, but was exactly what happened due to political reasons during a Norwegian hospital project described in Olsson and Hansen (2010).

2.3.2 Flexibility in the process: Incremental decisions

Process flexibility is about fitting the incremental information flow from the design decision process and the construction process together with as little disturbance as possible. Literature suggests late design freeze and postponement of construction tasks, off-site fabrication, and BIM as tools to implement process flexibility.

A study of several Norwegian projects found that hospitals seemed to be among those projects that needed to use this type of process flexibility also in the project execution phase (Olsson, 2006), because new information regarding the requirements of the building emerged late in the project. To continue researching the subject, Olsson and Hansen (2010) studied four Norwegian hospital construction projects and the use of flexibility during the project. They noticed that there was a tendency for the process flexibility to increase significantly from what was planned. Even when most of the buildings were designed as flexible by using the tools of product flexibility, there was the need to use process flexibility with design freezes and changes happening also in very late phases of the projects. In one of their cases, late lock-in of design did not lead to budget increases or overall delay, as it concerned only a well-defined part of the building and was properly prepared for, but rework was still needed. In some other cases, late changes resulted in both budget and time overruns. Gil et al. (2005) state that while overdesigning the product is favored by designers as the method to implement flexibility, the related trade-offs related due to for example cost often make the project managers turn to process flexibility instead.

Postponement and late design freeze

The effects of design changes are dependent on the level of sensitivity of the construction tasks in question. With high levels of sensitivity, design changes upstream of the task might require large amounts of rework, as opposed to low sensitivity that implies only limited reworking needs (Blacud, Bogus, Diekmann, & Molenaar, 2009). Postponement strategies try to defer commitments to uncertain, high sensitivity tasks. They can also reduce the sensitivity of entire work phases towards these uncertainties by executing tasks in a different order. Subsequently, postponement of construction tasks allows for a later final design freeze in the decision process.

Blacud et al. (2009) recognized four determining factors to the sensitivity to changes of a construction activity: *transformation*, the amount of modification done in the activity and the ability to reverse the process if needed; *lead time*, the time to acquire a necessary component or raw materials for constructing a replacement; *modularity*, the extent that different components are interdependent; and *interaction of components*, the physical relationships between them, for example the extent on which they are enclosed in or supporting other components. Isaac and Navon (2013) suggested using a graph-based model to recognize better different types of interactions between components and component clusters, and how the elements link to cost and performance goals. Gil et al. (2005) presented strategies for postponement found from case studies of semiconductor fabrication plant construction. One strategy was that project teams were instructed to delay design and implementation commitments for systems which were likely to change in a major way. Another strategy was to decouple as much of the installation work to happen before tools arrived, which helped to reduce work task sensitivity to the tool's uncertain arrival date.

Combined with the evaluation of construction task sensitivity, these strategies could be used in hospital environment to deal with uncertainty and design changes. One potential target for postponement strategies is the choice and installation of fixed medical equipment. The task of acquiring medical equipment is usually left to the hospital management as a separate project with own objectives and a different time frame compared to the larger construction project (Decouvelaere et al., 2007). Many of the larger and expensive equipment need very specific requirements for the surrounding infrastructure because of weight, sensitivity to vibration, connections to the HVAC and other technical systems. Those demands should be recognized as early as possible and having a medical equipment specialist in the project is vital to translating these requirements to the design (Suydam, Youngblood, & Berkowitz, 1995). It might be relevant to postpone the final design decisions on critical spaces until a purchasing decision has been made. This might also mean leaving large allowances for space and technical systems to enable later decision making, as not all work is possible to be left so late. However, in many cases the type of preparatory installation work as mentioned by Gil et al. (2005) could come into question if the interface requirements are sufficiently well known. Practically, postponement of the design might require handling the spaces as contractually different from the rest of the areas (Suydam et al., 1995).

Off-site fabrication

Off-site fabrication has been suggested as a way of making the construction production process more flexible. While postponement allows differentiating tasks in terms of their execution time and order, off-site production enables tasks to be executed in a physically different place and by different people than if done on-site. Off-site fabrication can therefore reduce the complexity of tasks otherwise very fragile to disturbances in the workflow of several different parties or tasks. However, certain amount of standardization or defining interfaces is required to be able to decouple a part of work to be done away from the site and fit to the systems later.

Prefabrication or preassembly of components can vary from just a few ready-made installation steps to providing finished space modules. The main benefits of prefabrication come from the faster, safer and less complicated installation on site (Gil et al., 2005). It also makes coordination easier, as the multiple work phases can be conducted outside the constraints of the construction site, and reduces uncertainty on the duration of those work phases. Healthcare projects can also benefit from the shorter execution times and less disturbance on-site, which makes them good candidates to use more prefabrication. An industry report from McGraw-Hill Construction (2011) found that healthcare was the sector with highest usage of prefabrication in North America. Typical examples of use in healthcare projects are bed headwalls and bathroom pods, typically combining expertize from multiple different contractor trades.

BIM can be used to support more off-site fabrication, for example by being able to divide for example electrical or automation systems to horizontal racks of prefabricated components with a ready bill-off-materials for each rack. Other construction trends driving the use of more off-site fabrication are lean construction and green building, both aiming to improve the resource efficiency of construction projects. (McGraw-Hill Construction, 2011)

Faster adaptation through Building Information Modeling (BIM)

Technological tools can also be of help to better react to changes when they happen. One such alternative is Building Information Modeling (BIM), which is used for creating a virtual model of the building to be constructed, through parametric modeling of objects and constraints (Sacks, Koskela, Dave, & Owen, 2010). The model contains the exact geometry, spatial relationships, properties of building elements and other data in digital format to support the design and construction during different stages of the project or even during the rest of the lifecycle of the building (Azhar, 2011). BIM is viewed as an important tool for efficient collaboration between project team members from different disciplines like architects, engineers, contractors and owners (Azhar, 2011), and has been presented as a tool to cope with the increasing complexity of construction projects (Bryde, Broquetas, & Volm, 2013).

BIM can be used for a variety of purposes, like visualization, shop drawings, building code reviews, cost estimates, construction sequencing, detecting design conflicts as well as facilities management (Azhar, 2011). Another way of describing the use is to see in which phases of the project BIM is used: in the preconstruction, design, construction, fabrication and operation (Ilozor & Kelly, 2012). The extent of actions where BIM is utilized is usually described with "nD" terms: 3D represents the basic level, 4D adds schedule and construction simulation dimension, 5D brings additionally the cost calculation and quantity takeoff functions and 6D refers to facilities management resources like warranty information and maintenance schedules combined to the model (Bryde et al., 2013; Ilozor & Kelly, 2012).

Major benefits in terms of costs, schedule, communication, coordination and quality have been reported from implementing BIM (Bryde et al., 2013), but the effects of BIM in relation to project changes have been twofold. On the one hand, the use of BIM has been shown to decrease the number of design changes in relation to design errors and conflicts radically. On the other hand, however, there is evidence of owner initiated changes increasing with the use of BIM, likely because of the better decision support for the owner/user that visualization provides (Francom & El Asmar, 2015). Additionally, the design changes that do occur are faster and less complicated to process with the help of BIM features. Identifying the consequences of a change beforehand is very demanding, and BIM can help with this by tracking changes in the drawings and automatically warning about design clashes (Mejlænder-Larsen, 2017).

In sum, BIM has the possibility to help achieve better communication and collaboration, less errors in design, resource efficiency, better visualization as well as support many core construction processes by automating tasks. The main benefits of BIM in terms of bringing flexibility to changes is the ability to more efficient, real-time communication on changes, as well as to explore alternative design options and their effects on the budget and schedule.

2.3.3 Integrated product-process flexibility: Flexibility maximization

Practicing integrated flexibility from the product and the process calls for new and innovative project delivery methods. In the traditional project delivery methods, the owner is mostly in charge of steering the design process, and thus they have the greatest influence on product flexibility. On the other hand, the contractors responsible for executing the project have the leading role in implementing process flexibility measures. To combine these two perspectives and optimize flexibility of a whole, ways of aligning goals and enabling the early involvement of contractors would be beneficial.

Here, two themes around increasing the combined product and process flexibility are discussed, namely intensified communication through lean construction and the use of modularity.

Intensified communication: Lean construction

Effective communication and sharing knowledge about changes openly are key practices in order to allow changes flexibly. Calling for intensified communication, Gil et al. (2005) presented the strategy of having start-up meetings early in the project to involve key players of the project in the design process and to be able to anticipate changes in the design criteria better. During the rest of the project, continuous communication should be encouraged in the form of coordination meetings, as well as by having suppliers visit the construction site and bring the most up-to-date installation information.

The idea of an integrative, early involvement of all project parties is one key element of lean construction principles. *Lean construction* is a term used for describing a new, theory-based methodology in the field of construction, associated most with an IPD type relational contracting method. Lean thinking originated from the Toyota Production System (TPS), but has since been modified to suit the construction industry. While the traditional emphasis in construction has been on Transformation (T), lean has introduced two additional dimensions of Flow (F) and Value generation (V), combined to a TFV model of construction. Lean construction is completely against the optimization of each activity in the construction value chain separately, which has only led to sub-optimal outcomes. In lean, representatives from different life-cycle stages are introduced right at the beginning, and the product and the process to create it are designed together. (Koskela, Howell, Ballard, & Tommelein, 2002)

Lean is a philosophy practiced through tools and techniques, which cover different tasks in the construction process. Some of the most important techniques presented by Ballard et al. (2002) include:

Scheduling: In lean, master schedules are only used for high-level phases, and in the lower levels the schedule is continuously adjusted. The scheduling technique is called the Last Planner System, where the different project parties are involved in lookahead and commitment planning, with which the workflow and detailed plans for executing the work are formed. The progress is continuously monitored and learned from. The longer-term schedules for each phase are calculated back, "pulled", from the target milestone.

Design: The whole life-cycle from construction, operations, maintenance, and decommissioning is considered in the design process. Design is done in cross-functional teams to a single model, and even incomplete information is shared. Lean principles have also been notice to benefit from BIM adoption and vice versa (Sacks et al., 2010). Design is not frozen as early as possible like in normal construction, but at the "Last responsible moment", which means the last moment when the decision can be still executed in the construction process. This facilitates creating multiple possible design alternatives, which is called set-based design.

Supply: Specialty and key contractors and suppliers are involved from conceptual design. Long-term relationships with contractors help incorporate the needed design details to avoid unnecessary iteration of design at later stages.

Assembly: First run studies in advance of scheduled tasks are used for identifying best practices for work to be done, creating a standardized way of working. Preassembly and standardization of parts are used for reducing variability and shortening cycle times. Planning work is distributed to the people doing the work. Continuous flow is pursued where possible, and this is supported by multiskilled workers avoiding fragmentation of work.

Modularity in building and technical systems

Modularity and flexibility maximization might at first sound like a contradiction, as modular construction is often connected with the image of prefabricated "lego block" buildings with rigid design. Here however, a different type of approach to modularity is discussed, as idea of using modularity on system or space level does not necessarily imply prefabrication. According to Hansen and Olsson (2011) flexibility can actually be related to modularity through dividing the project in independent sub-units. By using a modular structure in the design, the decision and construction processes can be configured in a different way than allowed with a different type of design, thus categorizing this strategy among the "flexibility maximization" quadrant. Hellström and Wikström (2005) argued that modularity by definition is a means to manage complexity, by specifying interfaces not only between the product parts but also between organizations.

Barlow and Köberle-Gaiser (2009) provided examples or modularity from case studies they made on hospital projects. Layout zones were mentioned as it allowed for changes to happen inside these zones, and modularized service and mechanical systems were seen to facilitate possible upgrading or expansion needs. The use of modularity in system or space level does not however mean that it must be implemented everywhere. A modular design could help to isolate only the most uncertain parts of the design, allowing for other parts to continue in the construction process as planned even if changes in these isolated parts would occur (Blacud et al., 2009). Gil et al. (2005) described a method used in chip manufacturing spaces, where the facility is divided into modules, some of which are only fitted with tools and other fit-outs at a later stage when the performance demands for the module have become clear.

Open building represents an extreme type of modularity, and has been addressed for example in the work of Kendall (2005). In the open building paradigm, the incremental process of decision-making is reflected in the physical design of the facility by separating building systems of different time-spans into independent layers which are also designed separately. The way of thinking emphasizes the careful design of interfaces between the layers. This quite extreme approach to designing and constructing was applied in the INO hospital project in Switzerland, where the experiences have been positive according to Hansen and Olsson (2011). Some problems have occurred due to the more complex task of designing the interfaces, but on the other hand the flexibility allowed by the layered design had already been used during the project.

2.4 Summary of literature review

According to the traditional view of project management, flexibility and change are seen as something to avoid, and careful planning and a clear definition are seen as critical success factors for projects (Olsson & Hansen, 2010). This however would require that the project stakeholders have a clear view on what they need, the ability to express those needs explicitly, and that those needs would be relatively stable in nature. There have been suggestions that not all requirement changes in projects even stem from actual changes but they can appear also from better understanding by the stakeholders about their existing needs (Olsson, 2006). Most research literature on changes does not properly address the issue of changing requirements, but focuses predominantly on finding the culprit, whether it be clients, designers, or contractors. This view is both simplistic and unconstructive, and thus far has reached little results in reducing changes and their effects in construction projects.

Contextual factors seem to greatly influence hospital construction based on research. Project complexity was chosen as one possible point-of-view to understand the specific difficulties during a hospital construction project, and possibly to shed light on the phenomenon of changes as a part of the project. Hospital projects are inherently complex, as there are technical, organizational, and social aspects to them that are beyond the control of the project team. It has been well understood by many authors that hospital buildings face a lot of uncertainties during their life-cycle, for example regarding requirements and uses (Barlow & Köberle-Gaiser, 2009; de Neufville et al., 2008), but fewer have given thought to how this affects work during the construction project. Therefore, a need for more understanding about changes during construction in this particular context is needed.

Project flexibility can be perceived as a balancing force to project complexity. If changes are regarded as often necessary and good for the project end result, the question arises of how then it could be easier to implement those changes even later during the project. Project flexibility introduces ways of leaving room to maneuver in a way that would not badly erode the execution efficiency. Depending on by who and at what stage project flexibility is executed, product, process, or combined strategies provide the possibility for allowing more and later changes with less disturbance.

3 Research design

3.1 Case study research

An exploratory multiple case study design was chosen based on the research questions to thoroughly understand the phenomenon of changes in hospital construction project. Exploratory research is about clarifying understanding on a problem and seeking new insights on it (Saunders, Lewis, & Thornhill, 2007, p 133). A case study approach was selected as the phenomenon of construction changes is hard to investigate separate from the project context where they are happening. According to Yin (2003, p 13), case studies are suited for investigating contemporary phenomena in their real-life contexts, but where the boundaries between these are not evident.

The research process started with only the broad research questions, and an inductive approach was used during the data collection. Thus, data collection was not directed based on any particular theory or hypothesis in mind, to allow for themes to arise from the interviews. However, during the analysis of data research literature was used to find relevant theoretical perspectives through which the findings could be presented and linked to different streams of current research. This has been suggested for example by Saunders et al. (2007, p 488) as a means to direct the analysis.

3.2 Case selection

The accessibility to key personnel and other data in the cases was a key issue in selecting cases, so a purposive sampling strategy was selected. An organization associated with the larger research project offered to provide access to a number of hospital construction projects they had been involved with and were able to provide the contact details of some key personnel from the project teams. In the choice of the exact cases, variation in terms of hospital type, project budget and location was aimed for, to create a heterogeneous sample. Heterogeneous or maximum variation sampling is helpful in identifying patterns which are of particular interest and value (Saunders et al., 2007, p 232).

Subsequently, five hospital construction projects were chosen to be included: two from Finland, two from Sweden and one from the U.S.. They ranged from 30 million to 200 million in total budget, and included hospitals for various types of psychiatric and somatic care. To ensure a good data quality, only projects finished in the past few of years or projects still in their final phases were chosen.

3.3 Data collection

Main data collection method were semi-structured interviews, which are recommended to be used when questions are open ended and flexibility with the order and logic of questioning is needed (Saunders et al., 2007, p 316). Altogether, 24 interviews with key project personnel were conducted, 16 of which in person and the remaining 8 as telephone interviews. The interviews took place between October and December 2016. The aim was to interview people from the different key parties in the project, and interviewees were asked to name additional people that in their opinion would be important for the study. On a few occasions, a person of interest for the study could not be reached, but all those who were reached were willing to be interviewed. Table 3 lists the project parties and roles found among the interviewees, and in Table 4 the division of the respondents from different cases is shown. Interviews per case varied between three and seven, which is in line with the initial target of five interviews per case. Majority of the interviewees were either from the contractor or owner sides, but in two cases only contractor representatives were interviewed due to poor accessibility to other project parties.

Table 3: Project parties and roles represented among interviewees

General and subcontractors	Owner/user representatives
Construction manager	Chief medical officer
Design manager	Design coordinator (x2)
District manager	Project engineer
Production engineer	Project manager (x2)
Project controls engineer	Trade supervisor (x3)
Project manager (x5)	**Designers**
Senior project engineer	Design coordinator
Senior project manager	Main architect
Site manager	

Table 4: Interviews by project

	A	B	C	D	E	Total
General and subcontractors	2	2	3	2	4	**13**
Owner/user representatives	4	4		1		**9**
Designers	1			1		**2**
Total	**7**	**6**	**3**	**4**	**4**	**24**

The interviews typically lasted about one hour, but ranged between half an hour and two hours. An interview protocol was created to ensure comparative data collection methods. The full interview protocol is found in Appendix 1, but Table 5 summarizes the key themes discussed and how they link to the research goals and the specific research questions. The protocol was followed in a flexible manner and modified according to who the interviewee was and their responses to previous questions. All interviews besides the interviews from Project E were attended by two or three researchers to reduce any bias and ensure that the interview topics were covered in a thorough way. The researchers took notes during the interviews, but the interviews were also recorded and subsequently transcribed verbatim for analysis purposes.

Table 5: Overview of interview protocol

Section of interview protocol	Purpose of section
Starting the interview	Explaining the interview topic and establishing confidentiality with the interviewee
Background information and the project in general	Contextual information: background information on the respondent and project
Change process: Roles and communication	Contextual information: clarification of the change order process and people involved
Changes and their management in this project	Data related to RQ1 and RQ2 through real life examples
Changes in hospital projects in general	Data related to RQ1, RQ2 and RQ3 through general experience of respondents on hospital projects
Ending the interview	Letting interviewees highlight any uncovered but relevant themes, asking who else should be interviewed, collecting secondary data

Secondary data to support the interviews was also gathered to ensure sufficient data triangulation, an important part of the case study design according to Yin (2003). This data included among others project presentations, change order data, meeting minutes from site meetings, and site observation during research visits. General information about the projects was searched for online. Due to the variety of data gathered from different cases, it was mainly used for supporting the findings from the interviews. An overview of secondary data types from the cases is presented in Table 6.

Table 6: Secondary data by project

	A	B	C	D	E
Publicly available information (schedule, budget etc.)	x	x	x	x	x
Project change order data	x	x	x	x	
Internal project presentation	x		x		
Project documentation (meeting minutes, drawings)	x	x			
Site visit / observation	x	x		x	x

3.4 Data analysis

Interview transcripts were downloaded to Atlas.ti qualitative analysis software for coding. Coding was done based on preliminary code categories stemming from the research questions, such as change causes and effects. More categories were added as the coding progressed, such as for different contextual variables, communication, design, and mitigation tools. Altogether, 112 lower level codes were utilized. Another method for processing the interview data was to list the examples gathered by using the "critical incident technique" described by Saunders et al. (2007, p 325), where respondents were told to give examples of change cases they had encountered.

Theoretical perspectives and frameworks from research literature and discussions with the other researchers were used to direct the data analysis after the initial coding. The process is described in Figure 6. The individual codes or themes identified in the first step were subsequently grouped and processed further. The listed change events were categorized in terms of change sources, and root cause analysis was conducted through crafting a cause-effect diagram. The coded interview data was used for bringing additional depth and explanations to the root cause analysis, and bringing insight on the themes from those cases where specific examples did not come up. Moderating variables theory was utilized when analyzing factors affecting change effects. Lastly, the tools for mitigation efforts were analyzed and grouped based on the project flexibility framework.

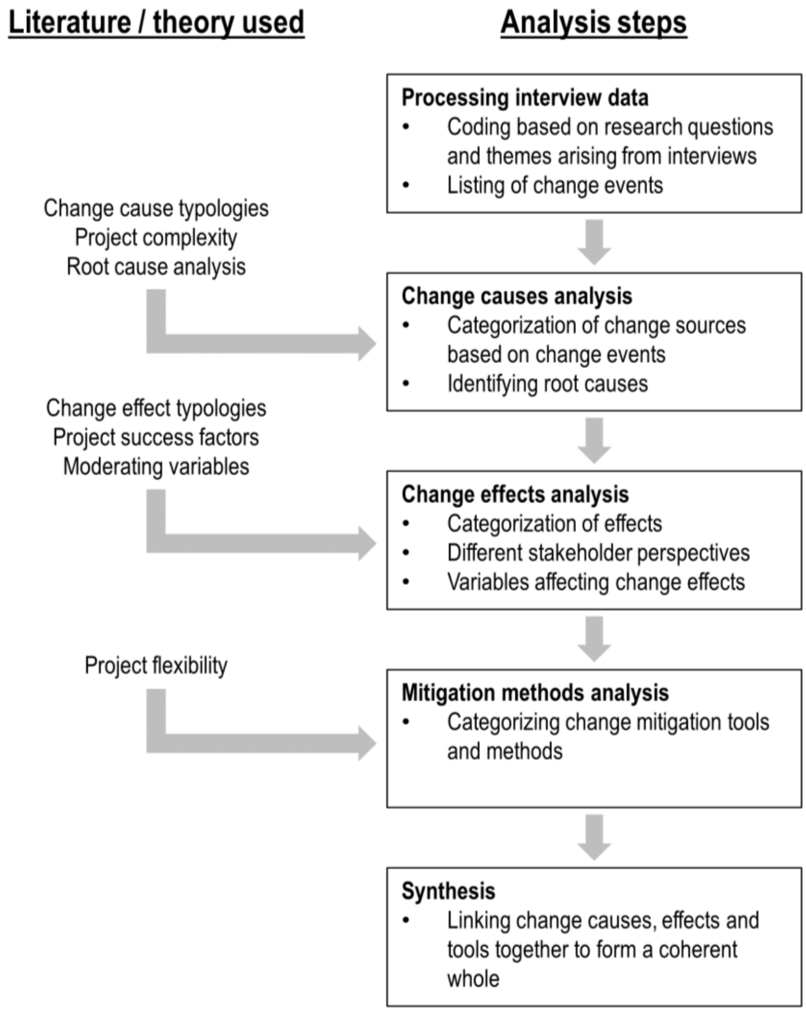

Figure 6: The analysis process, guided by previous literature

The data analysis was first done on the individual case level and project descriptions were formatted based on this single-case analysis. After looking at the cases individually, a cross-case analysis on the themes arising from the cases and from the categorization of change events was made for revealing commonalities and differences between the cases.

