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Business problems in timber multi-storey construction ecosystems: reasons to reorganize?

A view into building frame choices of Finnish main contractor companies in residential multi-storey construction.

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Abstract: Positive environmental impact and productivity gains from prefabrication are examples of arguments used to favour timber multi-storey construction (TMC). Despite governmental support, there has been little gain for timber in market share. The aim of this thesis was to find practical challenges that businesses should overcome if they wanted to increase timber use in large scale construction. 23 Finnish main contractor companies' directors and managers involved in decisions on types of frame structures in multi-storey residential buildings were interviewed. In addition to inquiring on timber specifically, their reasoning on using different frame solutions based on reinforced concrete (RC) were generalized to TMC.

Ten problems for TMC in residential construction were advanced. 1: Both timber element producers and main contractors markup timber frames significantly more than in RC construction due to prefabrication, risks, and incompatible operating models. 2: The public body in Finland supports TMC administratively, but the building code and municipal officials seem rooted to RC construction and therefore may be partial in considering the use of timber. 3: Large inherent fluctuations in construction volume make it hard for main contractors to manage in-house workforce and -element production capacity. 4: Nascent TMC is disadvantaged by the strong reliance on obtainability of experienced field professionals when main contractors make frame type choices. 5: Varying availability of building elements due to distances and market fluctuations often make or break elementized construction, including TMC. 6: Intense collaboration with timber element producers is incompatible with main contractors' operating model meant for commoditized means of production. 7: Main contractors' advantage is dependability, which makes radical changes in construction methods counterproductive for them. 8: Risks stemming from uncertainty of applying timber have a vast impact to risk premiums in construction. 9: limitations in element typologies decrease commercial viability of prefabrication, and 10: extra modification costs in elements with high degree of prefabrication may make them unusable in most builder vendor projects.

These problems may be solved by fitting TMC to construction industry's routines, but also adapting the existing modes of operation to TMC might achieve better outcomes. Based on a background of organization design and ecosystems, a draft of a new TMC ecosystem and ecosystem strategies is outlined for tackling the ten problems TMC face. Long-term coordination of the element producer- and main contractor roles is argued to be essential in accelerating TMC adoption.

Keywords Timber, elementized construction, prefabrication, ecosystems

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Työn nimi Liiketoiminnallisia ongelmia puukerrostalorakentamisen ekosysteemeissä: syy uudelleenorganisointiin?

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Tiivistelmä: Positiiviset ympäristövaikutukset ja esivalmistuksen tuoma tuottavuuden kasvu ovat esimerkkejä, joiden perusteella puukerrostalorakentamista (PKR) kannatetaan. Valtiollisesta tuesta huolimatta, PKR:n markkinaosuus on kasvanut hitaasti. Tämän diplomityön tavoite oli tunnistaa käytännön haasteita, joita yritysten tulisi selättää halutessaan kasvattaa puun käyttöä kerrostalorakentamisessa. Haastateltavana oli suomalaisista rakennusliikkeistä 23 päällikköä tai keskijohtajaa, jotka osallistuvat asuinkerrostalojen runkovalintapäätöksentekoon. Puun käytön näkemyksiensä lisäksi, heidän vertailuitansa teräsbetoniin (TB) perustuvien runkorakentamismenetelmien välillä hyödynnettiin yleistämällä PKR:seen.

Työssä havaittiin kymmenen ongelmaa liittyen PKR asuntotuotantoon. 1: elementtivalmistajat ja rakennusliikkeet asettavat suuremman katteen PKR:ssa kuin TB:ssa, johtuen esivalmistuksesta, riskeistä ja toimintamallieroista. 2: Suomessa viranomaiset tukevat PKR:sta hallinnollisesti, mutta rakennusmääräykset ja paikallisviranomaiset näyttävät juurtuneen TB-rakentamiseen, minkä takia ne sopivat huonosti puurakentamiseen. 3: suuri luontainen kysynnän vaihtelu tekee oman työvoiman ja -elementtituotannon kapasiteetin hallinnasta haasteellista rakennusliikkeille. 4: orastavalle PKR:lle on haittaa siitä, että rakennusliikkeet ovat riippuvaisia kokeneiden työmaa-ammattilaisten saatavuudesta tehdessään runkovalintoja. 5: välimatkojen ja markkinatilanteen mukaan vaihteleva rakennuselementtien saatavuus usein ratkaisee, voidaanko rakentaa elementoituna; myös puun osalta. 6: Tiivis yhteistyö elementtivalmistajan kanssa ei sovi rakennusliikkeiden organisaatioille, jotka ovat tarkoitettu vakioiduin menetelmin rakentamiseen. 7: Suoritusvarmuus on rakennusliikkeiden valtti, joten suuret muutokset rakennustavassa ovat heille haitallisia. 8: Epävarmuus puun käytössä johtaa suuriin riskilisävaatimuksiin rakentamisessa. 9: Rajoitukset tyyppirakenteissa alentaa esivalmistuksen soveltuvuutta ja 10: pitkälle esivalmistettujen elementtien lisämuutoskustannukset tekevät niistä soveltumattomia monissa omaperusteisissa rakennusprojekteissa.

Nämä ongelmat luultavasti ratkeavat ajallaan, kun PKR sopeutuu perinteiseen kerrostalorakentamiseen, mutta alan periteisten toimintatapojen mukauttaminen PKR:seen voisi tuoda lisäetuja. Organisaatiosuunnittelu- ja ekosysteemitaustaan tukeutuen, tässä työssä hahmotellaan luonnos uudesta PKR-ekosysteemistä ja ekosysteemistrategioista yllä mainittuihin kymmeneen ongelmaan vastaamiseen. Pitkäjänteinen elementtivalmistajien ja rakennusliikkeiden toiminnan yhteensovittaminen perustellaan välttämättömäksi PKR:sen käyttöönoton kiihdyttämisessä.

Avainsanat Puurakentaminen, elementointi, esivalmistus, ekosysteemit

Contents

Abbreviations

CIS	Cast-in-Situ. Method of construction where concrete structures are casted and cured on the construction site, not in an external factory.
CLT	Cross-Laminated Timber
CM	Construction Manager
CMA	Construction Manager Agency
CMAR	Construction Manager At Risk
DB	Design-Build contract arrangement; ”turnkey” construction service
DBB	Design-Bid-Build contract arrangement
GLT	Glued Laminated Timber
LVL	Laminated Veneer Lumber
LWTF	Light Weight Timber Frame
MEP	Mechanical, Electrical, Plumbing
RC	Reinforced Concrete
REIT	Real Estate Investment Trust
SGA	Sales, General and Administrative expenses
TMC	Timber Multi Storey Construction

1 Introduction

Driven by environmental concerns, the interest for replacing the two prominent structural materials in construction-, concrete and steel-, with timber has been continuously increasing around the globe. Modern development of (glued) mass-timber products like cross-laminated timber (CLT), glued laminated timber (GLT), laminated veneer lumber (LVL), and dowel-laminated timber allow building larger buildings, and timber frames' prefabrication allows building faster than previously possible. Although it is impossible to replace the whole global yearly usage of 14 billion cubic meters of concrete (GCCA, 2021) and all the steel with the around 4 billion cubic meters of yearly replaceably felled trees (FAO, 2020), there may be geographies and use-cases where timber would not only be a widely viable option, but also one that provides functional benefits over the usual alternatives. For example, around 30% of Europe's forests is enough to sustainably support all of its 750 million inhabitants accommodated in 41 m^2 of floorspace for each in apartments of timber framed multi-storey buildings (Ramage, et al., 2017). Positive environmental impact, increased living comfort, low-mass driven urban spatial efficiency (Dind, et al., 2018), and construction industry productivity gains from prefabrication are some of the arguments that may favour timber. The Finnish government aims for considerable increases in timber use especially in large buildings like schools and multi-storey residential buildings (Ministry of the Environment, 2016). The push for this has continued at least since the 1990's (Svatoš-Ražnjević, et al., 2022; Karjalainen, 2002), but timber adoption rate in the industry has risen slowly.

Conservatism in construction industry, high costs, and undeveloped timber construction practises and -supply chains have been given as reasons for the slow take up of timber construction (Jones, et al., 2016). Due to a small number of timber element producers that could supply builders with structural units, it is challenging to achieve cost competition through the normal tendering process that construction companies use in most construction projects (Hemström, et al., 2016). The lack of expertise and knowledge in the industry on what timber frame solutions are available and how to apply them is also one issue often raised for TMC.