4 Findings

4.1 Project descriptions

During the single-case analysis, project descriptions were written from each project, including their goals, schedule, organization, how changes affected the project, and how successful the project seems to have been. After each project has been individually presented, an overview on the key information from all the projects is summarized.

4.1.1 Hospital project A: Psychiatric hospital for the future

Hospital project A aimed at constructing a new and centralized unit for psychiatric treatment for the region, and the owner and client for the new facilities was a Finnish hospital district. The need for a new hospital arose already in the early years of 2000, and there were a few development projects, in 2004–5 and 2009–10 where new care processes but also demands for the future facilities were ideated. In the latter of the projects, a rough plan for the new building and needed functions was introduced. Facilities in the new building included inpatient wards for children, youth and adults, a hospital school and outpatient clinics.

The political decision to go ahead with the project was reached in late 2010, after which the detailed construction planning was started. The construction project was decided to be divided in two separate phases, first phase construction taking place 2012–2013 and second phase 2014–2016, and the project schedule is depicted in Figure 7. In analyzing the case, the focus is on the second phase of the construction project, as there was a different general contractor company responsible for the first phase. The total cost of the new hospital was around 35 million euros, with Phase 2 accounting for approximately 23 million.

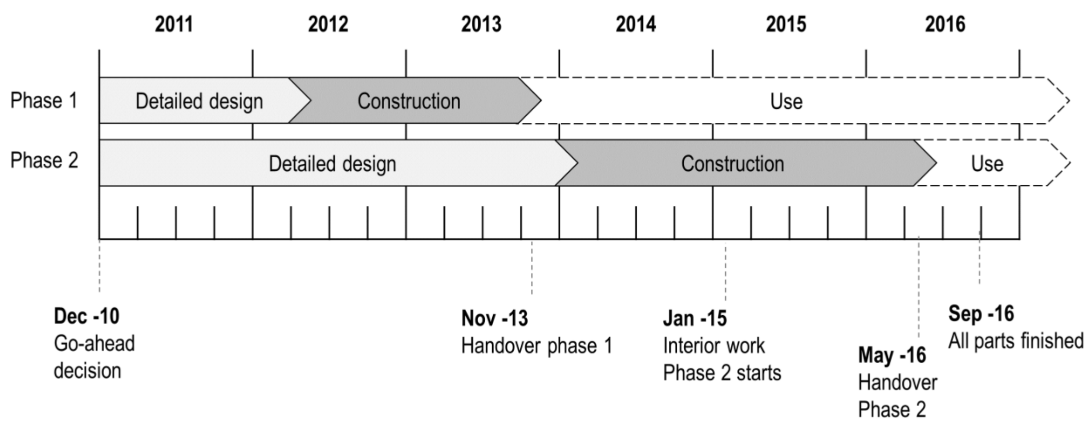

Figure 7: The phased schedule of Project A

This project had slightly different challenges compared to other kinds of hospital construction, as the building was to serve just one specific clinical field, psychiatry. Some respondents compared this type of hospital construction being more like building a hotel or office spaces than a somatic hospital, as there was very little medical technology involved. However, safety and security issues were proved to be quite demanding, as it is a priority to ensure patient and employee safety but at the same time make spaces comfortable and not prison-like. As an example, the locking system had to be carefully planned to work alongside the daily operations but also under special circumstances as fires.

It can be thus concluded that from the perspective of technical systems in the building this was a much simpler project compared to the other researched case projects. In psychiatric treatment change is typically not so much about technology evolving but about the balance between inpatient and outpatient care. In this project, a decision was made to reduce the number of inpatient rooms radically, while the trend in treatment is towards more outpatient or home care. This was given a lot of thought in the design phase, when also cost pressure to stay within the acceptable budget was high. The decision was also based on benchmarking visit to the Netherlands, which is known for innovative hospital construction. Additionally, one outpatient clinic needed to be left out of the plans already in the design phase due to cost reasons. The tight cost frame of the project posed some challenges, but also facilitated discussions about real needs and lead to a well-scoped plan.

Project organization and communication

The second phase of the construction project was contracted as a divided lump sum contract, with the general contractor responsible for the scheduling and project management. There were additionally five trade contractors with separate contracts with the owner, as seen from Figure 8. The general contractor had its own management team, comprising of both project and site management. From the hospital district side there was also a project manager and a team of a design coordinator and supervisors for different trades. Outside consultants were not used for project management.

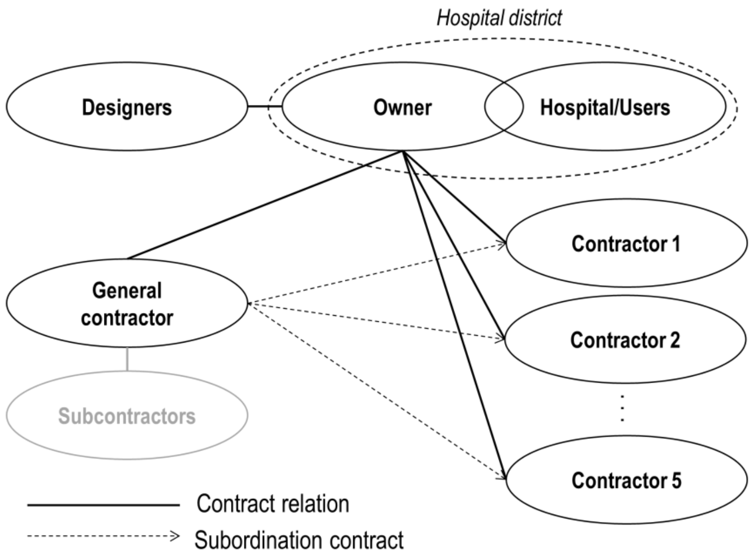

Figure 8: Organizational structure in Project A

Overall the atmosphere among the contractor and client project teams was very positive according to all of the interviewees. Information was shared extensively via informal channels like coffee table discussions or chats at the site, and even problems or controversial issues were brought up in a good spirit. Both the general contractor and the hospital district were open about communicating any upcoming events or changes that might affect the construction work, and the division of responsibility between people was clear. Relying on informal communication was also easy, because the overall project team was small and people got to know each other. The main formal communication channels during construction were site meetings and contractor meetings. Also at the beginning of each phase it was considered as a good practice to have a "start meeting" in the beginning of each work package, where the basic rules and expectations were revised with the supervisors, general contractor, and trade contractors.

The role of the design coordinator was highlighted as a key to mediating between the designer and construction teams and the end users of the facilities. It was her job to act as a translator between the clinical and maintenance staff, the patient organizations, and the project execution team, to make sure relevant requirements for the facilities were met. The project was described as very user-centric, which emphasized the role of the design coordinator.

Changes during construction

The project seemed to have had very little major changes, which is a finding also supported by the change order listing of the main contractor. A list of the change events mentioned during interviews can be found from table in Appendix 2, which gives examples of the types of changes, their source and cause as well as the effects on construction the changes had. The largest individual changes in terms of costs happened already early in the project during the ground work, where some surprises came up. The soil was different than expected which meant that more material had to be excavated from the site. Additionally, one sewer line had to be rerouted because it had not been shown correctly in the drawings.

During the interior construction, the most significant changes related to a part that was added quite late in the design process, a PET-CT machine and imaging space. This equipment has little to do with psychiatry, but was added because no suitable space was found anywhere else in the hospital campus. It was also the part of the project which most resembled typical hospital construction, and the space needed some costly additions like lead panels to the walls. The notice of the space came already before construction started and thus did not come as a surprise to the contractor, but the choice of the specific equipment was left very late in the project. Because the choice was made only months before the handover of the project, finishing work in the space had to be made after the rest of the building had been completed, including casting the foundation for the equipment, connections to building systems, finishing surfaces and closing the dropped ceilings to mention a few. It was a suboptimal solution from both the contractor's and the client's perspectives. The contractor had to keep project management occupied with the last details of the project for several months after the official end, and the coordination of tasks was difficult after most of the project staff had already moved to work on other projects. Having an operating hospital upstairs was also a challenge, not to disturb those activities with construction work. There was also another late choice with the nurse call system. The system used in the first phase had some issues and therefore the choice was brought up again during phase two. This posed a challenge to the construction, because the dropped ceilings could not be closed before the system had been installed by the electrical contractor.

The lack of late changes was credited to the thorough and user-centric design work. Mock-up rooms built on site were used with repetitive rooms like patient rooms and appointment rooms, where the users had the opportunity to familiarize with the space and give feedback on different design solutions before starting work on the rest of the spaces. The mock-up rooms lead to some minor details like socket places and furniture mounting types being changed, mostly related to safety issues. Some 3D modeling was used in the project, but not extensively, and the designs were mainly worked in 2D with the users. Because users are not necessarily used to working with drawings, change instances sometimes occurred when seeing the end results. A windowsill that had to be lowered for visibility reasons, while the user had not been able to imagine it correctly based on the drawings.

Attitude towards minor changes varied between the client and the contractor. Usually the smaller the change requested was, the easier it was to be accepted by the client. While both were agreeing that these small changes are usually not a problem, the contractor side was naturally more concerned about the effect of even seemingly small changes to the construction project. The notion of the changes stacking up, like those with the PET-CT space coming up little by little but in fact adding up to a bigger change was brought up by the contractor representatives. Some of the small details could have been probably avoided by paying more attention to them in the design phase, but still there is the possibility that something would have been missed.

Project success

The project finished on budget and the handover was done on time except for a few, separate scopes of work. The functional quality has been good from the user perspective, while the hospital has been in use for several months already. Some minor details are still being worked on, but in general no large omissions or mistakes have surfaced. It has thus been a successful project in both project management and product sense.

The length of the project, around 6 years from the start of detailed design is still challenging in terms of changes happening in the meantime, and a comment from one of the one of the owner representatives was that the final hospital would look a bit different if it was designed today. An example of a latent change need not yet fulfilled is that there is a new magnetic stimulation therapy, which requires some heavy equipment, but there is currently no place in the new hospital for this as it was not seen in the design phase. The placement of the equipment is an issue waiting to be resolved.

4.1.2 Hospital project B: Modern facilities to a university hospital

The hospital built in project B is a 24/7 facility at a Finnish university teaching hospital and comprises of for instance a surgery unit of 26 operating rooms, an intensive care unit, a maternity ward, dialysis unit, a sterile processing department as well as outpatient wards and cafeteria. The project was a part of a larger renovation and renewal plan of the hospital facilities running far to the 2020s. While none of the old hospital facilities could be renovated to fit modern care standards in the above-mentioned fields, it was clear that a new building was needed. The concept planning started in 2009, detailed design was done from late 2010 onwards, and construction began in the summer of 2012 after the final approval by the city council. Construction was divided into two phases. The foundation work and element frame were tendered first separately, as there were no offers to the construction management role which would have fit the budget at that point. Handover to the construction manager and rest of the trades was done stepwise during summer and fall 2013. The project was handed over in April 2015, 1.5 months late from schedule, but with first patients arrived already in May as had been planned. The project totaled just under 100 million euros, which was slightly over budget.

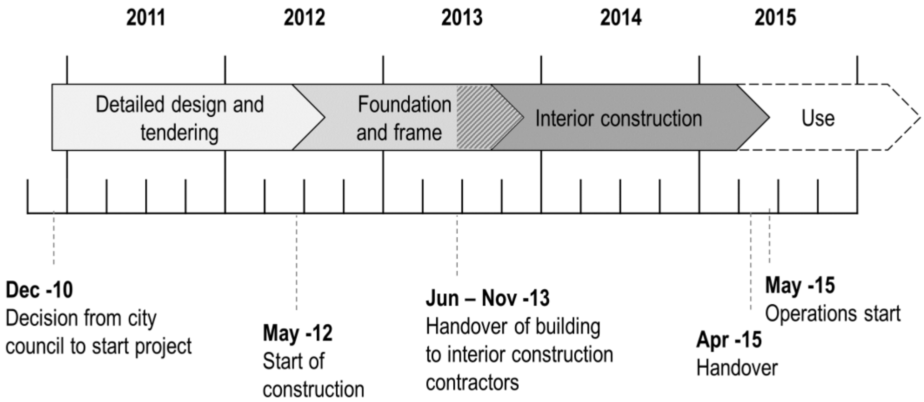

Figure 9: Schedule of Project B

The technical requirements for the project were high, as the facilities included multiple operation rooms and technical facilities with a significant amount of medical technology. The operating rooms were to serve the most demanding specialties like cardiac surgery, as those functions needed temporary facilities due to upcoming renovations. All the fixed medical equipment was new-generation and nothing was transferred from the old facilities. The project was also the largest project built in the hospital district so far and one of the first in the long-term renewal plan, which meant that many of the owner side project staff had no previous experience of projects this scale. The project was tendered in tens of separate contract packages, which also increased the project complexity significantly.

Project organization and communication

The interior construction was contracted as a construction management (CM) contract a guaranteed maximum price (GMP), with overall scheduling and project management responsibilities. The responsibility for the project was transferred stepwise from the contractor of the foundation and superstructure works. Additionally, there were a little less than 20 trade contractors which were subordinated to the construction management contractor, and 5 independent contractors with separate lump sum contracts. The hospital district as the owner took care of developer duties with their own trade supervisors and project management, with some specialized supervisors acquired from a publicly owned separate entity providing developer services.

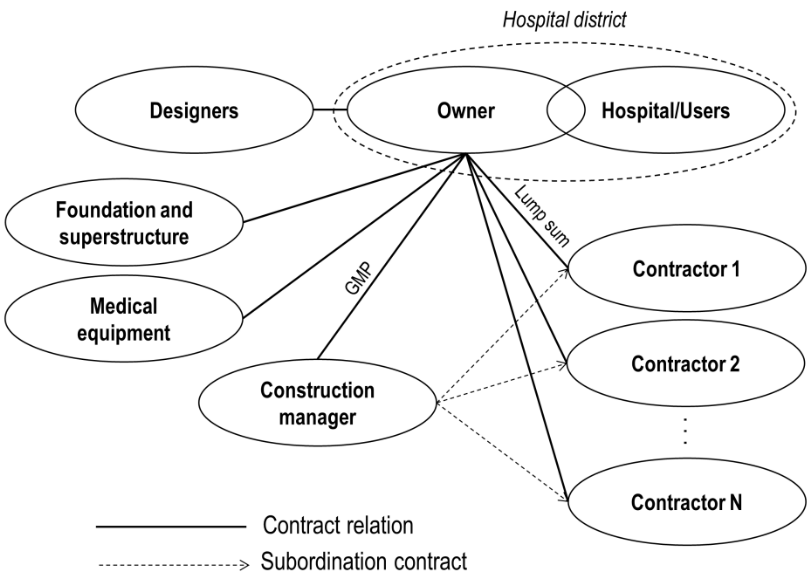

Figure 10: Organizational structure in Project B

CM type contracts should in theory facilitate more communication and cooperation between the client and the general contractor, as the owner has an incentive to actively take part and supervise the project progress. It seems that in this case the relationship between the construction manager and the client resembled more the traditional lump sum way than a combined effort to deliver the project. The hospital district had a strict schedule steering and tight milestones set in the contract, so the general contractor really had little freedom in the scheduling and planning actions. All the other contractors were having a traditional lump sum deal, which meant that it was in their interest only to cover their part of the contract rather than to work collaboratively for the good of the whole project. As some milestones were not met in schedule, extra tension built up between the contractors, and there were disagreements between them about who was ultimately responsible for the delays.

Some disagreements arose also between the client and the CM. One of these was the extent on which change orders from the owner side influenced the overall schedule. The client had a view that the delays had nothing to do with change orders but the CM thought otherwise. The extent of how much the change orders of other trades affected the construction tasks was hard to evaluate. Other disputes arose from the schedule management and what the real status of the project was, where the owner and the CM had some differing views.

There were many forums where project matters were discussed. Once a month there were site meetings where the owner, contractors, and designers all came together. The contractors met regularly themselves, and had also regular meetings with their respective supervisors. The owner's project organization had also internal meetings to discuss for example change management. The interpersonal relationships between the supervisor and the contractor in question was an important factor in the everyday work, and in some trades the cooperation worked better than in others. One example of the significance of the relationship was that a lot of the change order information went directly through supervisors to the trades, although the up-to-date plans were also found in the common project knowledge bank. The CM therefore felt that they did not receive enough information and heads-up from what was happening in the trades, and thus were lacking critical information about the project status and how it affected their work.

The project was described as typical when asked about the cooperation between the client and contractors. The owner representatives saw it as normal industry practice that differences in opinion exist when they are figuratively speaking "working on different sides". This represents a very traditional view of the construction industry as more of a struggle between the parties than mutual collaboration.

Changes during construction

The project faced few large changes in the construction phase. The room program remained virtually unchanged, apart from a few examination rooms being transformed to dental treatment rooms and some changes to interior walls in the breast milk center. User changes limited themselves to changes within rooms, like the positioning of furniture and appliances and locations of electric and medical gas outlets. Many of the user preferences had earlier been tested with mock-up rooms. These were built at two different stages: first ones before the construction had started on another location, and a second set of rooms were executed on the site. The rooms built included an operating theatre, intensive care room and a family room for neonatal intensive care. A comment from the owner was that the mock-ups should have been finished even earlier at the site, because now the construction had already progressed to a stage where any changes from the users were already too late from the construction perspective. However, the overall view on the use of mock-up rooms was that they saved the project from many laborious and difficult changes later, as it is difficult for the users to visualize how the rooms will look like from drawings only.

Most later changes during construction were related to the fixed medical equipment and other hospital systems. Work on the medical gas system had to be put on hold for quite a long time, when the locations and number of outlets was still uncertain. Also the nurse alarm system changed along the way and thus new cables needed to be installed. That in turn had a ripple effect on the dropped ceiling installation schedule. A common cause for the changes was that requirements for some of the MEP systems were not frozen early enough, because the system or equipment choice had not been made yet.

Electrical work was perhaps most influenced by changes. The percentage of change work in the electrical contract was not especially high, but the design work for electrical systems was almost double from what it was budgeted for, reflecting that there was quite a lot rework done with the designs along the process. Many of the user changes as well as medical equipment interface requirements had to do with the electrical systems, like the location of outlets and the size of switchboards. The electrical contractor was in addition affected by changes in the plumbing and HVAC works, because the changes in these systems usually meant some rerouting also in the electric system. Another trade that was usually affected by changes into the MEP systems was the general contractor or CM, while extra holes needed to be made or it was necessary to redo firestops, airtightness or soundproofing around those new holes. Extra work on the holes accounted for almost half a million euros, which is already 0.5% of the whole construction budget, highlighting the significance of seemingly small individual changes combined. The interdependencies between trades in change cases were likely one reason for the overall delay of the project, yet it is difficult to prove that.

An example of a good change in the project was the invention of a standardized ceiling mounting system for the medical equipment. It was one of the largest additions in terms of cost to the general contractor's contract, but saved a significant amount of money from the owner as the alternative system would have been much more expensive. In the original drawings, the medical equipment mounting flanges were designed to be attached directly to the concrete slabs which would have had to be reinforced with extra pouring of concrete. Some of this work had already been done when the owner ordered the installation of several hundred steel frames where all different types of equipment could be directly installed. It is not completely clear at which stage the decision formed to use this alternative system, but it definitely had a positive impact on the installation cost and time of the fixed medical equipment. All necessary connections could be brought to the frame and systems above the dropped ceiling installed before the exact equipment choice.

Project success

The project went slightly over budget and was handed over 1.5 months late. However, the opening of the hospital was done on schedule due to a fast move-in phase. Due to the late final handover, some of the contractors had to pay penalty charges for the owner, including the general, HVAC and electric contractors. Financially the delay hit most to the general contractor that needed to cover costs of running the site longer as well as the penalty. Their contract also reached the maximum price, which signals a very poor margin overall for the project. The other contractors did somewhat better although their financials were also affected by the penalties.

There have been some changes already to the hospital functions such as surgical robots added to the operating rooms, but overall the new hospital has fulfilled its expectations well. Compared to similar hospitals constructed elsewhere in Finland, the cost per square meter was estimated to be around the average cost, making it a rather successful investment for the owner. The users have been very satisfied despite the project management side issues.

4.1.3 Hospital project C: Capacity increase for growing demand

Project C was about extending a hospital with a new building to a growing region in Sweden. It was estimated that the hospital would need approximately 25% more capacity in the next years to cope with the growing population. The new facility contains a new emergency room, maternity ward, imaging department, a new surgical unit and intensive care unit as well as a sterile processing center. The project started with the demolition of old buildings, and the new building was connected to the old part of the hospital via a tunnel. Construction commenced in 2014 and at the time of the writing, the new hospital was planned to be commissioned spring 2017, three months ahead of the planned date.

Need for the renewal of the hospital campus was realized in 2009, when an analysis of the real estate needs for the future was carried out. The need to change wards to single rooms with own bathrooms and to cope with the space requirements would have meant a reduction of half the ward places without a new building. A plan was crafted to solve this problem, and the decision to go ahead with the construction of a new around-the-clock hospital and renovation of old buildings was reached in 2013. The new building accounts for approximately 80% of the contract value, with the renovation of old facilities continuing after the opening of the new-build.

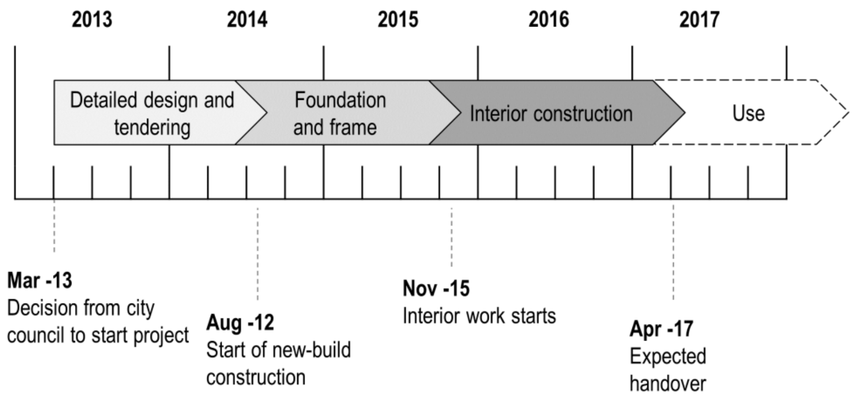

Figure 11: Schedule of Project C

Project organization and communication

The project was contracted by the region's real estate company for health care facilities, which is fully owned by the regional council, and they were responsible for developer duties. The tenant of the facilities is the hospital, which is also owned by the regional council, but there is no common steering for the two subsidiaries. The contract was a design-build contract, in which the design-build or general contractor oversees the detailed design and construction of the facilities based on the functional needs set by the owner. The contractor was taken into the project after the concept design phase, but there were still some open questions about the scope of the project at that point. Finishing the room program and requirements for each room type was one of the first tasks for the design-build contractor after they were hired to the project.