Instead of being guided by a company or an institution, this thesis is completely based on the author's personal interest on this role of timber in the future of construction. Especially developing understanding on practical applicability of larger scale timber structures seemed topical due to the global interest. While keeping this context in mind, the work for this thesis was started by figuring out what are the sectors of construction where timber is least incumbered by the obstacles recognized in previous literature. This stage involved a literature review on timber construction civil engineering, a construction market study on statistics, and a literature review on timber multi-storey construction (TMC) adoption in construction industry. Then, in the second stage of this thesis, the recognized likely best-case sector for timber adoption can be studied further. **The goal of this thesis is to understand what practical challenges large scale timber construction faces in adoption by traditional firms.** Insights of these kind of practicalities could help in business- and product development, which comes as the sub-goal for this thesis as **how adoption of timber in large scale construction could be accelerated.** In order to limit the scope and extent of this thesis, the first stage of the work will be summarized here as introduction. This summary, then, defines the scope and constraints of the study.

Compared to bridge building and other long-span structures like stadiums, the markets for multi-storey construction are larger (Euroconstruct, 2018). This is likely a reason for why timber framed multi-storey buildings seem more prevalent than other types of large timber structures. Considering different types of multi-storey buildings, residential ones are most monotonous and flexible in terms of viable structural solutions, making them more amenable to mass production methods. Commercial- and public multi-storey buildings, as well as large industrial buildings, usually require more large and open spaces that are not only more structurally demanding but also restrict the viable frame types. For multi-storey buildings in general, there are many alternative timber frame types, or structural typologies, that are already being used around the world (e.g. GLT post-and-beam, volumetric LWTF elements, panellised CLT elements, etc). All timber frame types can be used as such or mixed in frames of residential buildings, whereas commercial, industrial, and public buildings usually require posts and beams (Svatoš-Ražnjević, et al., 2022) to achieve the open spaces. Due to lower absolute stiffness of timber compared to RC or steel, deep beams and/or tight spacing of columns must be used. Deep beams tend to increase the required floor-to-floor height, especially if flat soffits are demanded, and thus make open spaces less efficient volumetrically and economically when built from timber (Ramage, et al., 2017). Thicker walls compared to concrete may be an efficiency problem in residential buildings though. Bridges, stadiums and other "one-storey" halls usually don't have restrictions in heights of structures, so timber would be sensible there especially if the market was larger.

Residential multi-storey construction naturally allows more reasonably-dimensioned timber structures compared to other types of buildings or structures, thanks to the possibility to use more densely placed and closed-off load-bearing walls and shorter horizontal spans for floors. Timber is also beneficial for tall buildings because the structure does not have to support as large of a self-weight thanks to timber's low mass (Ramage, et al., 2017). Even though lateral force resistance, noise- and vibration attenuation, and fragility in terms of long-term durability and accident safety (e.g. fire) are challenges for TMC, there are widely used commercial solutions to them. As examples, soundproofing party walls and floors with decoupled layers and plasterboard for additional spring-mass and for inert fire barrier; weather shelters, eaves, structural ventilation, and timber impregnation for durability; adding sand or concrete to floors for wind load-resistance and soundproofing; steel hold-downs and prestressing, or concrete, CLT, or steel-framed rigid building cores for stiffening are being employed. As is evident, just like all RC buildings, timber frames are also hybrids of many materials. However, in this thesis a timber frame is taken to mean the supporting structure of a building, the bulk of which is made of timber all throughout. Materials fixed to the supports, like sheathing and cladding, as well as connectors between supports can be of different materials. In hybrid frames, steel or concrete members are used as supporting structures alongside timber. In reinforced-concrete (RC) frames, the bulk of the supporting structure is made of concrete reinforced with rebar or pretensioned steel tendons. Different frame types relevant for this study are briefly presented in section 2.

Residential TMC seems flexible in terms of possibilities in frame types and technically the most viable target in increasing timber usage in construction. Residential construction is also the largest market. Likely, it is therefore economically and practically relatively viable as well, although competing materials to timber are not evaluated here. Thus, it is taken as the most promising large scale timber construction sector and the focus in the rest of the thesis.

Additional challenge to garnering knowledge on practicalities that hamper TMC adoption is posed by complexity of the construction industry. Each constructed product, especially in building construction, requires collaboration between an amalgamation of interdependent parties, who often change from project-to-project. No one alone can decide where, when, or how to produce a building and what it should be like. All participants fill distinct roles, and all of them have influence on which kind of buildings are built. The particularities of the construction process and built products are elaborated in the second main section of the thesis.

Continuing to bring more focus to this study, a literature review on TMC adoption aimed to find clues for which of these roles are key on the decision of which frame types are applied. Timber manufacturing companies and architects have been said to prefer TMC but not have enough influence to accelerate the adoption (Jussila, et al., 2022). For example, even if architects specify buildings as timber-framed, main contractors-, who are responsible for realising the buildings-, may not bid for the specified frames but push for using familiar RC frames (Hemström, et al., 2016; Jones, et al., 2016; Burnard, et al., 2016) which they see as more dependable and affordable (Xia, et al., 2014; Hemström, et al., 2016; Riala & Ilola, 2014; Jones, et al., 2016). Due to their risk aversion and relying on routinized construction methods, the influence of main contractors negatively affect TMC adoption, which has indeed been reported by engineers and architects (Riala & Ilola, 2014) as well as by developers and main contractors themselves (Markström, et al., 2019). Building clients, and developers who represent the client, were reported to have similar views and even larger influence, but some clients are actually the ones that push for the use of timber frames. Along the lines of observations of Hemström et al. (2016) it seems that most studies on TMC adoption focus on designer professions or builders that are already using timber frames, while the viewpoints of construction companies that have stuck with traditional methods have received less attention. Just like in their study, focus on understanding the viewpoint of traditional main contractors who mainly do not utilize timber frames, appear a worthwhile opportunity for building understanding on what is required to have main contractors use TMC more broadly. Coupled with a focus on residential construction specifically, a concentrated inquiry like this could bring additional insights to the general challenges recognized by previous literature. This is the route taken in this thesis in the form of an interview study conducted on main contractor representatives, who have an integral role in residential multi-storey buildings' frame construction.

Although Hemström et al. (2016) did provide insight into Nordic main contractor companies' contract managers' thinking behind timber construction, deeper understanding of what goes on behind the frame type choice could be helpful. More specifically, clearly distinguishing what specific factors are considered in the choice, and how, could help in forming practical solutions to challenges TMC face. It may also be that main contractors who traditionally use different RC frame types may consider the factors differently. Operational differences like outsourcing-rate and vertical integration may also prove to affect the choice, as well as how main contractors approach the use of ready-made building units like walls or room-modules prefabricated in an external factory by a supplier, regardless of the frame material. Additionally, project delivery methods or contract arrangements may also have an effect. Then, as Hemström et al. (2016) propose, including perspectives of different roles within the contractor firms, like directors and site-managers, could provide an important supplement to their inquiry on middle-managers. It would also be beneficial to notice if fundamental incompatibilities between timber construction and traditional contractors exist. There might be reasons why TMC does not make sense among traditional main contractors.

Hence, the goal of the study presented here can be finally particularized as **understanding the challenges that main contractor firms, as key decision makers for frame type choice, face in adopting TMC.** Due to the nature of the industry, this likely requires tackling organization design in the context of organizing multiple separate firms around a common value proposition that is not familiar to most in the industry. The ecosystem lens (Adner, 2016) was found to be an appropriate theoretical framework for taking on this challenge. Ecosystems also give tools for analysing leadership arrangements and strategies in the multiple-firms context. Together with the author's degree studies on organization design and leadership, ecosystems theory completes a set of lenses that may help see the adoption issues for TMC in different light compared to previous studies.

The background literature needed for understanding the choice and development of construction methods in multi-storey residential construction, and for engaging the challenges present in coupling the sector with TMC are provided in the second section of this thesis. Then the way in which data collection and analysis for the reported stage of this study was conducted is elaborated in section three. The fourth section lays out the primary findings from the data: the practical challenges that main contractors and the construction ecosystem face in adopting TMC. The themes underlying the findings are presented alongside mappings to the data as evidence for the findings. Section five draws implications that the findings have on TMC adoption and drafts and proposes a concept based on innovation ecosystem theory and ecosystem strategy that may help achieving TMC adoption more promptly. The last chapter summarizes the yield of this thesis and attempts to put it into perspective.