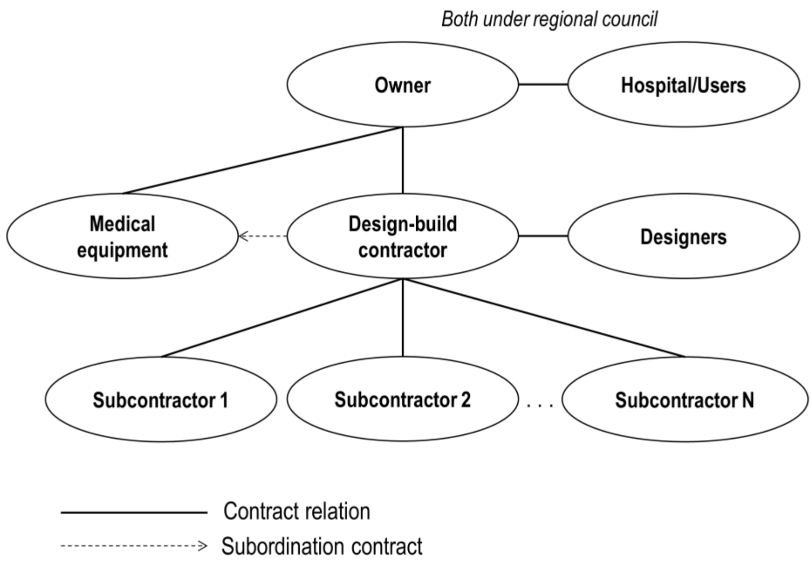

Figure 12: Organizational structure in Project C

The project management responsibility was fully on the general contractor, which had contracts to all the designer companies as well as all the subcontractors. Fixed medical equipment was not included in the construction contract, but their installation and fitting were also coordinated by the general contractor. Payment of the project was divided in two parts: a fixed sum of margin and an open account for costs from materials, labor, subcontractors and other variable costs.

The project organization was quite simple due to the design-build contract. The general contractor had all the different stakeholders involved in the design and construction activities contracted directly to them. The real estate company as the owner supervised the progress and was ultimately responsible for financial questions arising from scope increases and other change orders. The hospital side was tightly involved in the design of the facilities, although they did not have a direct contractual relationship with the design-build contractor. One of the contractor representative described having multiple roles in a way: the traditional role of a contractor discussing financial issues with the client but on the other hand a partner that had to be in very close collaboration with the hospital and the future users of the facilities.

The relationship especially with the hospital was described as good and trusting, with both sides understanding each other's opinions and arguments. For example in the case of unexpected changes or design requirements, the contractor side challenged the user to make reasonable requests, but also accepted the fact that in order to build a modern and functional hospital some changes are needed. Being in the role of a tax payer and user of the public health services themselves helped the contractors take a critical view on the requests if it was for to improve care quality or just something "nice to have". In the beginning, there were several meetings per week where the design details were discussed among the owner, user and contractor sides. Regular meetings continued until the end of the project.

The need to have a systematic method of documenting information, drawings and change requests was strongly emphasized by the interviewees. A design-build contractor representative stated: *"There is so much more information in a hospital … That is easier in the ordinary, smaller projects."* The process with which every change had to be accepted was well-documented, and included both normal and "fast-tracked" changes.

Changes during construction

The change logging during the project was slightly different from other studied projects as the design phase was not separated from the construction contractually. Also from the interviews it became clear that the respondents did not really separate those two phases in their minds when talking about changes. A change in their perspective was something that had already been signed off by the owner and users but then changed later, as it also required going back to the design and reworking the drawings. For instance, when familiarizing with the 3D model a nurse recognized that a windowsill in the post-operative recovery room was too high and blocking visibility. She had already earlier signed off the drawings so in that sense it was a change, but it did not have any effects on the construction operations. There were quite a lot of additions to the contract, almost 10% of the contract value, but majority of these changes occurred already during the design phase or before work in that area had started. These scope changes have not affected the project time, which actually shortened during the course of the project.

The largest changes had to do with different hospital systems. Some systems were added during the detailed design phase and changed even in the construction phase, causing some schedule issues and rushing on site. The electrical subcontractor was considered the most affected by the changes, as many of the added systems fell to their area of work. Examples of systems added and changed were the nurse call system, a location system to know where doctors are, door phone system and system for the ward rounds. The systems had different software and hardware requirements depending on choice of system, leading to more cabling work. The changes surfaced little by little, and even some rework had to be done due to the changing requirements. Additions to other MEP fields included the addition and changes to the purified water system in a part of the hospital, as well as a ventilation system for medical gases in the operating rooms also leading to rework and negative consequences.

In addition to the new systems, the number of power, computer and medical gas outlets in rooms changed quite a lot. For the medical gas piping, new connections had to be made after the system was already once finished, resulting in rework. The connections had to be validated again for purity after the changes. Usually user changes were detected early enough to avoid reworking. One reason for this might have been the proactive approach that the construction management team took in continuously communicating the status of work to the users. They made clear which decisions had to be made to keep up with the schedule and which parts could not be changed any more while they were already being built. The contractors also proactively suggested changes, and for instance the outer surface material of the building was changed to another one, enabling a faster closing of the building and earlier start of the interior works. This is an example of a change that increased the project quality and efficiency.

The installation of fixed medical equipment led to several smaller individual changes compared to the larger system changes, but altogether these small things accounted for a significant amount of work. Mainly problems arose from fitting the equipment in with all necessary connections. Sometimes there had been omissions in the installation information, as it was noticed that necessary mounting pieces were missing to attach equipment to the concrete ceiling due to parts being omitted from all the contracts.

Project success

The construction project has seen over 10% of changes, with the budget increasing to more than SEK 1.1bn (EUR 115m). However, much of this increase is money and scope transferred from other contracts to the construction budget and not actual cost increase itself. Schedule-wise, the project faced some delays in the foundation work phase due to surprises in soil conditions, but at the time of the interviews it seemed that the new building can be handed over three months ahead of the original schedule due to the efficient installation and interior work phase. Thus, it can be said that the project appears successful in both end result and process perspectives. The working relationship between parties has stayed on a good level to continue to the next, renovation phase of the project.

4.1.4 Hospital project D: Place for world class medical technology

Hospital project D was launched purely for one purpose: to build a facility for the most advanced imaging and surgical technology. The Swedish university hospital in question realized in the early 2000s that despite having multiple relatively new buildings, none of them could really answer to the high performance requirements needed by today's medical technology. Imaging equipment such as MRI, PET and CT scanners or combinations of those have strict vibration, ceiling height, load-bearing and radiation shield requirements to the surrounding structures, and none of the existing facilities could fulfill them. One of the most important requirements set for the new build was that it must be possible to install an MRI scanner weighting tens of tons anywhere in the building. The spaces in the new hospital are all unique including hybrid operating rooms, a movable MR-camera, cyclotron for making radioactive substances, new labs and sterilization center. Very little prefabrication was used in the hospital, for example the concrete slabs were all poured on site to enable layout and functional changes during the life cycle of the building.

First design drafts were made in 2007–2008, but the plans were put on hold for the next couple of years. The project later resurfaced in 2010–2011 and design work was resumed, but the designs had to be already reworked while changes had happened both in technology and the staff. The construction itself was divided into phases: in Phase 0 old buildings were demolished, the Phase 1 included the construction of the foundation and superstructure, Phase 2 accounted for finishing about 80% of the building and the remaining part is due to be finalized in Phase 3. The progress of the phases can be seen in Figure 13. By designing the building concurrent to the construction, the latest developments in medical technology could be utilized, with the third phase even further postponed. The project was described to target "a moving goal", and the phased design process helped to cope with this uncertainty of future uses. The second phase of the building was finished in May 2016, and the final phase should be ready in early 2018. The total budget of the project runs at about SEK 1.8–2bn (EUR 190–210m), with the equipment accounting for half of the sum.

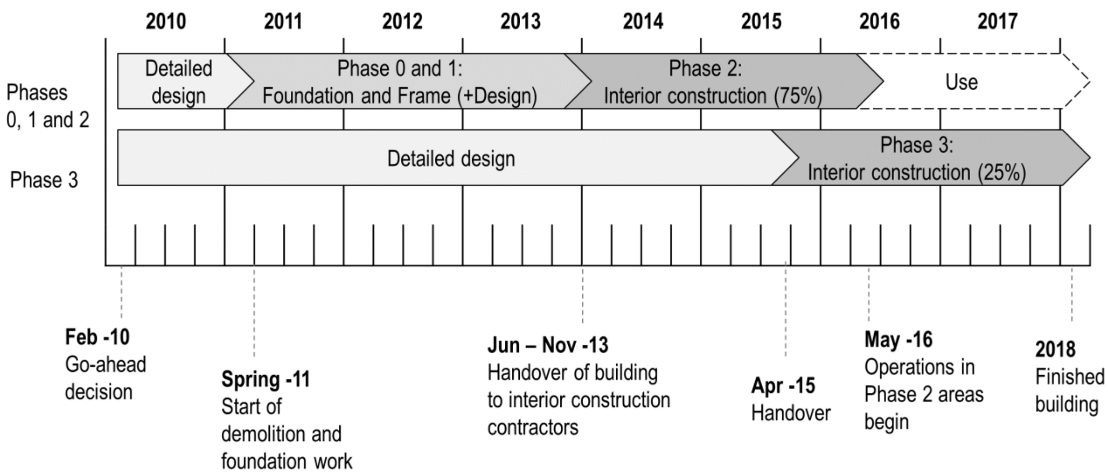

Figure 13: Phased schedule of Project D

Project organization and communication

There was discussion over which project delivery method should be chosen, but in the end the owner and designer parties did not think that contractors would have much valuable input in the design phase, so a traditional design-bid-build (DBB) method with a lump sum contract was chosen. Some of the contracts were actually procured with unit prices, which made it possible to extend the project scope when further designs were finished, as no plans for the third phase existed at the time of the previous tenders. The general contractor has had responsibility for scheduling and project management, and the subcontractors were contracted through them. The hospital has taken care of the procurement of medical equipment. The owner, which is the regional healthcare real estate company, has a project manager who has been supported by consultant trade supervisors for each field, typically coming from the design companies that had worked on the design. A design company that was contracted by the owner worked with coordinating the design activities and collaborating with the end users in design development.

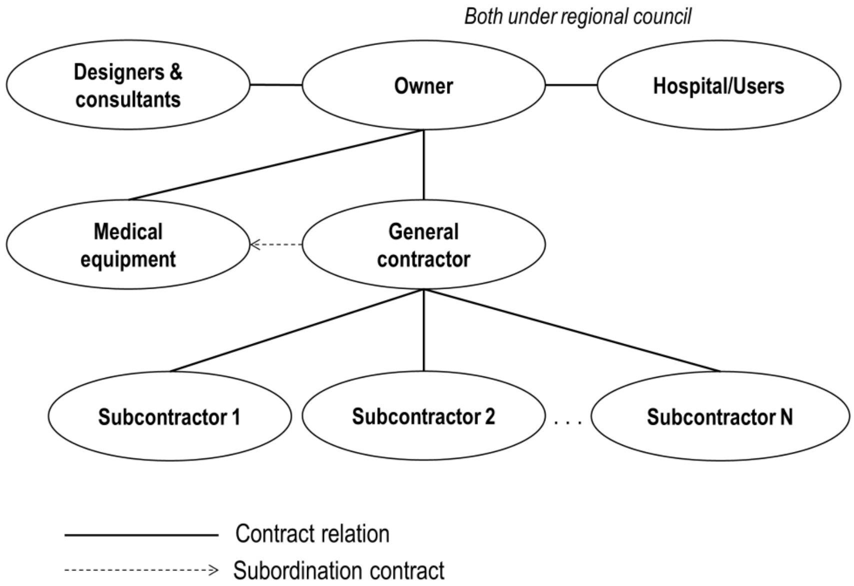

Figure 14: Organizational structure in Project D

At first the communication was stiff, as the formal route was to communicate via written RFIs that were saved in the project database. This was soon noticed to be too slow and arduous, and the subcontractors started talking directly with their trade supervisors. It helped the subcontractors hear about upcoming changes earlier or to adjust better the workload and resourcing. Still, a lot of formal documentation was done through the RFIs or at least a written confirmation before making change work.

The change process usually worked through either of two mechanisms: larger changes through new releases of drawings or smaller, owner-initiated changes in between releases not taken separately to the drawings but communicated by the supervisors. The sources of these design changes were not always clear for the contractors, if it was about new design requirements from users or if it had been an error in the earlier designs. At the stage when Phase 2 was supposed to get finalized, the general contractor banned the design team and owner to release any more new drawings for that part. The trick did not quite work as there were hundreds of smaller design changes posted during those last five months meant for testing and finalizing touches, showing the ineffectiveness of "putting a stop" to changes.

Changes during construction

As the whole building was built around the medical equipment it would contain, also changes were focused on this area. The largest change during construction was the postponement of one floor that was supposed to be built in Phase 2 to Phase 3. The reason was in the procurement process of equipment for the operating theatres. Because the technologies wanted for the ORs were very advanced and not even on the market yet, the hospital wanted to try a new kind of tendering approach, a dialogue-based process, to choose one supplier for the whole system. The process took a lot longer than expected, and at some point it became clear that the floor was not going to be finished with the rest of that part of the building.

A functional change happened when the ultrasound imaging department was decided to be moved out of the building as it did not need to be located in this high-tech building, leaving a quarter of a floor to other disciplines. The relocation was thus not made because operations changed but to optimize the use of spaces in the hospital campus. The freed space was redesigned for other purposes, but there were also construction consequences as some already built walls had to be taken down and the work in the area was delayed during the redesign.

Some change needs were not noticed until very close to the opening of the hospital. The installation of much of the equipment was focused on the last months so there were a lot of details that had to be taken care of, and information was coming from many different directions. There was no time to make new drawings if a change occurred, and control was slipping. A lot of small changes stacked together: the positioning of outlets, the mounting methods, and connecting pieces. A connection cable was forgotten to be procured at least on one occasion and then searched for through the country so that the installation crew could finish their job as planned and not schedule it for a later date.

One example of a change surfacing too late in the process was the installation of mandatory controlling devices for the electricity in ORs, as normal fuses are not allowed to be used in them. This safety requirement had somehow been missed in the design, and the change to add these devices was made while testing and ramping up the production in the hospital. The change prevented the thorough testing of the systems, which raised some concerns among the contractors and users. The electrical subcontractor was the most influenced by changes overall, both in number of changes and their cost, and they were at risk of falling behind the others.

Many things have been also learned from the construction of Phase 2 and will be done differently in Phase 3 of the project. Medical equipment suppliers will have more communication directly with the contractors, which helps coordinating responsibilities during installation. Small things mounted on the walls such as hooks, mirrors, holders, clips and so on will not be put in place based on the drawings, but the users will come in and show the places during the move-in in Phase 3. In the previous phase there had been a lot of rework happening while users wanted to change the locations of these small things, and it took a lot of time and two workers to get everything in optimal places. Also, all the changes happening during Phase 2 have been directly corrected to Phase 3 drawings.

The contractor side view to project changes was that most changes implemented were for the best of the project and therefore had to be made. More severe problems arose only when changes happened at a late stage and they could compromise the schedule for opening. It was signaled to the owner and the users that changes were not wanted any more during the last months before handover, but it was difficult to stop them if it was a critical issue for the functioning of the hospital. The largest changes did happen already in the beginning, and although changes kept coming later, they became smaller. The contractors have also learned during the project where changes would most likely occur, and sometimes deliberately postponed construction on those systems that from experience would change, taking the risk that eventually the original plan could be followed.

The exact consequences of the changes discussed are hard to quantify, but as the contractors emphasized, the efficiency loss has probably the largest "unnoticed" impact that was realized too late. While the compensation for most of the workers is based on production and not time, disruptions in the workflow caused by rooms that are put on hold to wait for decisions are significant to their efficiency and thus to profitability. While project planning is usually done in a very linear way, these interruptions in the work flow also make it hard to monitor progress and arrange work between different trades. Resourcing was pointed out as another problematic area in case of a lot of changes: declining efficiency means more hours to be spent on the same tasks, and it is not always easy to get more workers trained and available for the project to use. The electrical subcontractor evaluated that there were times when their estimated workload equaled 37 workers on site to stay in schedule but they were only 15 people in reality. However, they felt that too much extra time or resources is impossible to include in the tender offers as that would mean losing to the competition.

Project success

The original schedule given by the owner during tendering seemed as unrealistic to the general contractor that their first task was to revise a realistic time plan. This revised schedule was kept quite accurately, and in the end the operations of the facilities made in Phase 2 started only four weeks after the date set in the initial plan. However, the finishing some of the functions was postponed to be done after the opening date and work at the time of the writing continued in some areas of the original Phase 2 scope, including the whole floor moved to Phase 3. Other postponements were usually made for changes that occurred too late and were not able to be finished in time for the opening date. Working after the handover is very difficult and time consuming, and some of the work still stays unfinished due to the difficulty of fitting the remaining work to the schedules of the open premises. Even if the tasks left would be small in scope, when they are repeated in 20 rooms it takes considerable time with these restrictions. In addition, taking over half a house when building in phases has had its own difficulties, when the construction work should disturb hospital operations as little as possible. The trade-off needed for buying more time to design and learn from mistakes in previous phases has its downsides when the building stays unfinished.

Schedule seems to have been a more limiting factor in the project compared to cost, and the budget has increased with a few hundred million SEK along the way. This seems natural as the plans have gained detail and equipment choices were made. The robust structure demanded by the imaging equipment was of course more expensive to construct than in a normal hospital building. The final price tag will only be known after the rest of the building is successfully commissioned. Change in the facilities will continue long into the future, while there are some rooms that will be finished only when the technology in them is ready to be taken in use. The long-term adaptability and convertibility were paid a lot of attention to in the design phase, so for example equipment changes and modifications in an operating room can be made without affecting the use of the others. Only time will show if these up-front investments to building flexibility will be utilized, but the project has reached its goal in terms of the hospital not needing to adhere to limitations created by old and inflexible building stock any more. The end product can be said to be one of the most modern and adaptable seen in the Nordic countries.

4.1.5 Hospital project E: Patient tower to fulfil legislation

Updated regulations in hospital construction created the push to build a new patient tower to a private hospital in the United States, as old hospital beds would have become illegal to use after a cut-off date. The main part of the project consisted of different acuity patient rooms including intensive care, as well as some laboratory and sterile processing facilities, and the project value rises to about 200m USD (187m EUR). The new building will be attached to the older ones on hospital campus, and it is planned to be taken to use in the second quarter of 2017.

The most distinctive feature of this project compared to the other researched projects was that the client was a private, for-profit hospital and thus a very different kind of owner. There seemed to have been a very specific understanding about the wanted hospital, and the future users of the facilities had quite little impact on the design process, as there are strict standards inside the company on requirements for operational models and requirements for different spaces. The project had a very clear goal and was in this sense in much tighter control from the owner than most of the other projects.

The detailed planning and validation of drawings was done in increments, for example with increment one being the steel structure. In this way the design of the building could be done to some extent concurrently with the construction, as the approval of the plans by necessary authorities takes usually a significant amount of time, postponing the start of construction by years in some cases. The incremental permitting process as well as some other new practices like lean construction methods and prefabrication were tested on the project along the wishes of the owner.

Construction started in early 2014. When the interviews were conducted in late 2016, the project was in a stage where the interiors had been finished for most part, and installation of equipment had started. A part of the building around the elevator shafts was however badly postponed due to rework to ensure the structural integrity around the elevators. The initial scheduled handover was already in December 2016, but was postponed to March 2017 due to changes in the ground working scope. Because of the problem with elevators, the date was further pushed to June 2017.

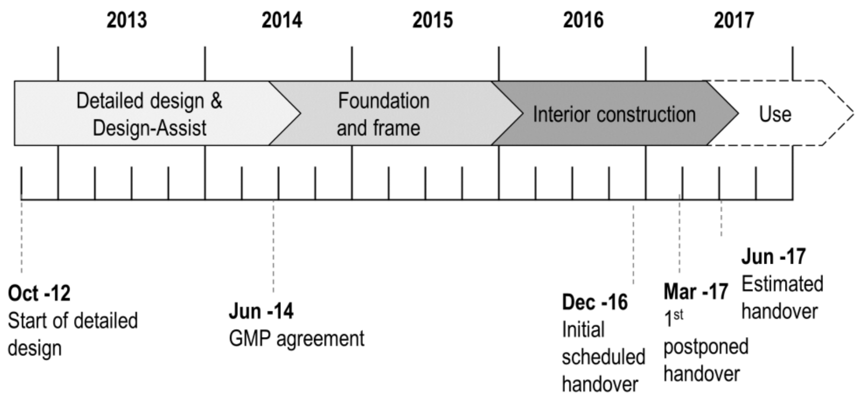

Figure 15: Schedule of Project E

Project organization and communication

The project was procured as a cost-plus contract with a guaranteed maximum price. The project delivery method was design-assist with early involvement of the general contractor and their subcontractors, which was found as a useful method acknowledging that over 3000 RFIs were solved at the pre-construction stage. The owner has a longer-term relationship with this specific general contractor from several previous projects, so in that sense the project setting was slightly different than in one-off projects. As mentioned, the actual client was the corporate level organization and their project manager, and the local hospital had less power and involvement with the construction project.

There was also an amount reserved for construction contingencies, which is a pool of money reserved for any unexpected changes in the scope of work. Unlike in typical projects, the owner insisted on managing the use of this pool of financing themselves, instead of the general contractor. This affected the change management process that needed to be on a much more detailed level than otherwise, when the contractor would use it as a buffer in case of small changes and would not need to report them to the client at all. More resources were needed for running the change order process, and a specific person was appointed to handle it.

There was also the will from the owner side to try some lean techniques, such as pull-planning for creating the detailed schedule. Overall the commitment level of the subcontractors had been good to the collaborative ways of working, but reportedly there was some tendency with them to “fall back in their old ways”, especially when the schedule pressure at the later stages started running higher.

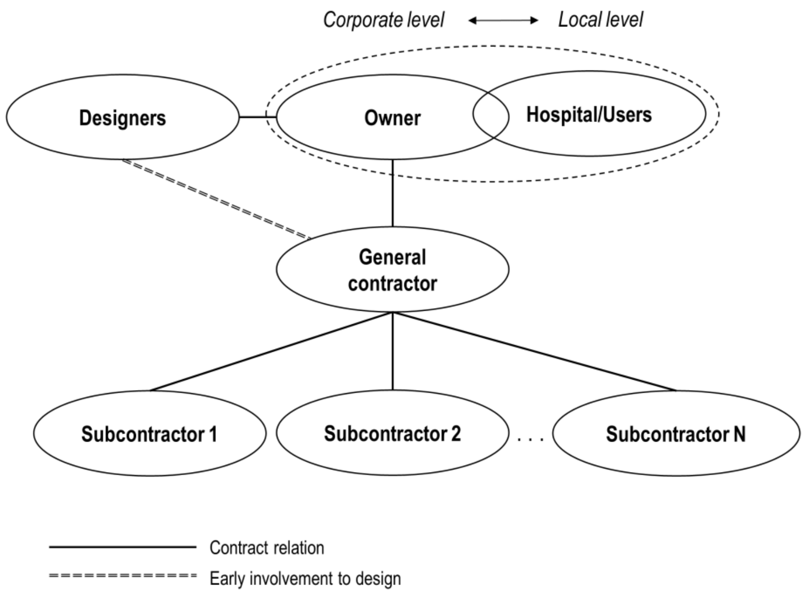

Figure 16: Organizational structure in Project E

Changes during construction

As mentioned, there have been very few user-initiated changes during the construction. When comparing to previous projects the same owner has commissioned, this project has faced fewer changes overall both in number and in cost. The lack of changes results most likely from the lack of user involvement altogether during the design process, but also as the spaces built are quite repetitive and in that sense simple. Interestingly, there were quite large changes happening in the one part where users had the power to comment the plans, the laboratory spaces. The issues came up almost accidentally, as the plans were only shown to the users when the interiors of the floor started to be built. Due to the redesign, walls had to be torn down and replaced to ensure that the operations would fit in the new facility. The people working in the facility had not been there yet when the design was made, and it was not based on the current operational model.

An interesting choice from the owner side was the construction of two floors as shell space, waiting for the funding decision from the corporate level to construct the interiors of these spaces later. Some of the shelled areas have already been decided to be built. The building of the areas has not caused trouble for the construction so far, as it was already prepared for in the designs that the spaces would be filled later and all needed connections to for example MEP systems existed already.

A larger issue have been the regulatory authorities who have demanded quite a few changes during the construction. One estimation from the interviews was that perhaps even half of the changes have come from the requirements of the authorities. It might depend on individual inspector what is allowed and what not, and there was even a case where a previously accepted solution had to be changed while it failed to reach the standards from another official's opinion.

Working with the authorities has thus been quite stressful and frustrating for the whole construction team. At this specific state, the relationship to the regulating authorities and even the personalities of the individual inspectors can play a large role as the building code can be interpreted in different ways, and most people had not been used to this while they had previously worked elsewhere.

Designing the building in increments and building concurrently had its downsides, when it was found that the structural frame was not enough to carry the loads of the elevators that were designed in a later increment. Due to this the structure had to be reinforced and it has been delayed a lot from the rest of the building. The elevators are also a critical part of the building, so it is not an option to open the facilities to use before they have been completely finished. The incremental design process was a new trial for the owner and general contractor, and the structure and elevator shafts should have been designed in the same increment and not separately.

Project success

The project faced some issues especially from the authorities and necessary approvals. The unexpected changes in groundwork and the rework of the elevator structures have had significant cost and schedule impacts, and combined delayed the schedule for 6 months. The project goal in terms of what the building should consist of has been quite clear from the start, so it would be surprising if there were any problems with the suitability of the facilities to their use.

4.1.6 Overview of the case projects

The five cases, of which two are from Finland, two from Sweden and one from the United States, represent different segments of hospital infrastructure needs. Psychiatric hospital facilities like in Project A have the least typical components of hospital building, and resembled more hotel or office building construction. In the other end of the spectrum there are high-tech imaging and surgical spaces that need advanced technology and a lot more specialized systems as seen in Project D. The other cases tend to be a mixture of these two types of construction, and lie in between in complexity and size.

Common to most of the cases is a strong user influence during the design and construction. Only in one case, Project E, the users of the facilities had a very limited say on how the result should look like. In some cases, the owner and the users are from different organizations, creating one more interface and stakeholder to the process. Even inside one organization there might be different levels of decision makers, like the local and corporate levels that can act almost like separate entities. A difference exists also between Sweden and Finland in how the ownership has been arranged, although through the healthcare reform this will bring Finland closer to the Swedish model. The balance between empowering the user and not taking their every wish as a command is delicate and requires strong project management capabilities from the ordering entity, no matter the organizational form.

The Nordic cases were all from the public sector, while hospitals in the United States are many times built by private owners. Private owners are further divided to non-profit and for-profit organizations. Different owners have different goals in their projects. Private owners might be in some way even more cost sensitive compared to public owners, as the operating profit of their units is of high importance. In the public sector, it is the political decision makers who have the power to set limits to the budget, after which the users and owners of the building start negotiating how to best use the money. For both types of users, an efficient use of space is important to get the most out of the built facilities.

Table 7 summarizes the key background characteristics of all the projects. All in all, the projects provide a variety of contexts where to observe the phenomenon of changes during the construction phase.

Table 7: Summary of case projects

	Project A	Project B	Project C	Project D	Project E
Country	Finland	Finland	Sweden	Sweden	USA
Time of completion	2016 Q2	2015 Q2	2017 Q1 (est.) (New-build)	2017 (est.)	2017 Q2 (est.)
Total cost	EUR 35m (Total) EUR 23m (Phase 2)	EUR 100m	SEK 1.1bn / EUR 115m (New build)	SEK 1.8bn / EUR 190m	USD 200m / EUR 187m
Total area	6 000 m^2 (Phase 1) 12 000 m^2 (Phase 2)	36 300 m^2	22 000 m^2 (New-build)	21 000 m^2	27 000 m^2
Project delivery method	Design-Bid-Build (2 phases with different contractors)	Design-Bid-Build with Construction Management	Design-Build	Design-Bid-Build	Design-Assist with Construction management
Contract type	Divided lump sum / Multi prime	Cost plus / GMP (for general contractor, others lump sum)	Cost plus / GMP	Lump sum, Unit price	Cost plus / GMP
Spaces included	*Psychiatric hospital:* Inpatient wards for children, youth and adults Outpatient wards Rehabilitation and therapeutic spaces PET-TT imaging	*24/7 hospital:* Operating rooms ICU Maternity ward Sterile processing Dialysis Outpatient wards Cafeteria	*24/7 hospital:* Operating rooms ICU Maternity ward Sterile processing Imaging Emergency room	*Imaging and surgical units:* Operating rooms including hybrid ORs Imaging (X-ray, PET, MRI, CT) Sterile processing Cyclotron	*Patient tower:* Inpatient wards ICU Pharmacy Laboratories Sterile processing
Owner type	Public	Public	Public	Public	Private
User and owner in same organization	Yes	Yes	No	No	Yes/No
Project complexity	Low	Medium	Medium	High	Medium
Change work impact on project	Low-Medium	Medium-High	Medium	High	Medium-High

4.2 Changes in hospital construction projects

Findings from the cross-case analysis of the five case projects are presented in this section. First, some descriptive information of the changes based on the interviews and change order data is offered. The emphasis is on the qualitative features, but they are supported with quantitative project data when possible. In the following sections, change causes, change effects, and change mitigation measures are discussed in more depth.

4.2.1 Change characteristics

The estimated change order percentages in the projects varied between approximately 5% and 20% or the original cost, with the originally less well-scoped Projects C and D at the higher end of the scale. The exact change order values or change order percentages from original cost estimates were however hard to come by, due to the diversity of data from all cases. Data was gathered from the actual project documents, which meant it typically was in an uninformative format and included items that were irrelevant to the research questions, such as index raises to contract sums. The percentages presented fall in the ranges reported for other types of construction projects by sources in the literature review, and as in those articles, the variation in the percentages seems to be quite high. Additionally, in projects like C and D change order percentages cannot be directly used to inform about how successful the project management has been, as the original estimated cost does not really represent what the scope was in the end. The value of change orders in these cases is rather a description of how much the project evolved during its course than a straightforward success measure.

Change order scale

Most changes in these projects were reported to be relatively small individually, both in cost and in scope. This was stated in majority of the interviews and confirmed with actual data from those cases where cost information on changes was available. The data is not completely representative in terms of change size, as for practical reasons some smaller change orders have been combined together as one larger change order, but still supports the view that changes to a large extent have been relatively small in cost compared to the whole project. Figures 17 shows the distribution of cost adding change orders concerning the general contractor in Projects A and B, where it can be seen that there were actually very few major individual changes. Those few larger changes accounted for the majority of change costs arising to the owner, and happened typically already in the foundation phase.

The small financial scale of most changes does not still necessarily mean that those changes would be easy to handle from project management perspective. The stacking of small changes to larger ones and the combined effect of having to deal with a lot of small issues was noticed to be one important reason for delays and difficulties in the projects investigated. The impacts on time and coordination of work might be significantly larger than the cost that the owner sees, making it a source of dispute between the owner and contractors.

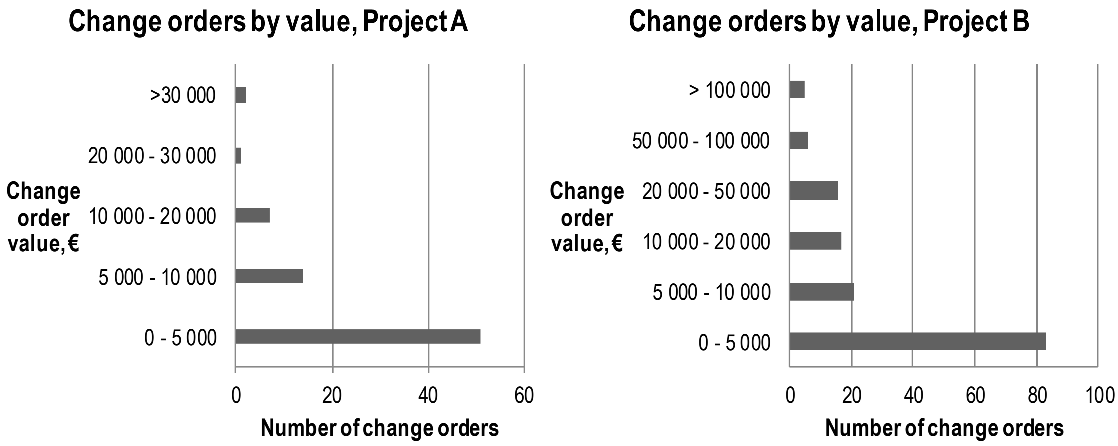

Figure 17: Change orders by value, Projects A and B

Change order timing and frequency

Changes were often described as occurring "continuously" during the projects, without any sudden peaks in the rate of changes. An example of a time when more changes did seem to occur at once was related to the mock-up spaces built on site. Feedback and change lists were typically collected from the users in relation to the mock-ups and those changes were then taken to the rest of the similar spaces, explaining the increased change amounts. Most of the change events identified from the interviews happened in the interior construction and installation phase. This is typically a long phase and prone to changes caused by user requirements or equipment fittings as the project draws closer to its finish.

Few but perhaps the largest changes happened in almost all of the cases already in the foundation phase, as changes in the excavation amounts or foundation types impose significant "one-off" costs. These types of changes can take a lot of time and money, but as the project is still very simple in that stage, the problems typically are not very complex to deal with. Most often the largest effect from an unexpected change in the foundation phase was that the schedule of the project was delayed from the planned one and had to be caught up in later, more complicated stages of work.

Both findings were supported by the interview responses. The project manager from Project D described that changes grew smaller and smaller in scale as the project went on, supporting the argument that the largest changes happened already early in the project. From Project B, the contractor representative stated that changes really started coming up in quite late phases of the project, when it was time to get everything finished in the rooms.

Trades affected by change orders

Different trades were seen to be differently affected by changes. Charts of the division of change orders according to trades from Projects B and D can be seen in Figure 18. The figures exclude those trades that had negative change order amounts, i.e. times when money was credited back to the owner.

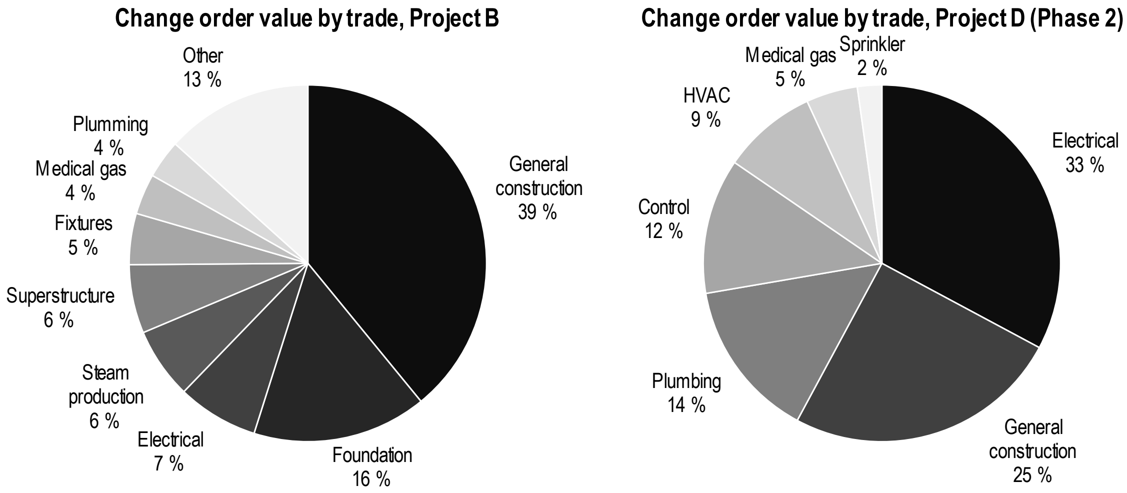

Figure 18: The distribution of change orders by value, Projects B and D

Electrical contractors were mentioned most often as a trade suffering from changes, and this seemed to be supported by the numbers from Project D in the interior construction phase (see Fig. 18). The electrical contractor representative felt that they had been stressed with many changes directly to the systems they were managing. Other MEP trades are also represented in both projects from which data is shown. A representative of the HVAC contractor organization from one of the projects had the opinion that they were not specifically affected by changes, while they typically were the first to start with installations. In Project B, the general contractor carried the largest part of the cost adding changes. There were some structural changes to how the building was done, but in addition the general contractor usually suffered from ripple effects due to other changes, for example by making additional holes for the changed MEP trades. Their overall contract was also by far the largest in value in the project.

The difficulty of resourcing was brought up in many interviews in terms of changes affecting different trades. It seems to vary depending on the situation, which trade is the bottleneck that is lagging the whole project behind. Resource problems were reported with at least general, electrical, HVAC and plumbing contractors as well as some designer groups. When changes occur, there might be the sudden need to increase the amount of blue collar workers or supervisors. However, to efficiently execute a project the resources have been optimized for the planned workflow, and skilled resources might not be available to be added with short notice.

This section of analyzing the scale, timing, and affected trades with change order data provided some insight in terms of the changes in the projects, but overall provided little help in answering the research questions about why changes come about in hospital projects. In the next sections, the individual changes are analyzed in more depth to be able to provide insight on their underlying causes.

4.2.2 Change root causes

Change causes were analyzed with the technique of root cause analysis. The tool used to conduct the analysis was the cause-and-effect or Ishikawa diagram (Andersen & Fagerhaug, 2006), named after its inventor Kaoru Ishikawa. The tool was initially developed in the 1960s for quality improvement to identify possible causes of variation in a manufacturing process, but has since been used for various types of root cause identification, including an investigation on rework causes in hospital design and permitting by Feng and Tommelein (2009). It is a way to systematically group and analyze causes, and evaluate which might of them might be the root causes (Andersen & Fagerhaug, 2006).

The categorization of the main sources of changes, used for defining the main branches of the diagram, is adapted from previous literature with a few additions and modifications. The main influence came from the taxonomy of Sun and Meng (2009) presented in the literature review. The client side as a source of change was divided into two categories, *Users* and *Owner*, as the users and the actual owner project organization were interpreted as two distinct players with different priorities and skills. *Design, Contractor,* and *External environment* categories were also recognized from existing literature. Specific to hospital construction, two new categories were created: *Equipment and systems*, and *Operations*. These emerged mainly based on the interviews, but also from the point of view of the special characteristics in hospital construction. Both of these categories are interesting in the way that they combine project internal decisions with external influences as sources of changes. An additional category of *Contractual relationships* was also added, as it was perceived as an important driver causing project change to individual contractors and steering their actions.

Root cause analysis aims to identify what factors are causing a problem, and it can be conducted as a brainstorming exercise (Andersen & Fagerhaug, 2006). Here, a different type of approach was used, based on the specific change events recognized and listed from the interviews. First, the individual change events were analyzed step by step, first recognizing the source category from the above-mentioned alternatives and then investigating further what triggered the change to eventually reach the root causes. Two levels of change causes inside each source category were identified in this way, each going deeper into the issue. Typically, there were only one or two specific change events per the lowest level cause. The resulting, full cause-effect diagram can be seen in Figure 19, and each of the individual source categories including the lower level causes is presented on its own in Tables 9-16, broken down by project. Lastly, the root causes behind the identified issues in each branch were recognized.

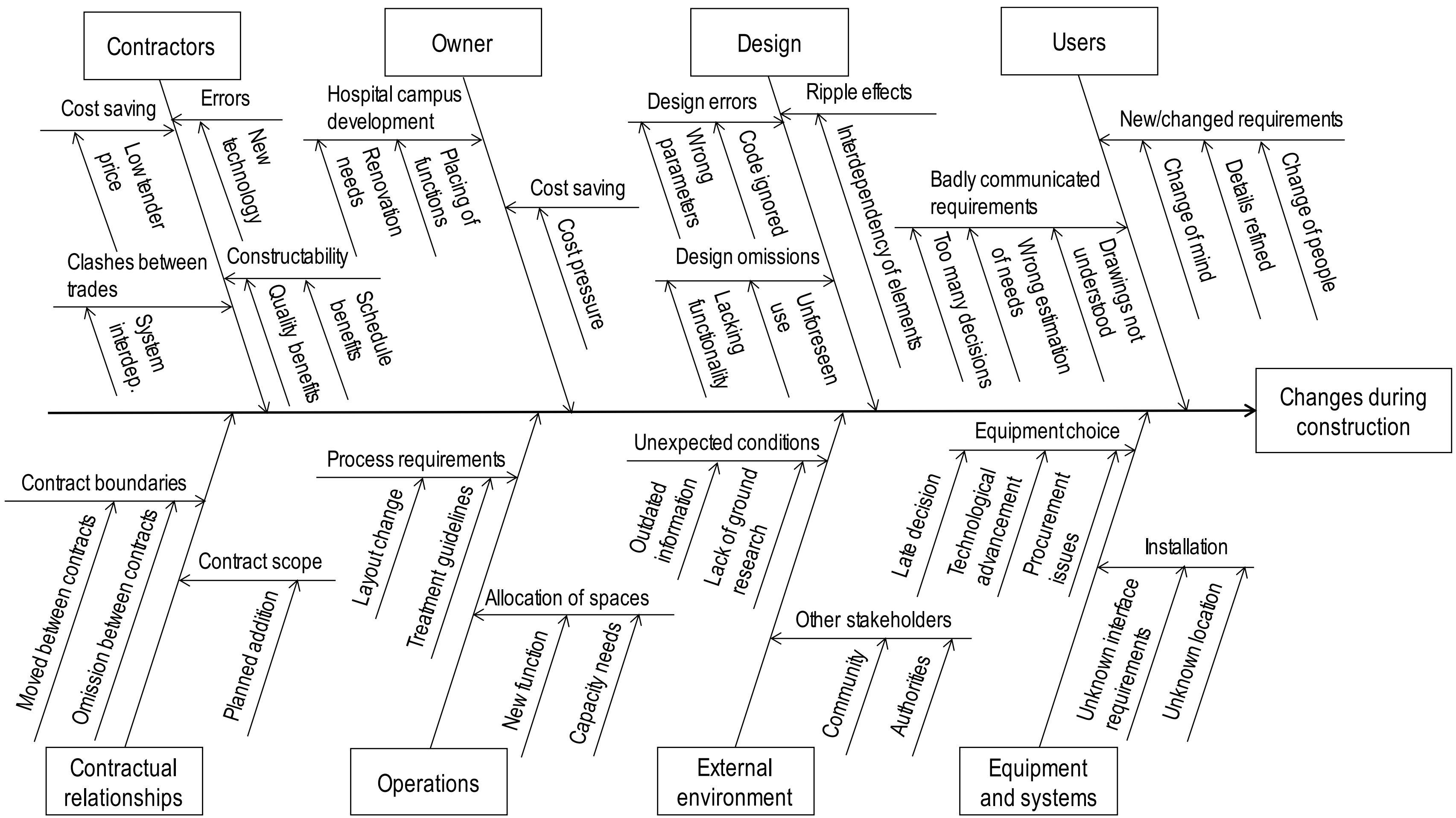

Figure 19: Three level cause-effect diagram of change causes

Figure 20 shows the relative proportions of the high-level change source categories by the total amount of change events. As the individual change events differ by severity, no definitive conclusions can be drawn from the number of events in each category. However, in general, the interviewees highlighted the categories with the most change events, namely Equipment and systems and Users, as especially problematic in terms of changes.

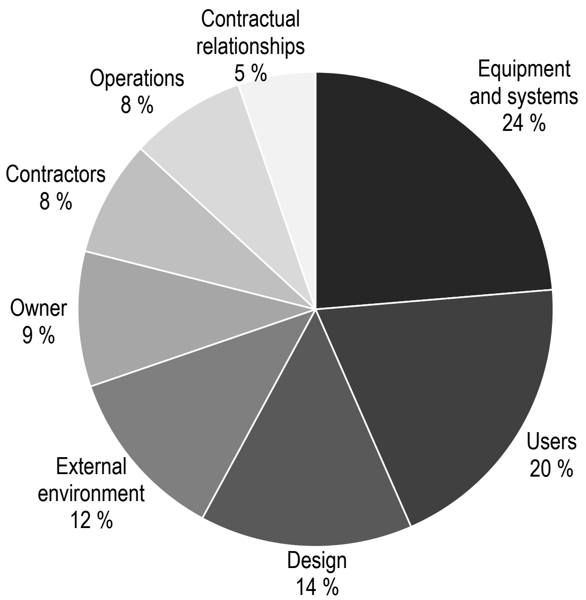

Figure 20: Change event source categories (n=76)

Moreover, the cases with the most interviews had also the highest number of change events discussed in the interviews (see Table 8). The Projects D and E had the least number of concrete change event examples mentioned. This might have been because the projects were larger and thus some smaller scale change issues were not perceived as important, or that these projects were still ongoing and likely no reflection on change matters had been done yet.