2 Background literature

In this section, the context that the construction industry forms for new product innovations, and the concept of ecosystems for complex stakeholders' interactions' organization are investigated. First, the peculiarities of the industry and their effects to the constructed products are covered. Also, the players and the basic types of interaction (i.e. contract arrangements) are introduced. Finally, the relevance of ecosystems concept to business, characterization of innovation ecosystems and how the ecosystems and their participants may strategize to improve both their own and the whole ecosystems competitiveness. The background literature take an integral role in the analysis of the data collected herein, and are thus important for getting closer to the goal of understanding the challenges that main contractor firms, as key decision makers for frame type choice, face in adopting TMC.

2.1 Primer for innovation in construction industry

2.1.1 First principles of constructed products

"Immobility, complexity, durability, costliness and high degree of social responsibility" (Nam & Tatum, 1988)(see also: (Blank, et al., 1953; Segerstedt & Olofsson, 2010)) are some of the fundamental characteristics that underlie all products of construction industry, like buildings, factories and bridges. These characteristics are the lead to many construction industry's peculiarities compared to other (manufacturing) industries, like "field oriented", "extremely conservative", "too many small firms", "fragmented", "technologically stagnant", "negligible R&D" (Nam & Tatum, 1988). The general view is that productivity in construction industry is and has for long been much lower than any other industry (Forbes & Ahmed, 2020, p. 1), e.g. only 3.5% increase in Finland between 2000-2017 (Ahonen, et al., 2020, p. 27). According to Nam and Tatum (1988), lack of mass production, regionality, seasonality, path dependence (Mahoney & Schensul, 2006) and separation of production from design are the most significant consequences that the construction products characteristics lead to. Next, the aforementioned factors are presented in more detail.

Immobility relates to the fact that construction products are assembled and maintained on the site of consumption (Nam & Tatum, 1988, p. 137; Segerstedt & Olofsson, 2010, p. 347). All other products, of which cruise ships and mobile homes are the most construction-like, are produced elsewhere and then transported to the user. Although modules and elements of buildings can be built off-site, it is only possible to transport the smallest of complete construction products. Although factory production shows promise, structures and facilities are still mostly built and at least erected on site (Nam

& Tatum, 1988, p. 138; Ahonen, et al., 2020). Skilful tradespeople and material providers (e.g. due to concrete curing) are thus required locally in each commuting area.

Complexity comes in many forms in construction products (Forbes & Ahmed, 2020, p. 9; Nam & Tatum, 1988, pp. 134-135; Ahonen, et al., 2020, p. 23; Clough, et al., 2015, p. 1). Individual users, designers, builders, communities, societies, and authorities all have different and evolving tastes and needs that lead to highly varying constructions (Forbes & Ahmed, 2020, p. 251; Clough, et al., 2015, p. 45). Thus, almost all imaginable types of materials are used. There are different specialized suppliers for all types of components and equipment, and a variety of specialized contractors for applying the different types of components (Clough, et al., 2015, p. 45). Component production can be and are industrialized because they do not possess the same fundamental characteristics; they can be mass produced and shipped to site (Nam & Tatum, 1988, p. 138). On top of it all, it is common practise for each project to be completed by a temporary organization of a varying set of participants (Forbes & Ahmed, 2020, p. 30; Segerstedt & Olofsson, 2010, p. 351). Many of the participants must work in the evolving environment of the construction site, not in a fixed, carefully laid-out factory-like setting (Koskela, 1992). Still, Koskela (1992) argues that although the end product and the construction processes as a whole differ significantly each time, there are considerable amounts of similarities and repetition in tasks, components and solutions used between many projects.

Durability means that, unlike manufactured products usually, there is little possibility to discard or replace a complete or a significant part of a construction product because of a defect or a problem with it (Nam & Tatum, 1988, p. 135). Instead, constructed products must last decades and be repairable if needed (Ibrahim, et al., 2010, p. 238). Constructions are often bulky and heavy, because they are required to endure harsh conditions of nature and heavy usage. This exacerbates the immobility of constructed products and causes additional logistics expenses. The high durability results in slow wear and possibility to postpone repairs and replacements during economic downturns (Nam & Tatum, 1988, p. 135; Segerstedt & Olofsson, 2010, p. 348), i.e. to seasonality. Durability requirements also hamper construction technology development.

Ownership of a home is usually the largest and longest lasting investment in peoples' lifetimes (Ibrahim, et al., 2010, p. 238). Over time, constructed products' high complexity and strict requirements for durability have trended further upward, which is a major reason for **high construction expenses** (Nam & Tatum, 1988, p. 136). For construction innovations to lead to cost reductions, they must first completely offset the cost increases just mentioned. High costs and durability make it hard for the industry itself to spur up additional demand just by offering new kinds of innovative solutions (Nam & Tatum, 1988, p. 136). Therefore, even significant product improvements cannot generate the construction companies decidedly more sales than before, which makes improvements less enticing. High costs also mean that trial and error type of improvement is hardly possible in construction (Nam & Tatum, 1988, p. 136). Rather, conservative and well proven designs and methods are used to hedge the high risks from high costs. Immobility contributes to the effect of low elasticity of demand by restricting the possible size of geographical market that can be affected by innovations. Even if some firm can build better or cheaper, it may be slow to spread that advantage to other regions where new suppliers and tradespeople are needed.

Societal concerns for health, safety and environmental impact are major reasons for a "**high degree of social responsibility**" of construction products (Nam & Tatum, 1988, p. 136; Clough, et al., 2015, pp. 40-44; Koskela, 1992, p. 48). A defective building is often expensive to bring up to par and may be left as a nuisance in the living environment for an extended period of time. So, through rules, regulations, and trades' licensing, authorities try help avoid large scale harms from inadequate construction. The social responsibility also further drives specialization, by a need to distribute responsibilities, and results in conservatism in both creators and users of construction.

Two of the most influential effects stemming from the above-mentioned fundamental characteristics are the requirement for **site operations** and extensive specialization (Nam & Tatum, 1988, p. 137). The tie to the construction site makes mass production of the whole product unfeasible: conventional mechanized mass production is hard to deploy on site, and customers/society rarely allow the use of highly standardized structures in their living environment. The tie to the construction site also makes it necessary for contractors to be familiar with local climate, labour, materials, and services (Nam & Tatum, 1988, p. 137; Clough, et al., 2015, p. 46; Forbes & Ahmed, 2020, p. 30). This makes construction business highly regional and distributed to among an unusually large amount companies, which is also provoked by varying local regulations (Nam & Tatum, 1988, p. 139; Ahonen, et al., 2020, p. 22; Koskela, 1992, p. 48). Last major effect of site operations is the vulnerability to weather, which inherently increases seasonality and costs of construction.

Durability was already mentioned as availing the possibility to schedule construction to better economic situations. Durability also means that only a small unit-number of constructed products need to be are added to or replaced in the existing stock each year, therefore any fluctuations in that small number are relatively large (Segerstedt & Olofsson, 2010, p. 349). Seasonal differences in weather lead to higher construction activity being more advantageous during certain time of year than another (Clough, et al., 2015, p. 40). This is one reason why construction employment and demand vary a lot within a year. High demand periods are also high-cost periods. Seasonality and variability in quantities and prices of construction cause major difficulties for planning construction business and even individual construction projects (Ahonen, et al., 2020, p. 26; Clough, et al., 2015, p. 40).

Turning our view to the non-technological aspects of construction is the **extensive specialization** that is inherent to the industry. Even the seasonality just mentioned has led to an increase in specialization: contractors avoid wasting resources and furloughs by increasing outsourcing to specialized subcontractors (Ahonen, et al., 2020, p. 23). As discussed, the high variety of specialized stakeholders involved in each construction project means that a complex system where all participants are capable and motivated to perform their part of the whole is needed (Nam & Tatum, 1988, p. 141). In construction, this leads to a strongly "locked in" system for which innovation can often be seen as a destabilizing force against the whole. So, it is not enough to provide a new and better solution to one stakeholder. Instead, the whole system must be addressed, especially the local governmental bodies and possible labour unions (Nam & Tatum, 1988, p. 141).

All innovations in construction must conform to local governments' building regulatory agencies requirements. This poses a major difficulty for technological development because the building code changes are slow and infrequent and because building codes vary regionally (which also enhances regionalism) (Nam & Tatum, 1988, p. 141; Clough, et al., 2015, p. 42). In addition, changes to the code are achieved through a political process, which is influenced by many viewpoints that favour basing the code on past methods and materials: subcontractors and labour unions do not respond well to labour-savings, and local bureaucracies favour conservativism due to safety concerns (Nam & Tatum, 1988, p. 142). The wider the effects of an innovation, the more daunting is its introduction to the whole construction system.

Specialization has also led to a wide gap between construction and the design of construction, whereas in other types of manufacturing, design is an inherent part of production management (Nam & Tatum, 1988, p. 143; Forbes & Ahmed, 2020, pp. 28-29). Many constructed products, on the other hand, are first designed by a separate entity, and a builder is selected afterwards to execute the design (Forbes & Ahmed, 2020, p. 9; Clough, et al., 2015, p. 17). So, designing for new innovative construction methods could risk finding a builder and lacking of competition on cost efficiency, unless a builder is found in beforehand. It has been doubted though, that a more collaborative approach where designers and builders work together to offer more cost-effective solutions could overweigh the cost advantages that competitive tendering and separating design from construction provides (Cassimatis, 1969).

Although improvements to construction products and processes have happened, in most cases the more novel ways of construction have not been able to provide benefits that would make them clearly beneficial compared to traditional methods (Nam & Tatum, 1988, p. 144; Forbes & Ahmed, 2020, pp. 1, 31). Especially, the costs have kept rising (Pan & Sidwell, 2011). Already in 1988, Nam and Tatum argued that for there to be meaningful improvements in construction, perhaps the only way is that the innovations lessen the effect of fundamental restrictions posed by immobility, complexity, heavy materials, costliness, and social responsibility in construction (see also: Segerstedt & Olofsson, 2010, p. 348). Both the supply- and demand-side concerns that underlie these characteristics should be understood and accounted for. Indeed, although many new solutions have been and will be technically feasible, a failure to understand the unique restrictions in construction industry has greatly restricted the adoption of the novel solutions (Nam & Tatum, 1988, p. 144). To overcome the limits in adoption, a broad perspective to all the aforementioned construction specific issues is required, the authors of the 1988 article said. As examples for clear goals to strive for, they gave developing constructed end products that are mass producible to a larger extent and integrating the design and construction processes.

The challenge is great, because managers in construction do not see investments in innovation as beneficial for their competitiveness (Forbes & Ahmed, 2020, p. 31). One must understand the prevailing practical arrangements that keep the industry running as it currently is: who are involved, what are their roles, how do they interact? (Nam & Tatum, 1988, p. 145). For example, Segerstedt and Olofsson (2010) highlight the direct contact between end-users and builders in detached housing construction as enhancing building systems development, whereas in multi-residential construction the often-unknown end-users are represented by a professional client. Otherwise, both inventing and applying solutions that may move the industry toward resolving the characteristic restrictions it and its products pose, may not be possible to a meaningful extent.

2.1.2 Organization of construction projects

Construction is a project business industry, where each finished product is unique, and each project is completed by a different set of participants (Forbes & Ahmed, 2020, p. 30; Segerstedt & Olofsson, 2010, p. 351). Every single construction is its own separate case that needs to meet the needs of the owner, tailored to a significant degree from the ground up to its specific purpose, to fit the environment and the site, according to personal tastes of the stakeholders involved (Clough, et al., 2015, p. 1). Designers (architects and engineers) always create a unique appropriate design for the case at hand based on the owner-client's needs. The design is then largely custom-built by the contractors. The participants often measure project success by timely completion, budgetary results and adherence to building codes (Clough, et al., 2015, p. 302), while productivity and end-user satisfaction receive less attention (Forbes & Ahmed, 2020, p. 6).

As was alluded to in the previous subsection, construction tends toward more specialization, e.g. more subcontracting in the execution phase. So, the so-called main contractors (also called principal-, prime-, or general contractors or -builders) often take more of a construction management role while, over time, performing a smaller and smaller portion of the actual production by themselves (Forbes & Ahmed, 2020, p. 6). The parties involved in construction projects, that are relevant for this thesis, are described in Table 1.

Table 1: Ecosystem players for multi-residential building frame construction (Source: (Clough, et al., 2015; Forbes & Ahmed, 2020))

Role / actor	Activities	Responsibilities
Building owner-client. e.g. municipality, real-estate investment groups or -funds.	Initiates projects based on housing demand. Can arrange for design, financing, and construction.	Long-term responsibility of building's performance, unless a separate developer is employed.
Regulators. e.g. building code officials, city planners, inspection officials	Attend to societal concerns relating to construction, e.g. health & safety, environment, fairness.	Develop and enforce building code and the Land Use Act, evaluate and grant building permit, inspect constructions.
Developer (if separate form owner-client)	Professionals who represent the owner-client. Arranges for design and construction, often financing.	Long-term responsibility of building's performance.
Architect-Engineer. e.g. Primary designer, structural-, lighting-, sound engineers etc.	Transform owner's requirements to concepts and detailed blueprints that guide the construction.	Use reasonable skill and care, conform all designs together and to the regulations.
Construction manager	Provides the owner with services. in managing the project. Can contract with subcontractors.	Can be responsible for project management as a whole, sometimes even for the building design.
Main contractor	In contract to the owner, leads and manages construction, procures materials, and provides labour for construction site work, and coordinates subcontractors.	Is responsible for construction planning and execution, subcontractors, sometimes the building design. Specifies the product/work of suppliers and subcontractors.
Element producer/supplier e.g. RC elements, bathroom modules, timber elements	Produces and delivers complete structural units like walls and beams. May participate in design as well as installation.	Responsible for element quality and on-time delivery. May verify proper application of their product.
Subcontractors e.g. MEP-, tiling-, excavation-, and frame subcontractors	Carries out specialized work on the construction site, like tiling and air conditioning.	Completes their part of the building, in schedule and as defined in contract to the main contractor.
Local building frame professionals e.g. tradespeople, supervisors, site managers	Fabricates/installs the building frame according to blueprints by adapting materials, tools, and their skills on the field.	In employment relationship with the main contractor or a frame subcontractor.
Material suppliers e.g. cement, rebar, timber or lumber, gypsum board, tiling, piping…	Provides component materials for main contractors, element producers and subcontractors.	Responsible for material quality and on-time delivery. May verify proper application of their product, like curing of concrete.
Individual apartment buyer. e.g. retail property investors as landlords, homeowners as end-users	May negotiate and pay for apartment modifications and remodelling, choose fixtures, interior design and apartment features.	Participates in the housing cooperative, maintains and pays maintenance charges for their apartment(s).
Tenant	End-user of an apartment "as is".	Pays rent, informs of problems to landlord .

In this thesis, the term "main contractor" is considered to include both main contractors and construction managers, unless specifically differentiated. Also, owner-client and developer are generally taken as interchangeable, except when a separation is made explicit. End-users and residents are taken to mean individual apartment buyers and tenants collectively.

The project-specific roles, authorizations and liabilities are defined in (bilateral) contracts formed between the parties (Clough, et al., 2015, p. 2). Depending on the project's contract arrangement, different parties (owner-client, construction manager, main contractor) could act as system integrators who bring all necessary actors and materials together to make the construction product a reality (Clough, et al., 2015, p. 10; Forbes & Ahmed, 2020; Segerstedt & Olofsson, 2010, p. 350).