Table 8: Change events by project

Project	Number of change events recognized	Share from total
A	24	32 %
B	20	26 %
C	15	20 %
D	11	14 %
E	6	8 %
Total	76	100 %

Especially the contractor side respondents had sometimes difficulties explaining why a specific change had happened. For example, one interviewee explained that they sometimes only received a revised version of the designs without any indication if it was a user requested change or a design error that had been fixed. When analyzing the data, the explanation provided by the interviewees was typically accepted and, when possible, cross-checked with documentation or other interview respondents' reports of the same situation if mentioned. Additionally, every event was placed in only one category, even if there had been some other factors influencing the appearance of the change. It should be noted that the whole interview data, not just the specific change events, was used for recognizing potential root causes for the issues.

Next, the eight change source categories are presented and discussed from most frequently mentioned to least, in the order presented in Figure 20. Lastly, a summary of all the root causes is presented.

Equipment and systems

Equipment and systems, many of which are specifically related to the care operations, caused changes in almost all the researched cases. It was also the most frequently occurring category among the change events as well as one of the most discussed topics in the interviews. This category includes a variety of different types of equipment: fixed medical equipment such as OR and imaging devices, medical gas and purified water piping systems, sterilization and washing systems, nurse and doctor call systems, and IT and communication systems to mention a few. The projects differed in terms of how much medical equipment was planned for the facilities, and how modern those systems would be. In Project A, there was only one, completely separate part of the project related to medical equipment, whereas in Project D, the whole building was designed to enable the most modern technology. Project E was not yet in the phase where majority of the equipment would be installed, which could explain the lack of examples from that project, although medical equipment was mentioned during the interviews as a possible source of changes.

The changes had two types of primary reasons: either related to the choice or the installation of the equipment or system. *Equipment choices* were reported as highly uncertain during the hospital design process. Although the general contractor had the coordination responsibility, the hospital was typically in charge of the procurement process and the choices needed to be postponed. Technology is evolving all the time and thus the final decision by users and procurement team is made as late as possible, as one interviewee noted: *"When you make a decision two years ahead, you lose the fast development in the medical equipment industry"* (Project B, contractor). Procurement was also described as an "arms race" between hospitals for the most modern equipment, as it is an important recruiting strength when competing about the best specialist doctors. The problem with late equipment choice is that construction of the facilities has started much earlier than when the final choice is actually made. An especially problematic area for the contractors was reported to be the large, expensive, and heavy equipment, such as imaging and OR devices, which have a lot of connections to the MEP systems and also require ceiling mountings or special concrete slabs to install to.

Dealing with individual equipment is laborious but the effect is usually limited to individual spaces, and only in one event it was mentioned that walls had to be moved due to the change of equipment and their new dimensions. On the other hand, electrical or communication systems like the nurse call system must be installed to the whole hospital among the other MEP systems, slowing work down all around in case of a change of system. The later a change to these systems occurs, the more trouble they will cause as closing the dropped ceilings and all subsequent work will be postponed. The nurse call systems are a good example as they have developed so much in recent years. There is naturally a discussion about what system would be technically best and most reliable as there is little previous experience about them. In three of the five cases, the final choice of the nurse call system was reported to have been too late from the construction perspective, as it affected the work flow in those areas.

Even if a "final" choice would have been made, new models of the equipment might come to the market and there will always be a demand from the users to get the very latest equipment. This kind of change coming from a sudden technological advancement can be even more detrimental than just a postponed decision, as the change can come as a total surprise after the space has already been finished and result in significant rework. This was observed in a few of the cases.

Procurement issues due to public procurement laws were mentioned as a delaying factor in Sweden, but similar laws apply in Finland and other EU countries as well. Tendering the equipment takes time, and the process can be put to a hold because of a legal complaint from some of the tenderers. When using a more qualifications-based tendering on the equipment it might take considerably more time to go through the process, which is exactly what happened with some rooms in Project D. It was mentioned in the interviews that there are also other technicalities involved in the decision-making, like financing requirements, which in practice could mean waiting until the next year's budget. These types of procurement related issues were outside the influence of the project team and thus hard to avoid, but further postponed the installation of the equipment or systems and caused uncertainty and disturbance to the project.

Installation as a category refers to a different kind of uncertainty. Even if the choice of system would be well-known in advance, the final installation details are often unknown or not documented well enough which leads to many minor changes during the installation phase. The interface requirements for different types of equipment seem to cause a lot of trouble because of the unclear division of responsibilities between the owner whose responsibility it typically is to procure the equipment, the supplier providing the equipment, and the general contractor who needs to coordinate the interfaces and installation to the rest of the project. It was mentioned that in some sense the simpler equipment are more problematic because not a lot of attention is paid to their interfaces before it is time to install, as opposed to larger and more expensive equipment, each having almost their own projects. Unknown location again refers to the lack of user or other input that would determine the exact place and number of for example purified water or medical gas outlets. Quite often the requirements for the system could change after finishing the installation, or the system put on hold until further notice.

Although the number of outlets does not necessarily affect the whole system, it can cause rework as some of the piping and testing procedures have to be redone.

Table 9: "Equipment and systems" lower level change causes and change events from projects

		A	B	C	D	E
Equipment and systems		**X**	**X**	**X**	**X**	
Equipment choice		X	X	X	X	
	Late decision	X	X	X	X	
	Technological advancement		X		X	
	Procurement issues			X	X	
Installation		X	X	X	X	
	Unknown interface requirements	X	X	X	X	
	Unknown location		X	X		

The change root causes in the equipment choice category were found in the technological uncertainty, as well as the structural complexity of the interfaces between medical equipment and the rest of the building. Nowadays, not only the mechanical interfaces, but also the software and data transfer linkages need to be handled. With interfaces, the hardships were related to the multiple trades that need to be informed about the details when equipment choices are locked and that the coordination responsibility is divided between the owner and the general contractor. The structural complexity in terms of number and interdependency of systems was mirrored as the structural complexity of the project organizations and difficulties in information flows between project parties. Also, the public procurement process added a layer of uncertainty about the timing of the decisions as well as a socio-political dimension. Overall, fitting the stepwise decision process with the sequentially planned construction work flow seems to be a constant struggle in hospital projects.

Users

In the Nordic projects, users were involved and listened to extensively during design and construction, so it seems natural that some changes arise from the user side. Users are a quite heterogeneous group: the most influential user groups seemed to be the clinical staff, nurses and doctors, but to some extent also facility management, security and patient organizations were included during the design process. It was mentioned that especially the patient perspective should be considered more than it is considered now, and the projects are still largely designed based on staff requirements. The reason for the power of staff members in the design process is that they know most about the actual operations and their requirements. Even in Project E in the U.S. the users had influence on the laboratory spaces where more technical expertise was needed and their complaints about the inefficiency of the original plan eventually led to major changes. However, many of the design choices users can influence derive from preferences concerning for example working habits, positioning of furniture, usability, aesthetics, and detailing, where there are no single right answers. An interesting theme brought up by some interviewees was, to what extent could the requirements be standardized and is it really necessary to involve the users as much as currently is the norm.

User changes could be divided roughly into two: changed or new requirements, and existing requirements that were badly communicated to the design team and therefore inadequately drawn. *Changed or new requirements* were typically related to the functionality of the spaces, where differing opinions were possible. Sometimes the opinion of the same person changed over time, or the change was resulted by one the employees with more influence, like the head nurse or doctor, changing. Change of people -category was also used when the people requesting the change had not been involved in the previous phase of the designing, like the facilities management personnel requesting something when the space had been previously designed with the help of nurses. Details refined refers to some smaller additions or changes that only come to mind later in the process when it has better materialized for the users, like the exact locations of shelves or other wall-mounted details in Project D. These could be thought of as omissions from the part of the user, while they could have potentially been acknowledged earlier. As small details, they are not especially difficult to change, but many smaller changes can cause a significant amount of extra work when repeated. Some contractor side respondents had doubts that the users did not really understand how construction works and thus did not see why it would be important to make these decisions early. It was also highlighted that users are doing the design work on top of their normal duties, which limits the amount of effort they can put into the design task.

Badly communicated requirements refer to the inability of users to be specific when defining the requirements. A typical way of capturing requirements is by filling "room cards", which define all the requirements the type of room will need to fulfil. A key finding for the project team in Project B was that the users cannot be relied alone with filling the cards, but need support in finding the right requirements. To begin with, there are so many decisions and requirements even for a single room that the users will most likely be overwhelmed by them. These are mostly technical requirements and the project typically has some guidelines already for many of these features. Further, without any reference point to start with, it can be very difficult to accurately estimate needs for things like the number of electric or data outlets in a space. Standardized requirement lists for different types of spaces have been thus developed to be used in subsequent projects. An important point highlighted many times by different project stakeholders was that users are not construction professionals and thus not used to working with 2D drawings. Without a physical representation, it can be tricky to define for example how large a window needs to be to allow visibility in a room or how large a space actually is. This lead to frozen features being changed when it occurred to the users that what was designed was not what they had expected it to be, despite that the designs would have been revised with them before freezing.

Table 10: "Users" lower level change causes and change events from projects

Users		A X	B X	C X	D X	E X
New/changed requirements		X	X	X	X	X
	Change of mind		X	X	X	
	Change of people	X				X
	Details refined	X		X		
Badly communicated requirements		X	X	X	X	
	Drawings not understood	X		X	X	
	Wrong estimation of needs		X	X		
	Too many decisions				X	

Root causes for user changes have a lot to do with socio-political complexity in terms of power struggles between different users and user groups who all want to have their wishes included in the design process, as well as the relationship between the users and the organization that is paying for the changes. It is important to understand that user requirements are rarely static but change dynamically when personnel changes, for example when new decision makers are appointed or a new user group is brought along to the design process. Even with the same people involved, uncertainty exists when there are several possible alternatives and no single right answer, only opinions and preferences. The long design process with many decisions can also create fatigue among the users, especially as they are doing it among their own work, and thus some decisions can be omitted in the early stages for the lack of time and effort to focus on them. Last, there is always the possibility of miscommunication between the users and the design team.

Design

Design issues were less systematically found in all cases. Some mentions of inadequate design were made in the interviews, but it was not a recurring theme in any of the cases. Overall, the issues with design seemed to highlight the difficulty of the design task where so many different areas and competing goals need to be fitted together. Selecting a provider who is capable to carry out the task is thus important, and it was mentioned that suspiciously low tender offers for design were sometimes turned down for doubts about the team's competence. With design-related issues, there is a fine line between what should be accounted as a design omission and what is a straightforward error. Here, if a feature does not fully serve its intended or unintended use, it counts as a design omission. If again there were conflicts between different types of drawings (like mechanical and electrical), the design did not fulfill the local laws and regulations, or if there had been clear mistakes in the way something was designed, the change was considered to be caused by a design error.

Design omissions relate to issues in design related to a lower than expected level of functionality or usability in case of unforeseen events. In Project A, they were related to the difficulty of estimating the required safety level of the facilities, and some underestimation was done even by the experienced design team about how many safety walls and fences are needed, how they should be placed, and which features are needed in them. Most of the omissions were only noticed after the handover of the building, which shows how difficult or practically impossible it is to make the design with every possible situation and use case in mind. Not all omissions ever translate to changes if fixing them would be too expensive and the performance gap is not too bad. Examples of these kinds of accepted defects from Project A were some doors where beds could not be rolled through or floor slopes being too flat so that water runs easily to the rooms. These were also things noticed only after starting to use the facilities.

Design errors seemed like an easier issue to notice early. While all the trades had different designers, sometimes additions or changes did not make it to all the drawings, perhaps due to a lack of communication between the designers. Another type of designer error was with using wrong dimensions or parameters leading to clashes at the site. The contractors told that when they spot a conflict in the drawings, they write an RFI to the designers, and that typically these clashes incur more costs. Knowing the specific legislation in terms of building codes and regulations is essential for hospital architects and designers, but at times details could be missed. That electrical fuses are not allowed in surgery rooms was one such detail specific to hospital construction, and was not acknowledge early enough in Project D. Concurrent design can lead to serious design errors, if the design packages are not correctly divided with interdependences in mind, and major discrepancies can occur between the plans developed in different phases, like happened in Project E with the elevator and frame designs.

Ripple effects from other changes refers to redesigns reflecting from a change to the design assumptions of another component, caused by the interdependency of design elements. One example presented in Project B was that when the electric contractor had dimensioned the switchboard to match the needed performance, it was discovered that the switchboard would not fit in the reserved space which had to be enlarged. As a routine procedure in case of changes in one system, all other interdependent systems and structures were checked for these ripple effects, and this was perceived as a laborious task as no full automation was available for the checking process.

Table 11: "Design" lower level change causes and change events from projects

		A	B	C	D	E
Design		**X**	**X**		**X**	**X**
Design omissions		X				
	Lacking functionality	X				
	Unforeseen use	X				
Design errors		X			X	X
	Multiple sets of drawings					X
	Code ignored				X	
	Concurrent design					X
	Wrong parameters used	X				
Ripple effects			X			
	Interdependency of elements		X			

Root causes for design omissions come from the difficulty of taking everything into account in advance. With experience, the designers are more likely to be successful in this, and none of the projects had any significant design problems, showing an overall good level of healthcare facility design. Design errors resulted usually from the existence of multiple, separate sets of drawings, and lack of coordination between those sets. None of the projects researched had fully been modeled in 3D, and the different trades were thus designed to some extent separately. With a high degree of structural complexity between trades, ripple effects from other changes inside and between trades can occur.

External environment

No hospital construction project is happening in a vacuum, and the project's environment consisting of the environmental, political, legal, social, and technological dimensions can be a source of uncertainty and change. From the researched projects, two very different types of themes regarding the external environment were recognized: the conditions of the site and the influence of external stakeholders of the project.

Site conditions varied between sites and in four out of the five cases there were some types of surprises found in the ground which affected the planned scope of work. Lack of ground research led to the finding of environmental pollutions or different type of soil, which influences how the groundwork should be done. Also, the information and drawings about what is in the ground or near the structures had in some cases been misleading. Examples of outdated information were an active sewer line in Project A and a new building in an area to be excavated in Project C, and alternative solutions had to be found for continuing construction. Overall, it was mentioned how challenging it is to be building at a working hospital campus without damaging and disturbing other buildings. All the projects were executed in operating hospital grounds, and the space for the new buildings could be in a rather small area between existing buildings.

From *external stakeholder groups*, authorities requested changes due to regulations in Projects B and E. For example with the fire safety regulations in Finland, it was told that it depends a lot on the individual safety inspector's interpretation about the code. In the US, states differ greatly in their hospital construction legislation and Project E was affected quite a lot from changes demanded by the inspecting authority. Another external stakeholder group reported to affect the construction were residents living near the Project A site, who made claims so that some trees could not be cut down, causing the site logistics route to be relocated.

Table 12: "External environment" lower level change causes and change events from projects

External environment		A X	B X	C X	D X	E X
Unexpected site conditions		X	X	X	X	
	Lack of ground research	X	X	X	X	
	Outdated/wrong information	X		X		
External stakeholders		X	X			X
	Authorities		X			X
	Community	X				

Although external environment is out of the influence of the project team, it does not mean that those factors should not be carefully assessed beforehand from a risk management perspective. Uncertainties related to the site conditions seemed to have realized often, so these risks should be perhaps better prepared for in the planning phase. External stakeholders can have a lot of power on the hospital projects, especially those that enforce laws and regulations, and knowledge on local circumstances is needed to know the most important ones to consider.

Owner

The setting about who owns the hospital varied between the projects, and seemed to follow from the healthcare system design in the specific country. In Finland, hospital districts own their hospitals, but in Sweden the facilities belong to a specific regional real estate company and are only rented to the hospital in question. In the project in the U.S., the hospital was owned by the country-wide corporation and rented to the local subsidiary. Thus, different higher level goals guide the actions of the owner.

Owners are typically managing many facilities, possibly in multiple locations, so an individual construction project is related to the larger *hospital campus development*. This includes the hospital campus role in the larger healthcare network, as well as future development. The owners make decisions on what kinds of services and care the campus will serve in the future, and new buildings are an important tool to implement those decisions. Sometimes functions could be added or removed based on the overall needs of the hospital and the situation with other buildings in accommodating to those needs. A PET-CT space was added to the psychiatric hospital Project A due to the lack of suitable space elsewhere, and a medical gas line was rerouted as part of the project to allow further construction development of the campus. In Project B, the operating theatres needed to be changed to serve heavier surgery when the other buildings would go under renovations. The high-tech building in Project D was initially planned to host an ultrasound department, but as that function did not necessarily need to be in such a high-performance building, it was decided to be moved elsewhere.

Cost saving pressures were running high in every researched project, which meant that on occasion, the design had to be reduced in cost and size. In Project A this meant building a couple of double rooms as well as leaving a clinic out of the scope. In some projects scope was managed in the other direction: if there was no confirmed funding for a part to be confirmed yet, the solution was to build the area as shelled space, which was extensively used in Project E. Already during the project some of the areas were added to the scope, but it did not really disturb the construction as it was prepared for. In Project D shell space was used for reserving areas which could be finished later when technology would have progressed even more, and the last of them was scheduled to finish long after the rest of the project.

Table 13: "Owner" lower level change causes and change events from projects

		A	B	C	D	E
Owner		**X**	**X**		**X**	**X**
Hospital campus development		X	X		X	
	Placing of functions	X			X	
	Renovation needs	X	X			
Cost saving		X				X
	Cost pressure	X				
	Funding not available					X

Majority of the owner initiated changes were made already early in the design phase, so they mostly did not affect the construction process. Still, during long projects these changes could occur also while construction is ongoing, like seen in Projects D and E. In a way, the changes stem from the owner's position as the link between many external and internal stakeholders and the expectations they have from the project. Owners might face a lot of cost pressures from political leaders or from being a for-profit organization, and need to balance investments and optimize the healthcare facility network as a whole. The main goal in the end is to be able to provide good quality care. Balancing between these, sometimes conflicting, goals is occasionally channeled to project changes.

Contractors

In a typical design-bid-build project like majority of the researched projects, the contractor is only involved in the project after the design is fairly finished. It also means that they do not have the possibility to address *constructability i*ssues in the design stage, and often they are hesitant to suggest changes, which could increase their liability in case of an error happening due to the changes. In Project A, the metal plate ceiling design to a garage space was left out based on the contractor's request, saving time and money for the project. Another change was made in Project C, when the building was closed with a different façade solution. This choice helped close the building faster and increased the quality of works done inside. These were seen as positive changes for the project as they increased the efficiency.

Contractors are sensitive about costs so they are looking for *cost saving* opportunities, due to the low-bid tender offer they have had to put to win the project. Changing materials or appliances to cheaper ones took place, when accepted by the owner. The attitude from the owner side was quite negative towards contractor changes, as they believed contractors could sacrifice quality in the end product in order to save costs. The contractor side felt again that they were forced to do that when the budget was stretched to the limit from the start. The negative attitude from owners towards contractor input in design might explain the lack of contractor changes.

Many of the normal MEP systems such as ventilation and electricity have special demands in the hospital settings. While the space for these systems is limited, the installation many times needs fitting from the contractors, and ripple effects from installation errors or changes can affect other systems that are installed later. Especially if the above ceiling area had not fully been modeled in 3D, *clashes between trades* and the need to adjust on site were common. The effects were evaluated to hit the electric contractors the most, as those systems are often installed last. Based on the interviews these seemed like common situations for contractors although specific examples were few, perhaps because they are such routine occurrences.

Finally, contractors might make *errors* and fixing them might be time consuming. In case of new technology, the risk for errors is higher. The finished steam production system in Project B did not fulfil the requirements so the whole system had to be disassembled and changed to another type. This error was explained by the new type of technology they were using and that they did not know enough of the system to begin with.

Table 14: "Contractors" lower level change causes and change events from projects

		A	**B**	**C**	**D**	**E**
Contractors		**X**	**X**	**X**		
Constructability		X		X		
	Schedule benefits	X				
	Quality benefits			X		
Cost saving		X				
	Low tender price	X				
Clashes between trades			X			
	System interdependence		X			
Errors			X			
	New technology		X			

There were several root causes found for contractor-initiated changes. First of all, the current contracting practices had several effects. Contractors in design-bid-build projects had very limited influence to the design at the actual design stage, and in some cases were under a lot of pressure to save costs because of the lowest bid tendering method. Second, the degree of structural complexity and system interdependence and uncertainty of methods when working with new technologies reflected on contractor changes.

Operations

The owner and user side respondents emphasized that planning a new hospital is always in a way building towards the future and not for the current state of healthcare. It was also seen as a great way to renew operational processes and change how healthcare is delivered, even in the form of new types of services. While the operations are the foundation on which the planning is done, there is the need to foresee what they will look like in the next 5, 10, or 30 years, but it was perceived as a difficult task to do this even for the shorter time periods. The views taken at the time of design might prove correct or not, and the accuracy of the predictions will determine whether large changes even during the construction project are necessary. During the hospital life cycle, running the operations cause the majority of costs and are the first priority, which makes design changes due to their development hard to turn down.

Almost all case projects faced changes in operations which affected the space requirements. Interestingly no large construction changes due to change in operations happened, which might suggest that the designed facilities had enough flexibility to allow for these changes. *Process requirements* might change due to new technology or treatment opportunities. The increased use of imaging for different diagnostic purposes increased the number of imaging equipment in different rooms at least in Projects C and D, leading to modifications in examination rooms. At times, changing an existing process required a new layout and even moving walls to allow for more efficient operations. The *allocation of spaces* between different types of needs was another point, like when more dental care rooms were needed and transformed from normal examination rooms in Project B, or for a completely new function, like a crisis room in Project A.

Table 15: "Operations" lower level change causes and change events from projects

		A	B	C	D	E
Operations		**X**	**X**	**X**	**X**	
Process requirements			X	X	X	
	Treatment guidelines			X	X	
	Layout needs		X			
Allocation of spaces		X	X			
	Capacity needs		X			
	New function	X				

The underlying uncertainty about future operational and functional needs sometimes realizes in the form of changes. The needs are affected by many external influences in technology and medicine, in the demographics of the population to be treated, and even political decisions.

Contractual relationships

When looking at construction projects from the contractor point of view, their scope of work is defined through what is agreed in the contracts, typically in the form of exact specifications or drawings. There is an inherent asymmetry of information between the owner and the contractor to know how frozen those contract requirements are, and this difference in expectations can make dealing with changes more difficult.