All multi-residential construction projects fall under three different general delivery method concepts: Builder vendor projects, competitive contracting (Ahonen, et al., 2020), and alliance/partnering models. In builder vendor projects (also called builder development, founder contracting or tract housing), a construction company acts both as a developer ("the client") and the main contractor (owner builder) (Clough, et al., 2015). The construction company also finances the construction by themselves, markets it, and attempts to sell the whole building or smaller parts of it, often apartment by apartment, to retail investors or final users. It has also been called "speculative construction" because the new real estate development and often even the construction is started before there is a known customer. In competitive contracting, for which there are many variations like Design-Bid-Build (DBB), Design-Build (DB), and Design-Manage (e.g. DMAR), the owner-client employs a main contractor and possibly other parties to have them create the design and execute the construction (Ahonen, et al., 2020; Clough, et al., 2015). The owner-client is either the final user of the constructed product or an investor whose goal is to sell or lease/rent the building to end users. Alliance models entail forming a team of players to conceptualize, design and execute the project. Depending on the type of contracting arrangement or project delivery methods used for each construction project, a specific stakeholder may have a slightly different role and carry somewhat different responsibilities (Clough, et al., 2015). Still, in most types of projects, the construction ends up split to many sub-contracts. Additionally, construction costs are always the factor that by far determines which firms will be chosen to carry out each part of the construction and how the construction is executed (Ahonen, et al., 2020), although reliability of delivery in terms of ability to reach required level of quality and finish on time also play a role (Clough, et al., 2015; Forbes & Ahmed, 2020).

Sometimes the construction project is split by the owner-client to multiple smaller construction projects and each of them are separately executed by different main contractors, who all choose their own sub-contractors (Clough, et al., 2015). These "separate contract systems" (Figure 1) are more common in large projects with multiple buildings or ones which can otherwise be conveniently split to many disparate parts. More often, the entire construction project is awarded to a single main contractor (examples in Figure 2 and Figure 3) by the owner-client (Clough, et al., 2015). No matter the contract type, the main contractors are accountable for costs, safety and quality, and the contract document specifies the requirements that the contractor must meet. The main contractors lead and arrange all activities and parties needed for the specified construction. Often the main contractors carry out some of the construction work by its own work force and subcontracts the rest, on a project-by-project basis (Clough, et al., 2015; Ahonen, et al., 2020).

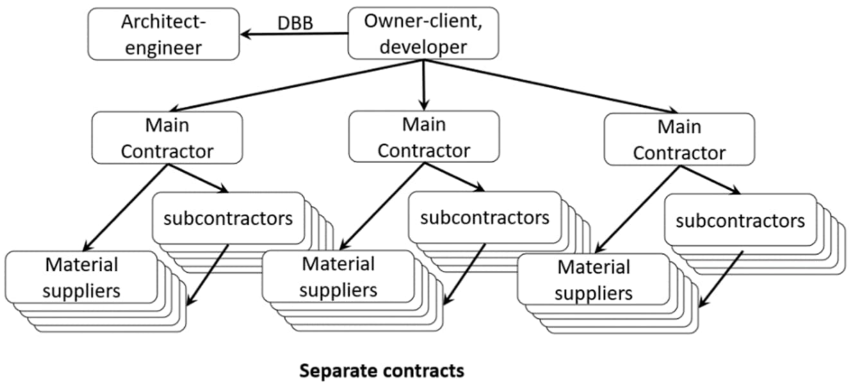


Figure 1: Separate contracts-contract arrangement for multi-residential construction project delivery (arrows denote privity of contract, from principal to agent) (Clough, et al., 2015; Forbes & Ahmed, 2020).

The simplest case of organization for a construction project are **builder vendor projects** (Figure 2) (Clough, et al., 2015; Ahonen, et al., 2020). In this case, the contractor is their own client, so all the building specifications and design are controlled in-house. A challenging aspect of this kind of construction is that the builder should also understand the potential apartment buyers' needs, even though who the individual buyers are, are often not known before the start-, or sometimes even the end of the construction phase of the project. Specialized construction companies that act more like construction managers or construction brokers who outsource all of the actual construction work are becoming more and more prevalent (Clough, et al., 2015). One example of growing popularity recognized by the literature is the Swedish property construction industry (Unger, 2006).

A **Design-Build (DB)** arrangement (Figure 2) leads to the owner paying an external party for a single point of responsibility for the entire design and construction process (Clough, et al., 2015; Forbes & Ahmed, 2020). The owner-client contracts with either a single main contractor who will outsource the designing of the construction, or a single architect-engineer who will outsource the execution of the construction. Sometimes a single firm may have in-house resources for both the design and execution. Most often a main contractor has the most resources and best understanding from small details to the big picture (Clough, et al., 2015). The design-build provider must be able to guide the design and end up with an efficient construction product that fits the owner's needs. This contract arrangement has become popular in the Nordics (Kadefors, 2004; Hurmekoski, et al., 2015).

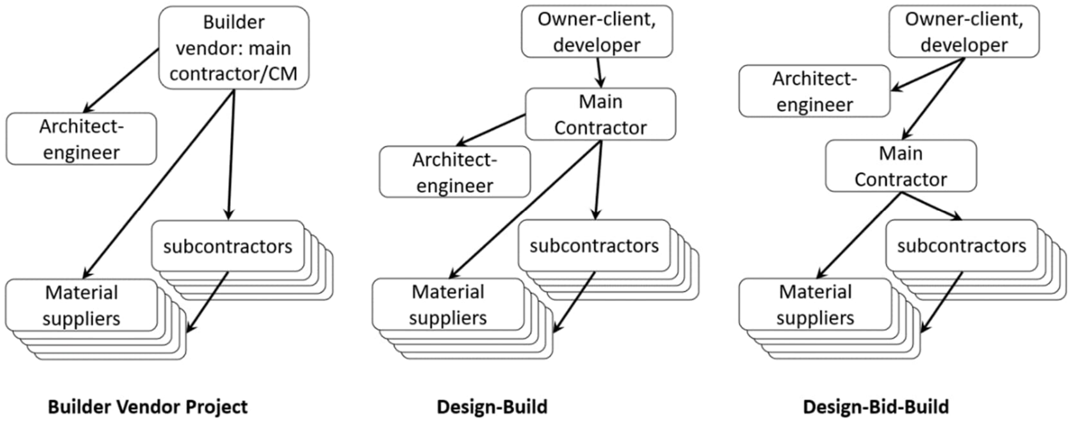


Figure 2: Single-contract contracting arrangements for multi-residential construction project delivery (arrows denote privity of contract, from principal to agent) (Clough, et al., 2015; Forbes & Ahmed, 2020)

The **Design-Bid-Build (DBB**, also called "linear construction") (Figure 2) is historically the most common type of contracting arrangement (Clough, et al., 2015; Forbes & Ahmed, 2020). The process goes as follows: in the "Design" phase, the owner-client contracts an architect-engineer to create the case-specific construction design for the project and the documentation required for a tender of the construction phase. In the "Bid" phase, the design and the project specification documents are used as basis for bidding competition on executing the construction, and the main contractor is chosen among the bidders. The "Build" phase involves the actual construction led by the chosen main contractor(s). The designer can help and represent the owner-client all throughout the project: they help provide the necessary information for and during the bid phase as well as aid in evaluating the bids and provide guidance and oversight during the build phase. The main contractor is often completely removed from the design in this arrangement (Clough, et al., 2015).

In **Design-Manage** arrangements, a construction manager (CM) is employed by the owner-client (Clough, et al., 2015; Forbes & Ahmed, 2020). The CM may just act as a consultant for the owner-client, separate from the other participants in the project. In that case, the contract arrangement is called Construction Management Agency (CMA). Or the construction manager could take on the broad responsibility for delivering the whole project, from planning, design, costs, and arranging and managing the contracts with all the required actors for the construction project. This arrangement, where the

CM acts almost like a main contractor, is called Construction Management at Risk (CMAR) (Figure 3). No wonder that main contractors often provide this service, but design-firms and construction management consultants could also act in this role (Clough, et al., 2015).

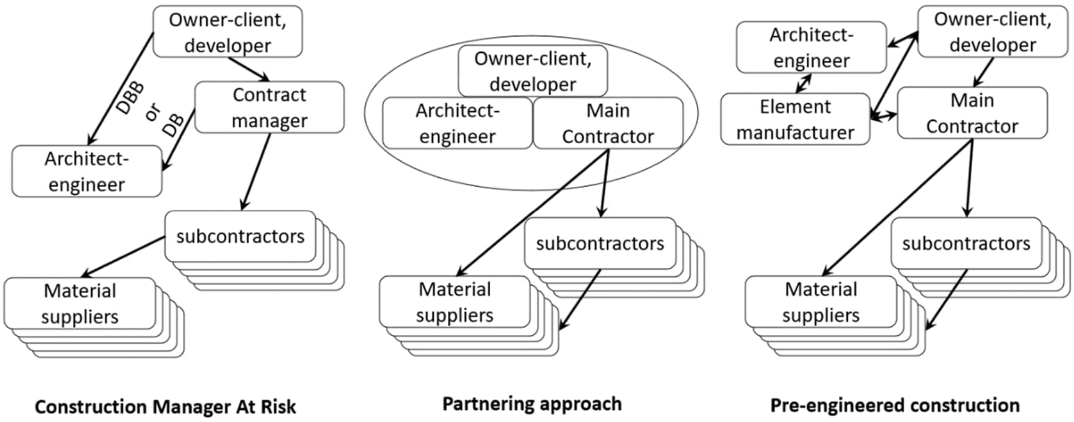


Figure 3: Contracting arrangements for multi-residential construction project delivery (arrows denote privity of contract, from principal to agent) (Clough, Sears, Sears, Segner, & Rounds, 2015; Forbes & Ahmed, 2020)

One project delivery method is to form a cohesive team for conceiving and realising the construction project right from the start. This method may called the **partnering approach** (Figure 3), also called team- or alliance approach (Clough, et al., 2015; Ahonen, et al., 2020; Forbes & Ahmed, 2020). In this approach, a team of firms that include the owner, an architect-engineer, and a main contractor collaboratively create the program and the design for the project and solve problems together during the construction phase. Each member brings in their own expertise and resources, but the interactions between them is more characterised as team work rather than contractual relationship-based (Forbes & Ahmed, 2020).

A more novel project delivery method, **pre-engineered construction** (Figure 3), is an approach outlined by Clough et al. (2015)where a building frame component manufacturer provides a construction system solution to owner-clients, developers, or contractors. They say that often the manufacturer is affiliated with specific main contractors who can provide a finished construction product using the manufacturers construction system. The construction system, e.g. a proprietary steel structural frame for low-rise buildings, is often tailored according to architects-engineers design to fit the needs of the project, but standard modules are also used, the authors continue. The pre-engineered construction is delivered to the site in pre-fabricated packages that are assembled into an unitary construction product.

As can be seen from the different types of construction project delivery processes, most, and traditionally all design, engineering and production happen in a sequential manner (Koskela, 1992; Ahonen, et al., 2020). Often, distinct specialized actors come in and execute their part of the project when the designs and preceding parts of the project are completed, and then they leave for the next project somewhere else and come back only to solve problems on a case-by-case basis (Koskela, 1992). Each actor does their part, which is specified carefully in contracts, and interaction between other actors and execution of other parts of the projects is at minimum. This leads to problems like:

- Lack of iterations in the design phase (long cycle times)
- Constraints in execution phase of construction are not acknowledged in beforehand in the design phase (poor consideration of other actors' requirements)
- Earlier phases cause unnecessary extra constraints to later phases of construction (poor consideration of other actors' requirements)
- Little feedback happen between actors (the processes are not transparent, project control is segmented)
- Most actors have lacking leadership and responsibility for the project as a whole (project control is segmented)

Concretely, these problems become visible through solutions that are not optimal, e.g. hard to implement construction, lots of changes and rework both in design and construction phase, and low level of innovation and development of practises (Koskela, 1992).

A higher level of industrialization, e.g. pre-engineering/pre-fabrication, has often been mentioned as a possible solution to improve productivity, overcome some of the traditional limitations of constructed products, and help solve the aforementioned problems (Jonsson & Rudberg, 2013; Segerstedt & Olofsson, 2010; Pan & Sidwell, 2011).

2.2 Business ecosystems

When describing or analysing networked or complex value chains, the ecosystem concept has been used and gained lots of attention both by researchers and practitioners alike. Ecosystems may provide products or services and they may or may not be built on top of some platform technology (Kapoor, 2018). Some examples of research context are the redirected integration of producers, installers and financiers of residential solar photovoltaic systems (Hannah & Eisenhardt, 2018); coordinating modularity of fast-developing PC components (Ethiraj, 2007); Michelins PAX run-flat tires that required integrating the tire and wheel hub delivery and repair services (Adner, 2016); and the smartphone ecosystem includes several integral complementaries to provide end-user value; handset manufacturers, operating system platforms, application developers, and network carriers (Bremner, et al., 2017). As highlighted in the previous section, construction industry has a networked and complex nature that could make an ecosystems lens useful for analysing it.

Indeed, Pulkka et al. (2016) found that the ecosystem concept may be beneficial for the construction industry especially for facilitating transition to a more sustainable construction. A few other researchers have also applied ecosystems to construction industry research (see e.g. (Cacciatori & Jacobides, 2005; Jacobides, 2008; Jiang, et al., 2016; Aksenova, et al., 2018)), notably Viholainen (Viholainen, 2021) in her dissertation on modern timber construction.

In his 1993 article "Predators and Prey: A New Ecology of Competition", James F. Moore (1993) introduced the concept of ecosystems to business from the field of biology. In his article, he wrote that just as nature adapts to evolution and radical changes in the environment, so do businesses: existing species may need to move or find new niches or synergies with others and new ecosystems with different combinations of organisms and animals may gain prominence. Businesses compete and cooperate with actors that differ across time and the competitive positioning between the actors shifts around and rearranges due to environmental and evolutionary (i.e. innovation) developments. Instead of analysing a firm as a part of an industry, Moore suggested that each firm should be seen acting as a part of the whole within a business ecosystem. The ecosystem is a broader viewpoint that may include organizations, institutions and individuals alike, as well as both horizontal and vertical linkages to suppliers, customers, regulators, the judiciary, and research- and educational bodies (Teece, 2007, p. 1325). Notwithstanding the connection to nature, the metaphor of ecosystems seems suitable (Thomas & Autio, 2019).

2.2.1 Characteristics of business ecosystems

When considering ecosystems in the context of business, there are a couple of slightly differing popular characterizations presented in the literature: "business ecosystems", "innovation ecosystems", and "platform ecosystems". As outlined by Jacobides et al. (2018), business ecosystems focus on a central firm and the environment from that firm's perspective; innovation ecosystems focus on a focal value proposition (e.g: "a targeted benefit" (Adner, 2016)) or innovation and the different players that are needed to make the value proposition desirable to the customer; and platform ecosystems revolve around a central system or technology that serves as the "platform" for the ecosystem's functioning (see also: (Thomas & Autio, 2019))

In business context, the same foundations underlie the different characterizations of ecosystems. First, in addition to the companies in the ecosystem having supply side interdependencies, ecosystem companies also have considerable consumption-side synergies between their offerings, often called complementarity or complements, and the like (Bremner, et al., 2017; Adner, 2016; Jacobides, et al., 2018; Kapoor, 2018). Ecosystems are indeed a novel way of organizing and cooperation that is strongly driven by complementarities that are not generic, i.e. available by default (Jacobides, et al., 2018). Thus, ecosystem firms often depend on their complementor partners to succeed (cf. Figure 4), and as Jacobides and his colleagues say, “are bound together by the non-redeployability of their collective investment elsewhere”. The ecosystem concept helps these interdependent firms collaborate while allowing significant or even complete autonomy, they say. The foundational aspect of complementarity between ecosystem members also means that a customer must also affiliate itself with a specific ecosystem, as it offers a kind of a packaged deal, that by definition cannot be gotten anywhere else except a competing ecosystem or a vertically integrated single firm (Jacobides, et al., 2018; Thomas & Autio, 2019).

Researchers (Jacobides, et al., 2018; Kapoor, 2018) subdivide complementarity in ecosystems to two distinct types: unique (or strict, strong) complementarity (Hart & Moore, 1990) and supermodularity, or “Edgeworth” complementarity (Milgrom & Roberts, 1990). All other complementary types do not require an ecosystem analysis (e.g. generic complementarity (Teece, 1986)). By unique complementarity they mean that an offering A requires a specific other offering B without which A is not desirable. Supermodularity means that “more of A makes B more valuable (Jacobides, et al., 2018). Both of these types imply a degree of customization that there needs to be, because B has to be specific or at least the most advantageous complement to A rather than to other offerings. An example of both of these types of complementarity would be an operating system and an app for a smartphone: the app does not work without the specific operating system and they both are the more valuable the more of the other is adopted by consumers.