In the interviews, it was implied by the contractor side that even if the owner might plan to add or change something, they might choose not to tell openly about it to the contractor. For example, in Projects B and C the *contract scope*s of the contractors were increased with certain additions which they assumed were known by the owner earlier but only communicated openly later, such as the geothermal heating system in Project C. This caused some issues for the contractors as the scope would have been implemented differently and more efficiently if known in advance. Interviewees from Project E called the situation a buyout, when the procured scope was known to be added all along but chosen to be bought only later in the project. Also, changes from other categories can have a similar, scope increasing effect, like the ambulance shelter from Project B which was originally decided not to be done but due to user wishes was added later to the scope. The issue with increasing scope is that it increases the work load for the contractors which might lack needed resources to execute the scope. Through resourcing, the changes also affect other work tasks that need those same resources.

On the other hand, the owners seemed to have paid a lot of thought on what would be the most economical way to procure a certain part or system. This reflects to the number and scope of individual contracts, which also defines where the *contract boundaries* between different contractors are drawn. Sometimes it would be revealed that their assumptions had been wrong and parts subsequently moved as parts of other contracts, like in Project B concerning the mounting of the ceiling centers. The original plan in that case was proven to be hard to construct and thus the standardized mounting frame was introduced. This, however, changed the general contractor's workload quite a lot, even if it made coordination between different trades easier and probably reduced the workload overall.

Contract boundaries and interfaces with other contracts are also risky, while it is important to ensure nothing is forgotten. Unclear boundaries can lead to a situation where everyone thinks it is someone else's responsibility to deliver something. An example with medical equipment came up in Project C, where the connection piece between the ceiling and the equipment had not been included in any contract. There had also not been contact between the equipment providers and the contractors doing the preparations for the installation, where the omission could have been noticed.

Table 16: "Contractual relationships" lower level change causes and change events from projects

		A	B	C	D	E
Contractual relationships			**X**	**X**		
Contract scope			X	X		
	Planned addition		X	X		
Contract boundaries			X	X		
	Moved between contracts		X			
	Omission between contracts			X		

Contracts are difficult to craft, especially if everything is tried to be included in them. They are legally binding, official documents, but on the other hand not completely fixed. The owner typically has a good understanding of what they still need to procure, but the additions might come as a surprise to the contractors even if they have prepared for a certain amount of scope increases. The more separate contracts and contract parties the project has, the more interfaces there are to manage technically and in communication.

Summary of change sources and root causes

Table 17 summarizes the root causes that were identified through studying the change events. The corresponding complexity dimensions are displayed in the next column and described by quotes from the interviews. As can be seen from the table, most change root causes can be directly linked to the project complexity factors. This supports the statement about hospital construction being different and more complex compared to some other types of construction. Typical answers justifying the complexity claim referred to the amount of technology and systems, and less on the intangible sides of the project like goal alignment or stakeholder management:

"It's more systems to take care, and also the rooms are more technically equipped and a lot more functions that need to be handled. You need to be more detailed in design and more prepared in design than other projects, I think." (Contractor, Project C)

Based on the analysis, the technical difficulty is also reflected on the stakeholder relations and practically on communication needs during the project.

Table 17: Root causes by change source category

Change source category	Implied root causes	Related complexity dimensions	Citations from interviews
Equipment and systems	Dynamic technological change in industry	Uncertainty in methods, Dynamics	"In this project we say that we're building towards a moving target, because when there's new technical development among the medical suppliers, we have to see what we can do to get this, into this building as well." -Owner representative, Project D
	Complicated interfaces between equipment and building systems	Structural complexity: Number, interdependence	"You have so many different types of equipment that should be in the building that you have to take care, so it's quite a big issue in the project" -Contractor, Project C
	Coordination and information flow problems between stakeholders	Structural complexity: Number, interdependence	"There are problems. In no way is it always clear to all, and information doesn't necessarily flow to everyone who needs it. There is definitely room for improvement:" -Supervisor, Project B
	Decision making process: legislation and disputes	Socio-political complexity	"And one of them (suppliers) overruled the process and then you are delayed." -Contractor, Project C
Users	Self-interest and promoting the needs of own user group	Socio-political complexity	"I think in the back of their head they do understand (the costs) but they (the users) don't want to since it's not their responsibility to care for the budget for the whole project, they don't care. Of course some of them care but a lot of them, I would say, they are very specific to their own needs and don't see the whole picture." -Contractor, Project D
	High power decision makers and changes in personnel	Socio-political complexity, Dynamics	"The perhaps largest challenges there were that it took such a long time from the design to the execution, so that the users changed their minds multiple times " -Trade supervisor, Case B
	Lack of knowledge and skills, inexperience of large projects	Uncertainty in goals and methods	"Well they (the users) are not used to work in the investment projects, they don't understand that you have to decide something several years before we built it." -Contractor, Project C
	Lack of time and effort to focus on design in early stages		"It is of course (difficult) for them (the users) too, when they do this on the side of their own work, so that there isn't necessarily any full-time person named from the department, who would be involved in the project." -Supervisor, Project B
	Amount of decisions to make/requirements	Structural complexity: Number, interdependence	"It's a thousand rooms in this hospital. And in each room there are maybe fifty requirements, and this is outside the building codes." -Contractor, Project C
	Miscommunication between users and designers	Socio-political complexity	"There were some individual (events), when you start to think, even when you try to understand but there still are misunderstandings." -Design coordinator, Project B "…, going through room by room and letting them (the users) look at the drawings and so forth, it's still very difficult for them to understand." -Owner representative, Project D
Design	Partly unknown requirements in terms of functionality and use	Uncertainty in goals	". . . does the building suit the operations at that time, when it was done some time long long ago in a requirement plan and some operational model was decided, was it the right guess." -Designer, Project A
	Multiple sets of drawings and separate design teams, communication difficulties	Structural complexity: Interdependence of elements	"… kind of my job is then to take the change issue forward to the designers, and I assume that these go to the plans but not always they did, […] when in the same design office there's the so called responsible HVAC designer but still the assistant designers do the work and the message doesn't always go through." -Design coordinator, Project B "So having so many separate people designing, it's hard to make sure that they all come back together and say hey I've put this here, make sure you account for it in the electrical drawings." -Contractor, Project E
	Concurrent design	Pace; Structural complexity: Interdependence of elements	"I believe there have been a lot more changes here than in the other project. And I think it's because they've been planning it during the time we're building it." -Trade contractor, Project D

	Ripple effects from other design changes	Structural complexity, Dynamics	"But here if you make one change, it's a lot of different people who need to be involved and to know of this change to put in on new prints. " -Trade contractor, Project D
External environment	Unexpected site conditions	Uncertainty in methods	"One change you can at least accept, or even that you could also have avoided that there was a lot more quarrying than thought, so it is what it is, but why do these groundworks also always go wrong?" -Contractor, Project A
	Authorities and legislation	Socio-political complexity	"I think it's like a rogue element that you can't really pin down, and it depends on who you get and it's like this entity that boils down to the personality of one person really. [...] And you wouldn't necessarily think about that in the beginning cause it's a code and you read it and you see what it says, but then twenty people read and they all read something different." -Contractor, Project E
Owner	Hospital as a part of larger care network	Uncertainty in goals, Dynamics	"But then after we started to plan the project, the management of the service region made a decision, or they actually just understood that we have heavy surgery like heart, cardio-vascular and neurosurgery in our existing surgical unit which had to also be renovated." -Design coordinator, Project B
	Cost saving and funding issues	Socio-political complexity	"So, the second floor was a shell space. They got the funding to build that out, and then we only had money to build out a portion of the fourth and sixth floors, and we just recently got released to build up the balance of those floors. They haven't made any design changes, though." -Contractor, Project E
	Inexperienced in developer duties	Uncertainty in methods	"In this project, we didn't yet have the know-how to support the users, because we came as new people here, no one had experience from making this kind of project." -Design coordinator, Project B
Contractors	Constructability improvements	Pace	"We changed the facade solution to get a closed building earlier and to get better quality control of the facade. It was hard to be successful with the facade that we designed from the client I would say in quality." -Contractor, Project C
	Cost saving		"This normal lump sum contracting is that we are trying to deliver the cheapest possible. And in this public construction when the client decides to go ahead with it, they first tender consultants and find the cheapest one. They then tender the cheapest designers, who tender the cheapest contractors and then in the end the best result is expected." -Trade contractor, Project B
	Fitting together with other trades	Structural complexity: Number, interdependence of elements; Socio-political complexity	"If one of the installation categories has fallen behind it effects all the others. " -Contractor, Project C "Pretty much these projects are personified kind of on what the general contractor leaders happen to be like, or any of the contractors' leaders, how they make the cooperation work" -Supervisor, Project B
	New technology	Uncertainty in methods	"We made a complaint and didn't sign off the work because it didn't match the quality it was supposed to be." -Owner representative, Project B
Operations	Changing diagnostic and treatment trends, capacity and layout needs	Uncertainty in goals; Dynamics	". . . does the building suit the operations at that time, when it was done some time long long ago in a requirement plan and some operational model was decided, was it the right guess." -Designer, Project A
Contractual relationships	Complicated contractual structure and small contract scopes	Structural complexity: Number, interdependence of elements	"Those big projects there are so many people and parts involved so it's hard to see if all these things are in someone's contract. You don't realize that before someone says where should I connect this thing." - Contractor, Project C
	Asymmetrical information between contractor and client and lack of trust	Socio-political complexity	"Sometimes I think some people are a bit naive when they think oh we're going to create a perfect product together with the contractor, and I know that contractors are only thinking about what's on the bottom line." -Owner representative, Project D

Table 18 combines the change source categories with the types of complexity affecting them, including the strength of the effect estimated from low to high, based on the analysis of interview quotes and researcher interpretation on the relative strength of each factor. From this table it is evident that most of the change sources are affected by multiple different types of complexity. In addition to the most established complexity dimensions related to hospital construction, structural complexity and uncertainty, also socio-political complexity affects most change source categories. Socio-political tensions could be sensed throughout and from different stakeholders, typically between different organizations as between users and owner, between contractors, or between owner and contractor.

Table 18: Change source categories and corresponding complexity dimensions (strength of effect from low (+) to high (+++))

	Structural complexity	Uncertainty	Pace	Socio-political complexity	Dynamics
Equipment and systems	+++	++		+	+
Users	+	+		+++	+
Design	+++	++	+		+
External environment		++		++	
Owner		++		++	+
Contractors	++	+	+	+	
Operations		++			+
Contractual relationships	++			++	

Moreover, the identified change sources are not independent from each other but interact within the project system. Figure 21 depicts roughly how the different sources can influence each other. The internal stakeholders act on different levels, others having more to do with the decisions and others with the actual execution of the project. Operations, Equipment and systems, and External environment influence the process between the stakeholders. For example, Operations impact on a higher level as opposed to the External environment, which has the most impact on the execution. Changes on a higher level also affect downstream, influencing more project parties all the way to the executors, finally accumulating at the contractor level.

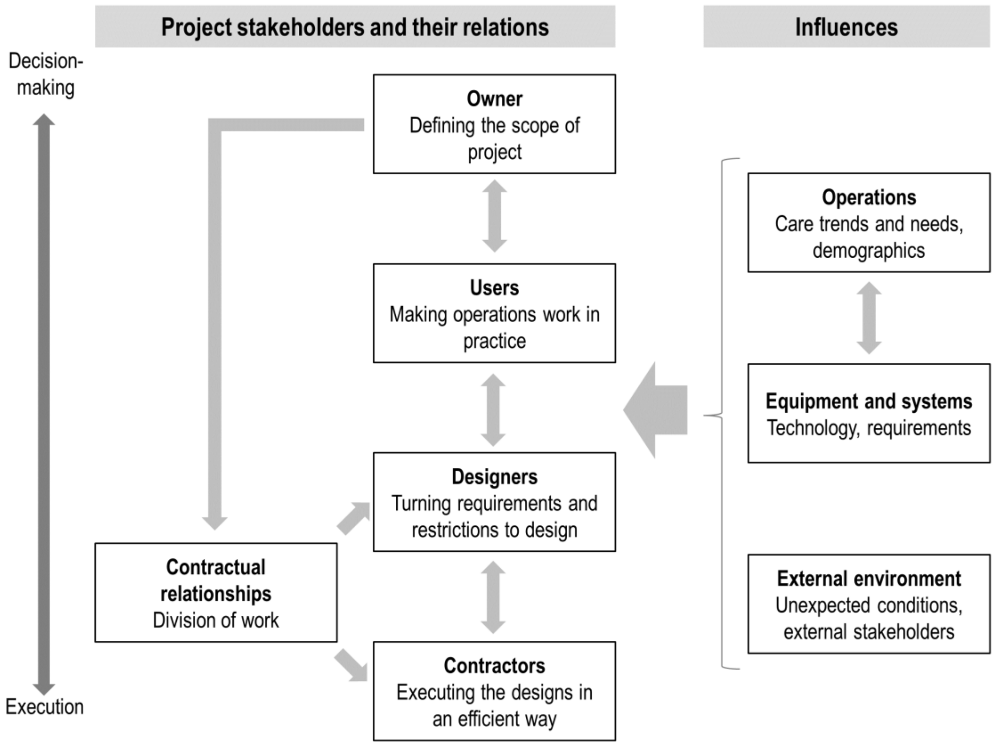

Figure 21: Change sources from internal stakeholders and project external influences, and their interdependencies

The main finding about change root causes is that changes stem from a variety of sources, which are influenced by various complexity factors and are interlinked with each other. Therefore, it is not possible to identify just a few specific causes for hospital project changes, but to admit that there is a complex change dynamic behind the causes.

4.2.3 Change effects

It became clear quite quickly during the study that change effects are perceived differently according to the organization or role from which they are evaluated. The different evaluation of effects was seen to hinder dealing with changes in the most efficient way and lead to disputes between project parties. It would be important to be able to accurately evaluate the changes and decide which change are worth implementing, especially when the decision is made by a different entity than the actual implementation.

Next, change impacts are discussed from the point of view of the most important stakeholders, that is the users, the contractors and the owner, and the differences between their attitudes to changes highlighted. Also, attention is given to different variables affecting change effects.

Change effects for stakeholders and attitudes to changes

The general findings about what kind of consequences changes typically cause were very much in line with the findings from the literature review. The emphasis in the interview responses was on project management effects rather than product effects, which is natural when a project is ongoing or recently finished. It was however mentioned from both the owner and contractor sides that changes often were good for the project, when they were done to solve functional issues, improve the facilities, or enable better technology to be used. These are all related to the quality of the end result from a usability perspective. Contractors felt that it was relatively easy to agree that changes are needed to some degree, especially when thinking from the perspective of a taxpayer and possible patient.

Table 19: Change effects according to category

Cost	Schedule	Efficiency	Scope	Other
Direct cost	Direct schedule effect	Rework	Left out of plan	Quality
	Need to rush the schedule	Disruption of work flow	Increased/decreased workload for some party	Disturbance to hospital
				Ripple effects
	Work done after hand-over	Additional work due to suboptimal working order		Underestimated effects
		Site congestion		

The project management effects were divided into five categories based on the area of impact: Cost, Schedule, Scope of work, Efficiency and Other. In Table 19, the different codes arising from the interview data are shown to depict what types of issues were discussed in terms of these categories. *Cost* was mentioned mainly through discussing direct costs from the change in material or other resources needed. *Schedule* concerns the direct schedule effects as well as the subsequent need to rush the schedule or even left work to be done after handover.

Efficiency was not only a concern when some part had to be reworked, but also when the planned work flow was distracted and tasks reconfigured in a suboptimal way. *Scope* dealt with on one hand by parts that were left out of the plan, or if the workload of some of the contractors was changed. *Other* category gathers more miscellaneous considerations, like effects on quality if defined as conformance to plans, disturbance caused to the hospital, ripple effects or otherwise underestimated consequences from changes.

Contractors felt that they needed to absorb a major part of the negative impacts themselves. Direct costs were compensated through the change order process, but schedule allowances or compensation for indirect costs were rarely awarded, so the contractors had to solve themselves how to deal with the lost time or efficiency.

"When the scope is increasing more than ten percent and then squeezed in the same number of months and the time schedule, it affects the project." (Contractor, Project C)

The contractors generally felt that the effects were diminished by the owner side, not necessarily on purpose, but because they actually believed that the changes were so small that they would not have significant effects to the project.

"When there's a change, it has costs and a schedule effect. And especially the schedule effect is usually the one that is hard for the client to understand." (Contractor, Project B)

The owner side acknowledged these problems to some extent, at least those people that were experienced in the construction industry, but their greatest concerns were with the cost consequences, as those are the most visible for them. The view on what effects or direct consequences a change has might be thus very different: for example, one owner representative wondered, why those kinds of changes where something is left out of the plan need to be compensated, when for the contractor it seemed clear that those changes also results in extra work in planning and scheduling. In addition, the need to rush the schedule to make up for time lost from changes was not seen as a problem by the owner side. The schedule pressure was high on the owners too, but they typically relied extensively on the contractors to use any possible ways to compensate for the delays. At the end stages of the project, they were more likely to notice the schedule risks also for themselves as the possibility of not finishing by the opening date became more tangible.

The zero-sum property of the change order process in the traditional project types makes it difficult to have a neutral discussion about changes, as there is the incentive for the contractors to exaggerate the change effects and for the owner to diminish them to negotiate the best deal. This was reflected by mentions of how the parties are "on different sides of the table" or that some amount of "struggle" is normal for construction projects. In the end, it seemed to come down to trust between the parties there was the attempt to understand the situation from the other party's point of view and come to a compromise. The situation seemed quite polarized between those types of cases where there had been a good and trusting working relationship between the parties and relatively open discussion, and other cases where the relationship was tense and conflicts about the changes emerged. It was seen to go so far that everyone just shut their eyes from the delays, as the first one to recognize them would probably be blamed for causing them. Any attempts to sort the delays through cooperation were regarded unlikely, as stated by one of the trade contractors:

"It would require a certain broadmindedness from everyone involved not to hide immediately behind the dispute clauses."

Variables increasing negative change impacts

The effects were also collected for the different change events along the introduced categorization, including if it was positive (reducing cost, schedule or scope; increasing efficiency) or negative, and are included in the tables of Appendices 2-6. Few straightforward connections were found between the different change sources and effects based on this analysis. External environment, basically through surprises during the groundwork, was found to consistently lead to major cost and schedule impacts as well as the scope of work but not having much effects to work efficiency. The Equipment and systems category was again found in most events to affect the efficiency negatively even while there were no large cost effects.

A possible explanation of the weak linkages between causes and effects was that it is not necessarily the change source that determines the nature and size of the impacts but some other variables from change or project level. In causal modes, *moderator variables* affect the direction or strength of a relation between an independent and dependent variable (Baron & Kenny, 1986). Next, five possible moderating variables related to both change and project attributes are introduced, including the direction of their influence to change effects.

Scope of change: The larger the change is, the more expensive it typically is. This is reflected on the effect most groundwork related changes have, as they almost by definition are large changes. Similarly, changes in whole sections of the hospital, like replacing a whole unit with another purpose tend to have significant effect. On the other hand, many installation or fittings related changes are typically much smaller in scope, and thus also less expensive.

Timing of change: An apparent variable determining change effects is the timing. Two factors are of significance: How far in the construction process the task has progressed, and the sensitivity of the specific task to changes. There are few things that are completely irreversible in the construction process, but changes tend to become more difficult the further work has already proceeded. If noticed early enough, the changes can be handled by simply redesigning, but at later stages rework might be needed. Still, even rework was not seen as the worst impact, as *"walls can be taken down and rebuilt"*, if there is still time to catch up the situation. The most harmful changes from the opinion of almost all project parties were those coming very near the completion, when any disruption would jeopardize the timely hand-over. Conducting work after the hand-over should be avoided as far as possible, especially as the operations in a hospital environment are very sensitive to distractions. Equipment installation changes were a typical example of a problematic change mainly due to their timing, as these occur mostly in the late phases of the project when a lot of tasks are happening at the same time and the deadlines are closing in. They were in almost all change events related to them seen to worsen the efficiency by requiring rework or tasks to be done in suboptimal order.

Another distinct category are also changes with unknown timing, meaning there is no knowledge when the final decision on the change will be made. It will also affect negatively to the change effects as it is not possible to optimize the mitigation mechanism and finalize new plans for the task. As a contractor representative from Project D put it: *"We thought that they would answer next week and they didn't and next week and next week and next week… They took half a year. […] But if we had known from the beginning, then we could have just done a temporary one (floor) and everyone could have done the rest of their jobs, we could have come back. So I think these kinds of solutions would at least limit the damage, I would say."*

Expected/unexpected change and communication: Expected changes are those where it is known for certainty that a choice made at a later time will result in some amount of changes, which allows being prepared for them. Unexpected changes happen suddenly and without any advance notice, like some details that should have been frozen for good but then for some reason change. Somewhere in between the extremes are probabilities to changes: for example, a room can with 85% probability use a certain brand of equipment, meaning that there remains a slight chance of change. The division between an expected and unexpected change is not always so simple to define. Due to bad information flows, changes that are known by some project party are not communicated to others who might still be influenced and thus seem as unexpected changes to them. As described by a contractor in Project B:*"It would have helped (to know about things that might change). Then we could have for example left some inner ceilings open in those spaces that the change will happen, so we wouldn't have to open them up again."* Similar experiences were found also from the other projects, when work that had just been finished needed to be torn down and reworked due to unexpected changes.

Number of trades or subsystems affected: This variable refers to how many different project parties are affected by the change, which directly influences how complex the change implementation will be. There are several problems that arise from the fact that the change has to be coordinated between many entities. Information flows tend to be worse between organizations than within them, especially if the contractual situation does not incentivize cooperation. Second, changes spanning to many trades often lead to unexpected side effects. A typical example related to difficulties in coordination were changes to doors. Even if they seem like a simple item to change, there are several reasons that make them difficult to manage. For instance, changing the opening direction of a door might affect several different contractors like general, electrical, and locking contractors, and coordinating the activities takes a disproportionate amount of time. Also, the change might have ripple effects to the location of light switches or other details further in the rooms. Last, there are so many doors in the hospital that even a small change multiplied so many times has a significant effect.

Project complexity: The overall complexity of the project, in any of the technical, socio-political, or pace dimensions is also a factor to consider about change events. For instance, there was evidence from the interviews that the more schedule pressure there was in the project, the larger the impacts on the schedule were in case of a change event. This seems natural as the stricter schedule requires a stricter and more carefully planned workflow, which will suffer from any deviations. Similarly, the more technical complexity there is, the more unpredictable the change effects can be, or if the socio-political complexity is high it might be harder to define and coordinate the needed change work.

Summary of change effects

Change effects were perceived differently among different stakeholders, largely based on where the benefits and costs of changes were most evident. Most problems in the relationship between the owners and contractors about changes were interpreted to result from this difference in viewpoints.

Some moderating variables in terms of change effects were identified based on the interviews. The question of "What effects do the changes from different sources have?" could be turned around to ask, "What are the typical attributes for changes stemming from the identified sources?", in terms of scope, timing, predictability, and number of trades involved. An important consideration is also the overall complexity level of the project, and how that amplifies change effects. Figure 22 depicts these previously discussed moderating variables and their influencing logic.

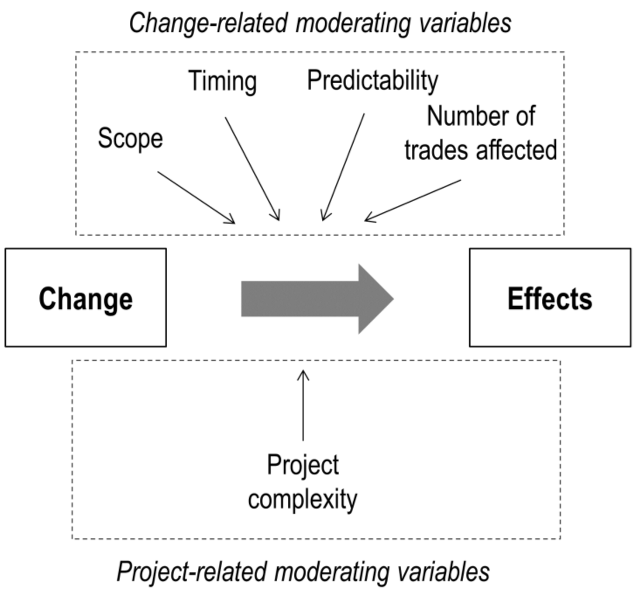

Figure 22: Moderating variables affecting the strength of connection from change to its effects

4.2.4 Strategies to mitigate changes: Flexibility approach

In the interviews, respondents were asked about what kinds of strategies, in the form of practical methods and tools, had been used in the case project for change management and mitigation purposes. They were also encouraged to share overall improvement ideas or best practices they had in terms of avoiding changes or handling them better. This section presents a categorization of those strategies from the point of view of project flexibility.

The product and process flexibility framework by Olsson (2006) and Gil et al. (2005), introduced in section 2.3, was used for analyzing these strategies from a flexibility perspective. Potential means for achieving building flexibility through a robust concept, process flexibility by allowing an incremental decision process, or maximizing flexibility through integrating project and process flexibility are introduced. Also, the situation of a stable environment assumption with no specific flexibility measures is presented, where communication and project control tools were suggested to improve collaboration between different project parties.

Stable environment – strategies to improve project communication and control

Even in the situation of low project flexibility in the product and process dimensions, meaning a relatively fixed construction process and a highly-specialized building, strategies were found that could help mitigate changes. A lot of the discussion was focused on the purpose of the project and how that could be cleared to everyone involved, which means aligning the goals of different project parties and enabling them to understand each other better. Difficulties were faced typically when communicating over organizational boundaries or different skill levels. Technically-oriented strategies were seen to allow a more efficient change order processing between project parties as well as tracking the overall project progress.

Having a clear goal was mentioned as one of the most important inhibitors of changes. It was regarded as the hardest situation from the project execution side if the project goals were to change completely after construction had started. On a more detailed level of planning, the contractors often had the feeling that the users sometimes only during the construction realized what was actually being built. More awareness from the owners was called for to really understand on which requirements the design should be based. This should include for instance realizing the trade-offs between the project scope and budget.

Design requirements elicitation and communication methods were used for overcoming the difficulty of setting and communicating the requirements to the project. First of all, the role of a design coordinator was emphasized in the requirement capture process. Design coordinators either from the owner, general contractor, or designer sides were found in almost all the cases and their role was to act as translators between the users and the rest of the project. It was mentioned by one of the design coordinators that the users and designers sometimes talked about completely different things and in some occasions lacked a common language, which is where the coordinators would step in to solve any issues. Another tool used for capturing the conscious and unconscious requirements of users were mock-up spaces. By asking the users to perform some of their daily tasks or routines in the mock-ups, they could comment on the design solutions based on what is working and what is not. Mock-ups were extensively used at least in Projects A and B. It is probable that if the mock-ups had not been built, the changes would have had a larger impact on the project by coming up only at a later stage. 3D visualizations were also used for a similar purpose, but none of the projects had been fully 3D modeled specially for visualization purposes.

While helping with the users to communicate their wishes earlier and more effectively, moderating the user change suggestions was still seen as an important, as a large part of them could be unnecessary or possible to take into account in other ways. There is room to challenge the users, or in the words of one design coordinator to "cool down", and see if they still have the same opinion next week. The project manager of the owner has a profound impact on change management through how well they can hold the user requested changes under control. There is always the need to prioritize and make choices, and this responsibility cannot be left solely to the users to decide.

Coordination is both about information sharing as well as scheduling and planning work. Information-wise, it was seen as good practice to have start-up meetings at the beginning of each phase of work, to settle common working practices and what was to be done during that phase. In scheduling sense, all different trade contractors and subcontractors were consulted about their respective tasks and their opinion of how long each task would take. Some projects (e.g. B and E) mentioned using pull planning, a scheduling method included in the Last Planner System, where all contractors are involved in the making of the schedule by calculating back from a milestone, defining which tasks should be done by then and in which order. By collaborating on the work plan together, it can also be adapted more easily to any changes.

Coordinating the schedule and other installation details with outside suppliers was regarded as especially challenging. Supplier visits to the site were used to plan for the installation of equipment in advance and to make sure nothing would be omitted from installation plans. In Project D, the owner and design consultant decided based on previous experiences that in the third phase of the project they would arrange for the suppliers and contractors to communicate directly to avoid installation related problems and changes. There is no good reason why they should not be able to settle details directly with each other, but it still had to be learned the hard way.

IT systems and up-to-date information were mentioned quite a few times when discussing the change management process. The efficient transfer of information between project parties was a key issue identified. Project data was usually stored in a common project bank, but there were different tools and practices used for change-related data management. User changes to room requirements were updated to a room requirements database, if such was used in the project. If this database is cloud-based, all parties have access to the most recent information, and automated notifications can be sent to the designers to make modifications to the plans. It was also mentioned that in the future, the requirement information can be linked directly to the 3D model of the building, and there being accessible to all users of the model. However, not always was updating the different data sets so easy, and many of the projects relied a lot on email as a communication method and as a trail of evidence on the change.

KPI tracking relates to finding deviations in the project as early as possible, to avoid for the problems to escalate into a point where recovering from them is difficult. Interviewees from Project B reckoned that due to the formal contractual ties, no party wanted to raise the possible problems as it would have meant partly taking responsibility for the issues. Therefore, the delays and issues were allowed to escalate until the project was inevitably not going to finish on time. Project C contractors showed, how they used metrics comparing planned and realized levels of production to carefully follow the progress of the project.

Robust concept – strategies for increasing building flexibility

Product flexibility is about increasing the options embedded in the design, so that changes would be possible without large modifications to the designs. Three main strategies for increasing product flexibility came up in the interviews: Standardization and adaptable rooms, design for worst case, and reserve space and capacity.

Standardization and adaptable rooms were seen as a means to both increase the flexibility of spaces in terms of use, but also to reduce user changes due to well-specified solution. In few of the cases it was reported that with minor changes, the type or function of some rooms had been modified during the project, showing that adaptability was actually used. Standardization would also help to use best practice solutions from previous projects, in a way that design should not be started from scratch. It was brought up that the use of standardized templates might reduce the need for such heavy user involvement during the design, as a proven solution would already exist.

Standardization was mentioned on different levels: component, room, and system levels. Components such as ceiling system interfaces for equipment had been standardized to some extent, through a grid system or a specifically designed steel frame, with the idea that any type of equipment could be attached to them. This increased the rooms flexibility towards changes in medical technology. On room level, some opportunities for standardizing them were given. In Project B, the starting point for operating theatre design was that they would be of about equal size and with similar space requirements to allow them to be modified to current needs, even if the specific fixtures and equipment in the rooms would vary. Support spaces such as cleaning facilities or office spaces were standardized in terms of size and layout during Project A, and these standards were meant to be used in subsequent projects to reduce the effort of redesigning spaces. System level standards on hospital campus level would make use and maintenance easier but also reduce the amount of choices to make during a new-build project, possibly reducing changes in system type during the construction. Suggested systems for standardization included security systems, nurse call systems, and some electrical components.

Standardization was not embraced in all projects. Some highly-specialized operations like imaging or surgical units were considered to have extremely specific requirement needs according to the respondents in Project D, and thus were designed very individually. In single projects and among smaller owner organization it seemed that experience and standards for different spaces and systems do not yet exist, although these could be benchmarked from other organizations or even abroad. On the other hand, in case of a large owner, a much higher level of standardization in terms of rooms and functions was possible to be used in Project E. Lastly, the local legislation probably had a large effect on standardization. For instance, certain states in the U.S. set strict boundaries on the requirement of patient rooms, but in Finland there is hardly any specific regulation on healthcare facilities (European Health Property Network, 2010).

Design for worst case was especially used with the uncertainty of medical equipment choice. The strictest design criteria from different suppliers in the market was taken e.g. in terms of height, weight, and vibration criteria, in order to fit any choice of equipment without major modifications to the space. Another technique needed to cope with differences in underlying technologies, for instance air-cooled versus water-cooled equipment, was to even provide parallel systems from which only one would be used based on the choice. Some concerns were raised about the chosen criteria still not being enough if new generation of equipment would enter the market, and overall of choosing the right level of preparation. On the other hand, it could be too expensive to take every possibility into account, and thus the option would be to make the design based on the most probable choice.

Reserve space and capacity designed to the building had typically less to do with the construction project at hand, but were utilized for longer term adaptability and convertibility of the facilities. However, they provide important flexibility already during the construction project, and it was reported that in some projects almost all reserves had been utilized after the building was finished. It was seen as common practice already to leave extra space to ventilation and technical shafts to fit with changes, as well as to have a large enough floor height so more systems can be fitted to the ceiling without compromising operating requirements in the space. Possibilities for further flexibility where mentioned in the form of reservations in the building frame for opening new mechanical shafts to be used in the future, or through a structural system which can suit multiple layouts in terms of columns and that floor structures fulfill higher load-bearing requirements. In addition to physical dimensions, extra capacity was dimensioned into the installed systems like the electrical systems. Again, with all the mentioned methods in this category, the extent of preparation was determined by the owner by evaluating the future benefits from the extra investment.

The theme of adaptable and convertible buildings came up frequently in the interviews as the idea has been around quite long in the hospital design discussion. But when asked about how this has practically been taken into account in the design process, the answer especially in Finland was that it was paid quite a little attention as for example cost issues were perceived more important. Adaptability in rooms by making them general in terms of size and other features was seen to negatively affect the room plan by making it looser, and thus reducing the amount of functions that can be fitted to a building. The general perception seemed to be that if the functionalities would change, a large-scale renovation of e.g. the whole floor would anyway be needed, questioning the value of building standardized or adaptable rooms. Most attention in terms of building flexibility was paid to the structural frame, allowing for convertibility and expandability in the future but contributing little to everyday adaptability.

Incremental decisions – tools for increasing process flexibility

Process flexibility balances between the need and availability of information needed to build a hospital. Many issues related to the information flow, basically the timing of the design decision process, and how the construction process could be modified to allow for postponed decisions were covered. Four separate themes about actions to achieve this were identified: 1. realizing the need for process flexibility due to uncertainty and recognizing those areas where postponement could be an advantage; 2. scheduling decisions in a way that would suit the needs of both the decision-makers and the construction process; 3. modifying the work on-site in a way that tasks can be postponed, decoupled or conducted in a different order; and 4. decoupling some work to be done off-site through prefabrication or preassembly. Figure 23 depicts the process flexibility strategies in relation to the design and construction processes.

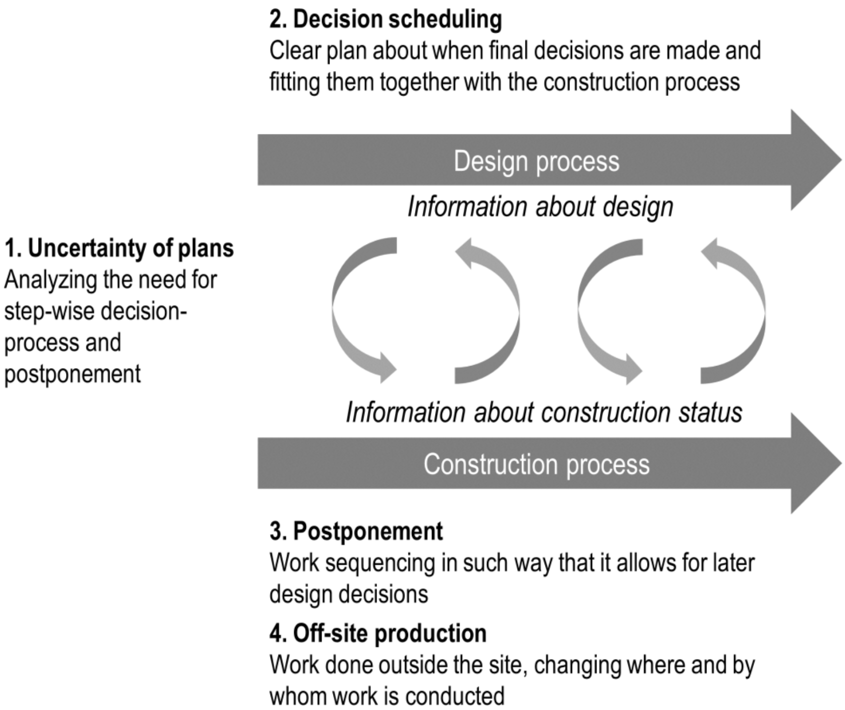

Figure 23: Methods for achieving process flexibility

Uncertainty of plans and being prepared for changes is about the mindset of the owner, designers and the construction team in terms of planning. Especially interviewees from the contractor side many times referred to the knowledge they had gathered during the projects which made them more critical towards the initial plans and helped recognize change sensitive parts of them in advance. While the owner side and designers do not typically leave any blank areas to the drawings for signaling an area still under development, it would be important information for the contractor to have the knowledge about which are the most uncertain areas. Owner representatives and supervisors recognized that for example for rooms with large medical equipment, a sequence of design-purchase-redesign-construct often occurred. However, due to their lack of communication about the plans this was not always clear for the contractors and prevented them from taking preparatory actions such as changing the work sequencing, schedule, and resource allocation. Leaving such buffers without knowledge of changes is practically impossible, while in a low-bid tender the contractors need to place their bids based on a flow-scenario, and most owners do not want that the contractors to reserve significant contingencies themselves.

Decision scheduling and stop to changes addresses the information needs and how in practice the decisions must be fitted with the construction process. There must be a clear structure on how the design choices and procurement of equipment are matched to the production plan, if decisions need to be postponed. It seemed to be a common problem that discussions tended to come up when it is already too late to adjust the design and construction to the new demands. The scheduling seemed to have worked better when the general contractor was coordinating both decision and production schedules, like in Project C, than in those projects where the owner had full responsibility for the design and the general contractor was only responsible for the production plan, like in Projects B and D. In the former situation, the contractors also had direct contact with the users and equipment suppliers as opposed to the other configuration. Stop to changes relates to the schedule by setting a clear deadline, after which no changes should be allowed. However, this has been a lot harder than expected to implement in many projects. It still emphasizes the importance of giving the users and procurement team proactively notice that their input is needed by communicating beforehand about those areas which are being built and should not be changed any more.

Postponement of work tasks or phases by work sequencing, prioritization, and sectioning of the site relate to how the actual construction process on-site is arranged. Construction still is a quite strictly linear process, which means there are limitations to the working order and thus to which tasks can overall be postponed. The use of BIM has allowed for different work sequencing for example among the MEP trades, when the spatial locations and reservations for other systems can be provided to the workers, reducing the interdependency of tasks in the same area. Postponement and separation of installation work could be done by doing as much as possible beforehand, so that the remaining work after the equipment delivery date could be done faster. The work site sectioning allows for work to be conducted independently in different sections or even phases. This permits for achieving the strict cleanliness standards in some sections even if in others work has not progressed as far. Changes also have different urgencies: some have plenty of time to react to and some "*should have been done yesterday*".

Prioritization is thus needed in the presence of scarce resources, by starting with the most urgent and interlinked tasks.

Off-site production gives flexibility in terms of where and by whom construction tasks can be executed. By prefabricating or preassembling entities, work tasks needing expertize from multiple different trades could be combined and moved to be done outside the work site. It was seen to contribute to allowing faster construction on-site, as well as create a loose coupling between the prefabricated "elements" and other systems in the building. When the interfaces between the element and rest of the building has been defined, disruptions to the previous work phases no longer affect the prefabricated tasks. In Project E, it was also mentioned that it is possible to use more low-skilled workers on-site for the assembly of the prefabricated entities. Examples given in the interviews included bathroom pods, patient headwalls, doorframes with cabling as well as MEP racks with preassembled cables. All these entities built in a traditional way would be very interconnected with other construction tasks as well as need multiple work phases from different specialist contractors to be conducted.

Flexibility maximization – enabling integrated product-process flexibility

Integrated product and process flexibility describes the situation where both flexibility in the product design and the flexibility in the decision and construction processes are designed for simultaneously. It is however difficult to reach this under a fragmented project environment where design and construction are strictly separated and contractors only involved after the design has been finished. Two themes, the early involvement of key contractors as well as use of modularity in the sense of creating independent "modules" inside the hospital structure, were identified as possible ways to conduct process flexibility.

Early involvement of key contractors, which is an important feature both in alliancing-type projects as well as in lean construction, was a theme on which the opinions of the contractor and owner representatives were very divided. The opinion on the owner side seemed to be that the contractors have little added value to give to the project, and that they would only protect their own interest if allowed to affect the design. The contractor side on the other hand felt that if they could present their view on the project, it would help save a lot of resources for both sides. Eventually it comes down to issues of trust and goal alignment between the project parties. One Finnish respondent analyzed that the traditional culture in the construction industry, relying extensively on contract agreements, penalties and disputes, does not encourage cooperation nor contribute to the overall success of the projects. Similar cultural issues were mentioned in the other countries too. Contractors in Projects C and E had influence to the design, in C as a coordinator for detailed design and in E as a design-assist type of project. However, in both of these cases the general contractors were not part of the project very early on, and thus helped mostly on finishing the construction drawings and removing errors and constructability issues but did not have an effect on higher-level plans.

Modularity was mostly associated by the respondents with prefabrication issues already discussed in the previous section. Some of the projects however used modularity on a larger scale, not necessarily related to prefabrication but using it to as a tool in the building design to postpone decisions and allow large changes to specifically bounded areas. In Project D, the different operating theatres and imaging rooms were designed as self-sustaining modules, which can be modified without affecting the use of other rooms. The main systems were located in the corridor area, which was acting as a platform from where the room-specific systems would branch off. The ability to close down parts of the systems for modifications or renovations was thought as an important feature there, and already used during the construction project. Similar methods of postponing specific areas were used in Project E, where entire floors were left without internal installations, as so called shell space, which can be then fitted out later either during or after the main capital investment project. However, the space was acknowledged in the design by locating the main building systems so that the empty spaces can tap into those easily.

The methods of combined planning for building and process flexibility were still scarce among the interviews, which depicts the general lack of a holistic approach to flexibility issues. For example, if the project is known to need a lot of flexibility and possible postponement, through modular thinking these areas could be separately managed from others and thus have a smaller effect in the overall progress of the project. In two of the projects, namely C and E, the contractors had been involved to some extent in the design process, but maybe not early enough to affect the most fundamental design choices.

Summary of mitigation strategies

The recognized mitigation strategies were interpreted in accordance to project flexibility, and they are summarized in Table 20.

Table 20: Summary of change mitigation strategies

Flexibility category	Stable environment	Robust concept	Incremental decisions	Flexibility maximization
Strategies	Clear goal Design requirements elicitation and communication IT tools and up-to-date information KPI tracking	Standardization and adaptable rooms Design for worst case Reserve space and capacity	Uncertainty of plans and being prepared for changes Decision scheduling and stop to changes Postponement of work tasks Off-site production	Early involvement of key contractors Modularity

The categories are not exclusive but represent different levels of emphasis on flexibility on the two axes. For instance, the strategies in the "Stable environment" -category can well be used in combination with the flexibility-enhancing strategies. The differences between the far ends of the model are due to different approaches to organizational, contractual, and design aspects. Under the "Stable environment" -category, the organizations are fairly independent and are managed through strict and almost mechanistic contracts, while the actual building and its systems are integrated in the design. In the “Flexibility maximization” end of the spectrum, the building is actually less interdependent through the use of modularization and prefabrication, but to reach this in the design, the project organization needs to be more integrated and organic from the start as too strict contract boundaries can prevent from organizing work in a novel way.

Not all these strategies are yet used to their full potential. In terms of product flexibility, short-term adaptability of rooms and wards had been considered much less than structural convertibility, reducing the ability to modify operations at a low cost in the short and medium term. Many process flexibility methods were on the other hand used, but more in a reactive way than systematically planned for, thus increasing their costs. An integrated approach to flexibility has been even less used as new project delivery methods are still rarely utilized, which is mostly due to the adversarial culture traditionally dominating in the construction industry. The key to benefitting from the different flexibility strategies would be to really analyze the project context and what kind of flexibility would be needed. At the moment, the stable environment assumption still dominates in most projects, leading to a less than optimal amount of flexibility preparation.

5 Discussion and conclusions

The improvements in technology and operations in healthcare are not slowing down in the near future, but more likely they even get more dynamic and hectic. The introduction of trends like mobile and telehealth, self-treatment, and day surgery might change the facility needs in a radical way even on short term. Major changes in scope were avoided in the researched projects, but all went through a series of design and other changes that shaped the end result to what it is now. The users have been very happy with what they have received, but many times at the cost of project efficiency and the timely opening of the facilities. Based on the results of this study, there seems to be a lot of potential to improve the capabilities to execute changes and achieve savings for all parties involved.

5.1 Combining the perspectives of change causes, effects, and mitigation mechanisms

The research started with three distinct research questions, translating into three different perspectives to observe changes: what kinds of changes happen during hospital construction projects and why are they needed (RQ1); what effects do changes have on the project performance and success from the point of view of different stakeholders (RQ2); and how could changes be managed to minimize the negative and emphasize the positive effects (RQ3).

The three perspectives link together through the need for changes, occurring as change causes, and the ability to make those changes during the construction, determined by the level of flexibility. Both sides need to be considered when the effects, namely costs and benefits, related to the suggested changes are assessed. Figure 24 depicts the synthesis of the three researched perspectives.