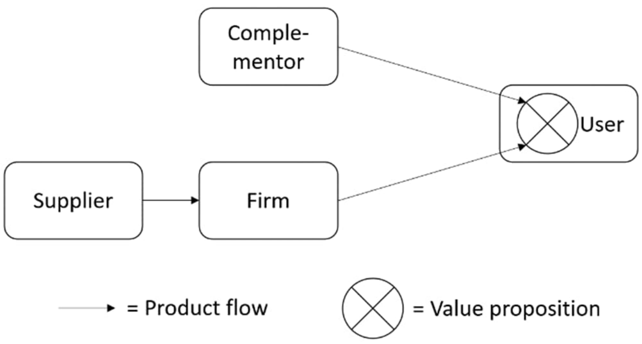


Figure 4: Illustration of ecosystem complementarity, adapted from (Kapoor, 2018)

Secondly, competition among the partners for capturing value that the ecosystem produces is just as defining of a characteristic in ecosystems as is the cooperation between the partners to create value (Hannah & Eisenhardt, 2018). This is because depending on ambitions and capabilities of the firms collaborating in the ecosystem, in order to capture a larger share of the ecosystem value, considerable jockeying for better positioning, division of roles and activities may always be present (Adner, 2016). Ultimately, all ecosystems need to determine a structure for collaboration and alignment to fill these strategic needs without hierarchical control or vertical integration (Jacobides, et al., 2018). This is a challenge not only because complementors should be allowed to make business decisions for themselves, but because interdependencies must also be facilitated at the same time but also because the combination of competitive and cooperative interests may affect simultaneously but differently across different locations of the ecosystem (Hannah & Eisenhardt, 2018).

In each specific ecosystem, there should be both enough competition, as in firms pursuing the interests of their own, and cooperation, as in the joint pursue of shared goals and advantages (Das & Teng, 2000). Too much competition means failure for the value proposition and even the ecosystem structure to materialize. Too much cooperation would mean too little value captured in some firms, for the firms and ultimately the whole ecosystem to survive (Hannah & Eisenhardt, 2018). Ecosystem strategy, which will be discussed more closely later, should therefore consider cooperation and competition within the ecosystem as well as competition against other ecosystems and other external actors (Jacobides, et al., 2018; Adner, 2016).

Then, collaboration patterns in an ecosystem must always fit its context, which is the industry or the industries that the ecosystem cross into. The context could be called the industry architecture (Jacobides, et al., 2018). Even though ecosystems often reach over traditional industry boundaries, the way things work in each industry form a base for how work and value creation happen in the ecosystem, and what kind of strategies and alliances are possible (Ferraro & Gurses, 2009). Usually, this context-dependence leads to the ecosystem being modular between member firms: rarely a single firm can cover all the required elements in the industry architecture, so different interdependent actors need to be able to produce complementarities with limited coordination (Jacobides, et al., 2018; Bremner, et al., 2017; Kapoor, 2018). Hence the ecosystem consists of modules, that at least in theory are shiftable and modifiable within the module's boundaries as long as the interface to the rest of the ecosystem is respected. When firms from multiple distinct industries work together on increasing the ecosystem created common value, complexity increases through integrated industry architectures, but this cross-industry collaboration may be key to achieving new competitive advantages (Casadesus-Masanell & Yoffie, 2007).

Finally, considering the architecture of an ecosystem, the concept of bottlenecks often come into view (Hannah & Eisenhardt, 2018). Due to complementarity required for ecosystem offerings, its is no longer sufficient to have knowledge of bottleneck for a specific product, but ecosystem members also need to understand ecosystem level bottlenecks (Jacobides, et al., 2018; Kapoor, 2018). At a basic level, an ecosystem can hardly be said to be beneficial to all members if a firm residing in a membership position as the bottleneck "module" in the ecosystem architecture takes advantage by rent-seeking instead of allowing the ecosystem common efforts toward unrestraining the bottleneck. Because ecosystem bottlenecks create special strategic considerations, it is also worth to note that bottleneck in context of ecosystems may contain one or multiple firms (Hannah & Eisenhardt, 2018).

The "crowdedness" of the ecosystem bottleneck has direct implications to the balance between cooperation and competition within the ecosystem (Hannah & Eisenhardt, 2018). Paradoxically, the more competition within the bottleneck position, the more cooperative those firms must be to win over complementors to their side. Otherwise, if the bottleneck position is not contested, the firm doing the bottleneck activity can wield more control over-, and induce competition around-, the whole ecosystem and therefore capture more value while simultaneously creating value by resolving the bottleneck. Due to these ecosystem bottleneck dynamics, whether there is an expected or unexpected shift in the locus of the ecosystem bottleneck, it will have a destabilizing effect to the ecosystem (Hannah & Eisenhardt, 2018). Ecosystem bottleneck dynamics therefore cause several types of advantageous possibilities for firms in ecosystems and thus offer an interesting way for ecosystem analysis.

As becomes evident from the above conceptualizations, complementors, architectures, and bottlenecks are distinct principles that underlie all ecosystems and manifest themselves through actors, platforms or other coordination mechanisms, and activities respectively (Kapoor, 2018). Identifying these terms and the way that they depend on and affect each other are some of the defining characteristics of ecosystem research. In broad terms, different types of ecosystems are arrived to through differing nature of complementarities between the ecosystem firms: what is the extent of non-fungibility of contributions, the breadth of complementarity, the type of complementarity and the aggregate of dependency directions between ecosystem firms largely drive why and how the firms are aligned or fail to align (Jacobides, et al., 2018; Kapoor, 2018).

Summarising what sets the ecosystem concept apart from the network concept or other similar ones, and what makes ecosystems a concept of merit is that ecosystems form around a value proposition formed by a set of final component products or services that are complementary to each other and technologically interdependent (Hannah & Eisenhardt, 2018). These component products in an ecosystem have little value without the other components the ecosystem produces. Furthermore, what sets ecosystems apart from supply chains (or value chains) is that there are not only dyadic supplier-user relationships but also indirectly connected complementaries that may produce a completely distinct product that a customer may also procure to achieve synergy benefits. But, just as in supply chains and production processes, there are bottlenecks in ecosystems, i.e. offering-components, activities or actors that restrict the performance of the ecosystem in some way.

2.2.2 Adapting extant industries: Innovation ecosystems

In business- or platform ecosystems, or "ecosystems-as-affiliation" as Adner (Adner, 2016) calls them, the platform firm or the central firm is often called a "leader", "ecosystem manager", "hub-" or "keystone firm" (Iansiti & Levien, 2004), "kingpin", "lead firm" (Williamson & Meyer, 2012), "platform owner" (Kapoor, 2018) or "ecosystem captain" (Teece, 2014). This text will use the term "affiliation-centric" ecosystems for these ecosystem types. Their analysis often bring issues like membership and availability to the centre, particularly the membership numbers and connectedness and positions in the ecosystem (Adner, 2016). General governance of the ecosystem, collaboration benefits, and such more generic issues are often in the forefront of such ecosystems' strategies, instead of the specific mechanisms of value creation. These may be the most familiar uses of the ecosystem concept (Thomas & Autio, 2019).

According to Adner (2016), innovation ecosystems compared to affiliation-centric ecosystems are less concerned about membership: only to the extent that what set of members is required to make the focal value proposition to be realized. His definition of innovation ecosystems, or "ecosystems-as-structure" as he calls them, is: "The ecosystem is defined by the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize." This definition perfectly converges with Thomas's and Autio's earlier definition of innovation ecosystems, that in addition explicitly mentions the involvement of "both production- and user side participants" in the ecosystem (Thomas & Autio, 2019). In the following, more detail about what the definition concretely includes is covered.

All "actors" in an ecosystem, as Adner posits, have some specific jobs ("activities") to do, which helps in materializing the value proposition. In the definition, "alignment structure" refers to how, -and the extent to which-, these jobs and the mutual understanding of the jobs are in line towards the common value creation. Even for a single firm, multiple means of alignment could apply, especially if the same firm performs many separate activities in the ecosystem (Adner, 2016). The alignment structure must consider the motivations and incentives that help keep the roles and the job done by everyone along that line. Possible means of alignment are varied, but often determined, even intrinsically, by the nature of a particular ecosystem: open or closed ecosystem, imposed or emergent-, de juro or de facto rules. Some examples of means for alignment are IP-rights, standards, agreed upon specifications and different types of formal contracts (Jacobides, et al., 2018). Accordingly, a well working ecosystem enables extra value in a manner that satisfies all the members. Concretely, extra value usually means acquiring more customers and final users for the ecosystem by designing or adjusting all members' responsibilities and rewards for the end users benefit (Jacobides, et al., 2018).