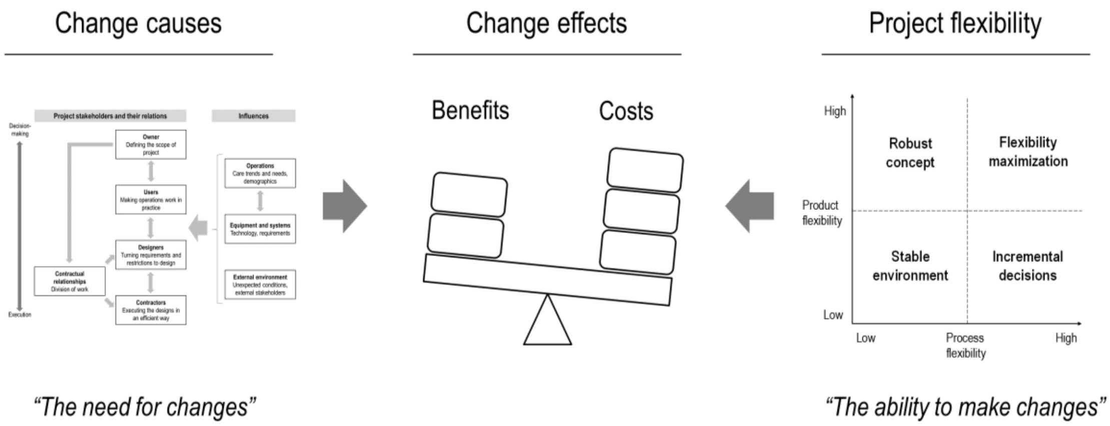

Figure 24: The link between the three research perspectives

Changes were found to happen continuously during the projects. Some changes did arise due to errors and omissions in the design or construction processes, but generally they were more about the project facing internal and external change pressures over time. Changes reflected the uncertainties and dynamics from the internal stakeholders or outside influences such as operational or equipment changes. In this sense, changes are essential to the success of the project, and allow the project to adapt to changing goals. These results challenge the dominant view on changes during construction as a wasteful activity which should be avoided as far as possible. The evidence presented here depicts changes as many times necessary, even vital to ensure the functionality of the finalized building. The ultimate goal of the hospital projects is to provide the best possible facilities for the operations, and changes in many ways reflect this higher-level goal. The project needs to adapt to dynamics even during the execution phase, and the ability to do so can be increased by addressing project flexibility issues. It is a significantly different attitude from what has been traditionally associated with construction changes, as failures in the design and execution phases, causing only disturbance, costs, and delays (Burati Jr. et al., 1992; Love & Edwards, 2004; Olawale & Sun, 2010).

The view on what eventually causes changes in the hospital construction domain has also some new light. While the previous literature on hospital buildings and construction mainly emphasizes uncertainty due to external changes in the healthcare service domain (Barlow & Köberle-Gaiser, 2009; de Neufville et al., 2008; Olsson & Hansen, 2010), this research provides evidence of several additional factors contributing to construction changes. While the dynamic change in the industry and technological advancement was proven to induce changes especially in the equipment area, also socio-political reasons, the contractual set-up, the expertize of the designers, owners, and contractors, and unexpected outside influences were recognized as sources of changes. The socio-political dimension of complexity has not been an area previously emphasized in hospital construction literature, but was found to have a profound influence on many of the change sources.

As explained, changes are important from the end result point of view especially for the users, but tend to cause some negative effects to the execution side, mainly contractors, in terms of cost, schedule, scope and efficiency. Owner representatives seemed to locate somewhere in between these two ends in terms of perceived effects, while they have the responsibility both for the functionality but also for budget, schedule, and quality control. Direct costs of changes were typically compensated to a large extent to the contractors, but other, less obvious negative effects they had to absorb without compensation based on this research. This division of effects is bound to lead to tension between the owner and the contractors, and thus new ways of allocating the costs and benefits are needed. It can be concluded that the negative change effects reported in the literature review are very much real, but fail to account for the benefits of changes.

To increase the ability to make changes, both improved communication and coordination and the different project flexibility strategies were regarded as ways to reduce, earlier recognize, or more efficiently execute changes. As complexity was found to be the underlying reason for a number of changes, it would pay off to try to mitigate the project complexity factors as far as possible with effective project management principles and then use project flexibility to answer the changes that are unavoidable in order to have a successful end product. Some of the discussed strategies were already used in the projects, but significant gaps were also found in the way that project flexibility was implemented in practice. For instance, none of the projects used the integrated approach to project flexibility or had a proactive approach to process flexibility.

One reason for the shortcomings of the use of flexibility in the researched projects can be found in the project delivery methods. In the typical project delivery methods emphasizing formal control (Caldwell et al., 2009) and having a strict price focus (Eriksson & Laan, 2007), there is little possibility or incentive for the contractors to make their approach more flexible. As Walker and Shen (2002) found in their study, not only is the ability to use flexibility but also the will to do so that affect the realized level of flexibility.

5.2 Theoretical implications

First, this study contributes to the knowledge on construction changes in a specific industry, hospital construction. The new categorization of change sources and the root causes related to each category showed clearly that context specific factors like the medical equipment and user influence on designs play a significant role in the emergence of changes in the hospital domain, challenging the usefulness of the more general change categorizations found in the literature search. On the other hand, hospital construction might not be a completely unique setting either, as similar contextual complexity factors and flexibility strategies as found in this were presented for example in the research of Gil et al. (2005) on semiconductor manufacturing plants. Finding the right balance between the special characteristics and commonalities in the industry would help theory building in the future.

Another important theoretical contribution is that project complexity factors were linked to project changes as possible root causes. The framework of Geraldi et al. (2011) was used for analyzing the complexity factors related to different change causes. The results highlight that project complexity is a key driver behind hospital project changes, and this connection needs to be better understood in order to further address the issue of changes.

The third contribution the thesis makes by applying the concept of project flexibility to analyze change mitigation measures. Olsson (2006) and Olsson and Hansen (2010) compared the planned and realized levels of flexibility in projects, concluding that there clearly is a need for more flexibility than initially thought in many hospital projects. This thesis focuses on changes specifically and how flexibility can be used to mitigate their effects, providing a more thorough explanation of why flexibility should be needed in the first place.

5.3 Managerial implications

From a managerial point of view, this thesis addresses two main audiences: hospital owners and contractors. The most important implication of this study to both groups is the understanding of the nature of hospital construction and what are the typical factors that create complexity in this domain. The managers of hospital projects should thus not only be proficient in dealing with technical complexity but in addition they need to be able to manage the different stakeholder groups, which applies to both the owner and the contractor sides. It is important to recognize that project complexity can many times be self-induced from several decisions made when planning and executing the project. The information flow between the users of the hospital and the project is of vital importance. Barlow and Köberle-Gaiser (2008) noticed that some hospital owners approach the project with an idea of a "ready-made house" without understanding the importance of continuously providing information for the project to advance. They stated that the more complex the communication interfaces between the project and hospital operational system were, the less adaptable the end result tended to be. Also low budget allocation from the owners tend to work against flexibility in the building (Barlow & Köberle-Gaiser, 2008), and was overall noticed to courage short term thinking in the researched projects. The finding from this study was that an unclear organizational structure and a large number of separate contractors tended to make the project communication more difficult.

The owners have a lot of power on the organizational structure of the product by choosing a project delivery model that reflects on the number of separate parties and their formal relationships. From the results of this study, it seems that a strong systems integrator role would be needed, and that in the construction phase the role would naturally fit the general contractor. However, not always were they positioned centrally enough in the project network to be able to fulfil the role. The contractor side would be more than willing to take a larger role in the overall project planning, provide additional services and have their incentives linked to the performance of the end product rather than just to the project management success. Trust remains a significant barrier to making the projects more collaborative. The owners are reluctant to give more power to contractors and rely on contractor self-control while moving from price and authority focus to trust focus in the project delivery and contracting methods, as presented by Eriksson and Laan (2007). The contractors also need to prove their effectiveness and that they can be trusted to make this shift.

An interesting observation is that despite the relative complexity of hospital construction projects, the project delivery approaches did not vary much when moving from the simplest projects to the more complex ones. This shows that to some extent there is still an expectation among the project owners that one universal approach would work best with all different types of projects. However, it has been long recognized in project management literature that understanding context is a key success factor in project management (Maylor et al., 2008; Shenhar & Dvir, 1996). Although both product and project flexibility are used already to some extent for change implementation, the combination of the two in the form of using relational project delivery methods and lean or modularity was not reached in any of the researched cases. It depends mainly on the owners how projects will be organized in the future. Recent announcements of new hospital projects in Finland show that the trend might be moving to alliancing and partnering models, which tells that the problems of typical project delivery methods have been noticed among the owners too and attempts are made to explore other alternatives. It is interesting to see how these new projects will differ in the change dimension from traditional projects.

The framework conditions of the healthcare sector and cultural differences have been interpreted as significant factors affecting hospital projects and their flexibility (Olsson & Hansen, 2010). There were similarities but also great differences between the healthcare systems in the researched projects, mainly between the Nordics and the U.S.. Between Finland and Sweden, the separation between the ownership and use of hospital facilities was one key difference noticed, but in addition there might be underlying cultural differences affecting the way projects are done. Sweden is known for a very consensus seeking discussion culture, which affects how the internal project relationships are formed. Still, differences existed also within the countries between projects, signaling that relationship quality is not solely dependent on cultural differences but also project-related factors are significant. An important takeaway for project managers is to identify those complexity factors, be they technical or socio-political, that most influence in the specific project context and adapt their approach to them.

Lastly, the categorizations and frameworks used in the thesis work as templates or check-lists for the people managing hospital projects. The change source categorization, root causes, and related complexity factors hopefully help project managers to identify the most important areas where changes are likely to emerge. The change effect categorization and moderating variables list work as tools to understand the project management implications of a change and increase understanding among the users and owners on what types of changes cause most trouble for the execution of the project. The flexibility framework presents different possibilities to prepare for changes, with four different emphasis areas along the quadrants. By determining in advance the main type of flexibility needed, the owner can make choose a suitable project delivery model to fit the project profile. For instance, if the project is under great uncertainty on the choices of medical equipment, it would be beneficial to explore process flexibility strategies to fit the incremental decision process to the construction work. Another example could be uncertainty of the number of different types of patient rooms needed in the future, which could be taken into account by designing universal patient rooms suited for multiple uses, leveraging on product flexibility strategies.

5.4 Limitations and possibilities for further research

The reliability of the study has been considered and thus detailed description of the data collection and analysis methods are well-documented and listed. The interview protocol is provided as an appendix. The presence of multiple researchers in the interviews and discussing the data analysis and findings together reduces the possibility of researcher bias. Interviewee bias was considered by including persons from different roles, organization, and countries, as well as by providing anonymity to the respondents by concealing their names, organizations and the exact projects researched. It should be noted that the Swedish and U.S. interviews were conducted in English by non-native speakers, so it is possible that misunderstandings could have happened. All interviews were recorded and transcribed to reduce this possibility.

Internal validity is concerned with the causal explanations developed and the possibility of spurious relationships (Yin, 2003, p 36). Internal validity is supported in this study by using data triangulation through multiple different sources of evidence, and ensuring that all data, not only the converging part, is represented in the analysis. Any causal statements are made with caution. In terms of external validity, the extent to which generalizations can be drawn from the study (Yin, 2003, p 37), the thesis makes no claims of statistical generalization or generalization outside the researched context. However, analytical generalization of the results to similar contexts could be made. More specifically, the results are likely to generalize well inside the hospital construction industry as multiple different project types and sizes were researched, although some restrictions apply. Projects from three countries were studied, so the geographical coverage is quite limited. Extremely large projects were deliberately left out of the research, which means that the results may not be applicable to mega hospital projects. With certain caution, the results could possibly be also expanded outside healthcare and hospitals to similar, relatively high technology industries that need highly customized operating facilities. Earlier, the similarities between semiconductor fabrication plants researched by Gil et al. (2005) were highlighted and it is probable that also other relatively good comparisons exist. However, hospital construction is a large sector within the construction industry, and research on the topic can be thus motivated solely for its own purposes.

Future research is needed to further expand on the results of this study. Firstly, the research included only fairly traditional design-bid-build, design-build and construction management project delivery types, and further comparative research between these traditional methods and the relational project delivery types is needed. Second, the moderating variables related to change effects should be further elaborated and hypotheses on their effects tested on real project data. Third, more research is needed on determining the value of flexibility in hospital projects, which would help make fact-based decision about the choice of which flexibility strategies to use. While product flexibility has been valued based on real-options approach, there have not been efforts to quantitatively value process flexibility. Lastly, this research supported the finding that human factors play an important role in the emergence of changes in projects, but the shared decision-making processes related to changes have not yet been thoroughly investigated.

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Appendices

Appendix 1: Interview protocol

Starting the interview

- We are researcher from Aalto University in Espoo, Finland. We are involved with a research project looking into new ways of managing healthcare facilities and their construction. Company X is our partner in the research project, and the project X is selected as one of our study cases.
- We are particularly interested in change orders during the construction phase in hospital construction projects, and how they are managed. We are keen to get some concrete examples of changes that have happened in the focal project.
- The interviews are confidential and shared information will not be given to any third party outside the research team. Consent to record the interview asked.

Background information and the project in general

Could you first please introduce yourself and tell us about your background?

Have you been involved with hospital construction projects before? How many projects and where?

- What is/was your role in this specific project?
- Could you name the different organizations involved with the project?
- How does/did the project organization look like?
- Who do/did you collaborate the most with? Who are the contact people from the other project parties?

In your own words, describe the project (contract type, budget, schedule, phases, main goals)

- Have you and your organization been involved with the project from the beginning?
- Tell us about the different phases of the project. Were there any significant events during the course of the project?
- How successful was the project in your opinion?

Change process: roles and communication

Tell us about the process of managing change orders in the project. What happens in practice when there is a need to change something?

- Who in your organization is the primary responsible for the change management and execution? What about from the client/contractor side? Is it also the contact person for the whole project?
- Can you give examples of how the process of receiving change orders happens in practice? What is the line of communication?

Changes and their management in this project

What type of change orders did you receive in this projects during construction (after the planning phase)?

For each change case:

- At what point did the need for change occur? Was it expected or unexpected?
- What was the reason behind the change?
- What were the consequences to the project?
    - Were there issues associated with the change? What kind of issues?
    - How did the change affect the schedule, budget, or process?
    - In hindsight, were the issues and cost of the change assessed correctly?
- Could the change have been avoided somehow?

Did all the different changes made during the construction have a joint, major impact on the project?

Changes in hospital projects in general

How are hospital construction projects different from some other types of projects, such as offices, residential, educational etc.?

In hospital projects, what are typical change needs in the construction phase? What seems to cause them, in your opinion?

At what point do these needs for changes typically occur?

Can you prepare for changes? How?

Ending the interview

Did we miss something? Is there something you would still like to say?

Who else do you think we should interview?

Are there any written documents that we could use in the study? (change orders, meeting minutes…)

Appendix 2: Change events from Project A

Phase	Description	Change source category	Secondary cause category	Tertiary cause category	Cost	Schedule	Scope	Efficiency
Design	Section left out (addiction clinic, 1000m^2)	Owner	Cost saving	Cost pressure				
	Some single rooms turned to double rooms	Owner	Cost saving	Cost pressure				
	PET-CT imaging space added to cellar	Owner	Hospital campus development	Placing of functions			N	
Foundation and superstructure construction	More groundwork than expected	External environment	Unexpected conditions	Lack of ground research	N	N		N
	Sewer line rerouted	External environment	Unexpected conditions	Outdated/wrong information	N			N
	Site logistic route rerouted	External environment	Other stakeholders	Community				
Interior construction	Inner window of an office lowered for visibility	Users	Badly communicated requirements	Drawings not understood				
	Room interior solutions changed (shelves, carpet mounting)	Users	New/changed requirements	Details refined				
	Washing hoses added to security rooms	Users	New/changed requirements	Change of people				
	Medicine room transformed to room for ward assistant nurse	Operations	Allocation of spaces	New function				
	Office of ward nurse turned into crisis care room (Phase 1)	Operations	Allocation of spaces	New function				
	Nurse call system change	Equipment and systems	Equipment choice	Late decision		N		N
	Washing machine connections - fitting	Equipment and systems	Installation	Unknown interface requirements				N
	More protective glass walls/railings were built	Design	Design omissions	Lacking functionality	N		N	N
	Window mountings changed after Phase 1	Design	Design omissions	Unforeseen use			N	
	Room electric switch centers - double walls added for soundproofing	Design	Design errors	Wrong parameters used			N	
	Change of carpet material	Contractors	Cost saving	Low tender price	P			
	Reduction in inner ceiling material	Contractors	Cost saving	Low tender price	P	P	P	
	No metal ceiling to the parking garage	Contractors	Constructability	Schedule benefits	P	P	P	
After handover	Medical gas line rerouted	Owner	Hospital campus development	Renovation needs	N	N	N	
	PET-CT equipment installed late, modifications during installation	Equipment and systems	Equipment choice	Late decision	N	N		N
	Doors and locking system reconfiguration	Design	Design omissions	Lacking functionality			N	N
	Rooftop garden space added railings	Design	Design omissions	Unforeseen use			N	N
	Shower heads in the patient room bathrooms changed	Design	Design omissions	Lacking functionality	N			

Appendix 3: Change events from Project B

Phase	Description	Change source category	Secondary cause category	Tertiary cause category	Cost	Schedule	Scope	Efficiency
Design	Some operating rooms were changed to accomodate heavier surgery	Owner	Hospital campus development	Renovation needs				
Foundation and superstructure construction	More groundwork, reinforcement to existing buildings	External environment	Unexpected conditions	Lack of ground research			N	
	Frame holes under 150mm	Contractual relationships	Contract scope	Planned addition			N	
Interior construction	Ceiling mounting system, standardized for all manufacturer mounting devices	Contractual relationships	Contract boundaries	Moved between contracts	P	P	P/N	P
	Two dental treatment rooms added from normal examination rooms	Operations	Allocation of spaces	Capacity needs			N	
	Drywall changes in the breast milk center	Operations	Process requirements	Layout needs				N
	More gas outlets and control cables, changes to ceiling system outlets (OR and ICU rooms)	Users	Badly communicated requirements	Wrong estimation of needs			N	
	Shelter for ambulances	Users	New/changed requirements	Change of mind			N	
	Lamp positions in the ceiling changed	Users	New/changed requirements	Change of mind				N
	Steam production problems, had to make a rerouting for steam from old hospital	Contractors	Errors	New technology		N		
	Cable racks needed to be changed due to change in HVAC	Contractors	Clashes between trades	System interdependence				N
	Larger switchboard space	Design	Ripple effects	Interdependency of elements				
	Medical gas system was put on hold for a couple of months	Equipment and systems	Installation	Unknown location		N		N
	Operating room control and image system changed	Equipment and systems	Equipment choice	Late decision			N	N
	Sterile processing department layout changed	Equipment and systems	Equipment choice	Late decision				N
	Fixed medical equipment outlets changed	Equipment and systems	Installation	Unknown interface requirements				N
	Nurse alarm system change	Equipment and systems	Equipment choice	Late decision		N		N
	Smoke ventilation system changes	External environment	Other stakeholders	Authorities			N	N
After handover	More gas outlets and control cables	Users	Badly communicated requirements	Wrong estimation of needs			N	
	OR fitted with a robot-assisted surgery equipment	Equipment and systems	Equipment choice	Technological advancement				

Appendix 4: Change events from Project C

Phase	Description	Change source category	Secondary cause category	Tertiary cause category	Cost	Schedule	Scope	Efficiency
Design	After surgery monitoring room windowsill lowered (had been frozen)	Users	Badly communicated requirements	Drawings not understood				
Foundation and superstructure construction	Emergency room layout changed	Users	New/changed requirements	Change of mind				
	Facade solution changed	Contractors	Constructability	Quality benefits		P		
	Environmental pollution in the ground	External environment	Unexpected conditions	Lack of ground research		N	N	
	Connection corridor to existing hospital needed more foundations	External environment	Unexpected conditions	Outdated/wrong information	N	N		
Interior construction	Nurse call system, doctors' location system, changed in requirements	Equipment and systems	Equipment choice	Late decision			N	N
	Connectors added to rooms (computer, power, medical gases)	Users	Badly communicated requirements	Wrong estimation of needs			N	N
	Geothermal heating added	Contractual relationships	Contract scope	Planned addition			N	
	Purified water piping system	Equipment and systems	Installation	Unknown location			N	N
	Surgical smoke ventilation system	Users	New/changed requirements	Details refined			N	
	X-ray needed in room that it was not planned into	Operations	Process requirements	Treatment guidelines			N	
Installation and commissioning	Installation of MRI and X-ray delayed and extra work needed to fitting	Equipment and systems	Equipment choice	Late decision		N		N
	Operating theater equipment delayed due to procurement law	Equipment and systems	Equipment choice	Procurement issues		N		
	Medical equipment installation was missing a part (between concrete ceiling and connection box)	Contractual relationships	Contract boundaries	Omission between contracts		N		N
	Washing machine connections needed differently	Equipment and systems	Installation	Unknown interface requirements			N	N

Appendix 5: Change events from Project D

Phase	Description	Change source category	Secondary cause category	Tertiary cause category	Cost	Schedule	Scope	Efficiency
Foundation and superstructure construction	More metal sheet piling needed	External environment	Unexpected conditions	Lack of ground research	N	N	N	
Interior construction	Ultrasound department removed from building	Owner	Hospital campus development	Placing of functions		N	N	N
	Pre-operation area office/control room walls removed	Users	Badly communicated requirements	Drawings not understood				N
	Old CT place moved from room to room, in the end stayed in old building	Users	New/changed requirements	Change of mind				
	Medical equipment procurement for advanced floor took longer than expected	Equipment and systems	Equipment choice	Procurement issues	N	N		N
	Changes in concrete slab for CT scanners	Equipment and systems	Equipment choice	Late decision				N
Installation and commissioning	Small, wall mounted details changed	Users	Badly communicated requirements	Too many decisions		N		N
	Extra work in fitting of medical equipment	Equipment and systems	Installation	Unknown interface requirements				N
	New version of the same suppliers' equipment chosen to a otherwise finished room	Equipment and systems	Equipment choice	Technological advancement				N
	Changes into electrical systems in ORs, controlling device added for continuous power (code requirement)	Design	Design errors	Code ignored		N	N	N
No specific phase	More MRI scanners added along the way (2->6)	Operations	Process requirements	Treatment guidelines			N	

Appendix 6: Change events from Project E

Phase	Description	Change source category	Secondary cause category	Tertiary cause category	Cost	Schedule	Scope	Efficiency
Foundation and superstructure construction	Different type of shoring wall (in the foundation) had to be built	External environment	Other stakeholders	Authorities	N	N	N	
Interior construction	Extra steel enforcement added to elevator structures	Design	Design errors	Concurrent design	N	N	N	N
	Some floors built as shell space and finished later	Owner	Cost saving	Funding not available				
	Laboratory space redesigned completely	Users	New/changed requirements	Change of people	N			N
	Air curtain missing from electrical drawings	Design	Design errors	Multiple sets of drawings	N			
	Duct and steel beam clash	Design	Design errors	Multiple sets of drawings	N			