An important aside that Adner (2016) brings up about the ecosystem construct relating to an alignment structure, relates to situations where there is no need for alignment: no alliance relationships are needed when all required members are working in alignment already by default, like in cases traditional operations- and project management (Adner, 2016) where a focal firm already controls the whole value chain or contracts with those that are used to providing a required part of it. In these cases, the ecosystem is latent and there is no benefit in introducing ecosystem logic. In most cases of mature industries, the ecosystems are in fact latent; with stable activities, members, roles and connections between firms (Adner, 2016). Only when these stable characteristics require change, an ecosystem analysis becomes critical for strategy. In general, the requirement for change comes from the relative advantage of new ecosystem benefits against the disadvantages of co-specialization (i.e. cost of specialization and later costs for redeploying) (Teece, 1986). The higher the redeployability of capital tied to co-specialization, the easier it is to recruit ecosystem members but harder to have them stay motivated to participate. In that way, unrecoverable sunk costs would create intrinsic lock-in within the ecosystem but is also a hinderance to recruitment of ecosystem members.

Next, relationships, or “links” as Adner (2016) calls them, between ecosystem members are not simply just traditional bilateral interactions between two actors. In many cases of ecosystems, a firm neither buys from or sells to a complementor, so familiar management of sales and procurement require an ecosystem-fitting addition for such complementors (Kapoor, 2018). Instead, for example, successful collaboration between two companies A and B also critically requires that either of them successfully also contract with company C or that there indeed exists some other members that have an indirect tie to the success of the value proposition. This “multilaterality”, as many authors call it (Adner, 2016; Jacobides, et al., 2018) would then mean that for business networks with simple chains of direct and indirect ties that all are bilateral, ecosystem approach brings no additional value.

In Adner (2016) definition above, “set of partners” simply refer to the reality that all ecosystem members are necessary for making the value proposition a reality, regardless of their connectedness to other firms in the ecosystem. Finally, “for a focal value proposition to materialize” directs focus to a more extensive analysis than just a product or a deliverable of a single firm. Value proposition is a targeted benefit, which in case of ecosystems always require a certain level of coordination to be materialized. Therefore, it is central to consider the unallowable amount of divergence in terms of actions, interests and perspectives among the ecosystem members as limits to when the value proposition cannot be reached.

According to this definition (“The ecosystem is defined by the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize.”), the ecosystem boundaries naturally lie around a specific set of actors that are necessary for the value proposition to materialize (Adner, 2016). Partial or even complete overlap of different ecosystems' boundaries in terms of member companies is therefore possible if separate value propositions with differing alignment structures are in question. It could be argued that there would be no boundaries if every piece necessary in supply chains need to be included in the analysis but focus on an "alignment structure" easily leaves out actors who are and will be expected to be in alignment be default. Teece (1986) calls these the cases of actors that provide "generic" complementarity. For example, all companies need electricity, but only in extreme cases the consideration of availability of viable electricity and thus the alignment of the electricity providers' activity could be under concern.

To recap, the major distinction between innovation ecosystems and affiliation centric ecosystems is that innovation ecosystems start with a value proposition, and member firms and connections between them are only such that the activities needed to make the value proposition a reality are facilitated (Jacobides, et al., 2018; Adner, 2016; Kapoor, 2018). Affiliation-centric ecosystems start with membership, usually of and by a focal firm like a platform owner, and the ecosystem then comes up with possible value propositions and synergies that the ecosystem is able to produce with the members it has (Adner, 2016; Kapoor, 2018). Also, in innovation ecosystems, there is no one focal firm, but the focus is determined by the viewpoint of the analysis (Jacobides, et al., 2018; Adner, 2016). Accordingly, it could be that no single focal firm has control or direct contact to or power over all other ecosystem members in innovation ecosystems (no hierarchical control (Jacobides, et al., 2018)). This naturally leads to a need for distinct "ecosystem strategies" that take an extended view which recognizes and manages these indirect connections in a way that is unusual for traditional strategies to do.

2.2.3 Ecosystem strategies for industry adaptation

When talking about ecosystems, strategy plays an exceedingly important role in defining success. Due to the inherent complexity of competition and interaction between collaborators in ecosystems, strategic prowess may be even more important than domain related capabilities of the firm (Hannah & Eisenhardt, 2018). According to Adner (2016), ecosystem strategy is defined "by the way in which a focal firm approaches the alignment of partners and secures its role in a competitive ecosystem". He says that the strategy must answer the question of "How will the innovator[s] create the impetus for other actors, who may not be directly linked to the innovator[s], to change?". Hannah and Eisenhardt (2018) offer a more condense meaning of ecosystem strategy as the way each member company balance cooperation and competition within (and without) the ecosystem. They distil the ecosystem strategy down to three fundamental choices: "1) how many and which [ecosystem] components to enter, 2) with which complementors to align, and 3) how to balance cooperation and competition." As examples, cooperation could mean combined effort on solving bottlenecks. Competition could mean encouraging other ecosystem members to compete against each other, for example by using market power to enforce standardization (Jacobides, et al., 2015), but a situationally proper balance is key.

Going deeper into his definition of ecosystem strategy, Adner (2016) says that since there is no single focal firm for innovation ecosystems in general, all firms in an ecosystem have their own strategy. The strategy addresses things like the ecosystem structure, roles, and risks and they may or may not be consistent with other firms' strategies in the ecosystem. The gaps between strategies may be due to for example "co-innovation risks", "adoption chain risks", or risk coming from differing expectations, he says, and the strategies should attempt to recognize and rectify such gaps (Hannah & Eisenhardt, 2018). By co-innovation he refers to the ability to pursue new activities required for the value proposition and by adoption chain risks to the firms' motives or lack thereof to do so. Expectation risks in turn stem from unclarity and disagreement on who does what and who gets what (Adner, 2016).

Next, because of the often-inherent competition both outside and within an ecosystem (hence "in a competitive ecosystem"), each member's ecosystem strategy must somehow address how the firm "secures its role" or secures its "position" in the ecosystem. Many firms could fill the bottleneck position, in which case standing out in some way could be required if a firm wants to attract the best complementors to its side and survive (Hannah & Eisenhardt, 2018). It might mean ceding some market power by offering better terms to complementors. In a similar cooperative vein, a firm securing a non-bottleneck position may be required to choose to co-specialize with some other complementors or a specific firm in the ecosystem bottleneck position. On the other hand, if there is little competition for any focal position, then securing it may mean the use of a more competitive strategy of creating higher barriers for entry in the focal position, and lower barriers to entry in other (e.g. complementor) positions.

How to strike the balance between competition and cooperation is what Hannah and Eisenhardt set out to answer in their (2018) multiple case theory-building study. They found tree successful ecosystem strategy types (cf. Figure 1Figure 5Figure 5: High-level ecosystem strategy choice for a firm (adapted from)) that have different emphasis on specialization (Farrell, et al., 1998; Arora & Bokhari, 2007). A competition focused "system strategy" has been used in mature industry contexts and when a firm has a large breadth of abilities. That strategy simply sets out to produce and capture the margins of multiple end components for the ecosystem. A cooperation focused "component strategy" does the contrary, focusing on achieving profit through scale and cost reductions from specializing in a single product or a small set of products, and cooperating with other component producers for everything else. Finally, a "bottleneck strategy" is a complex mix of competition and cooperation, where firms collaborate on other components and enter to compete for successive bottleneck components in the ecosystem to resolve them one after the other to achieve growth in the ecosystem value (Hannah & Eisenhardt, 2018).

The advantage of systems strategy for ecosystems is that it offers the capture of several profit margins and a higher degree of control in the ecosystem (Hannah & Eisenhardt, 2018). Downsides are expensive and slow implementation, and vulnerability to frequent or significant shifts in demand because of a large amount of capital and labour tied to operations. Managing risks of investments to capacity is therefore important if a systems strategy is utilized. For a component strategy, advantages are e.g. faster implementation, the possibility to choose a niche component/activity with higher margins, and specialization induced savings and improvements. A component strategy is more dependent on complementors in the ecosystem and thus requires a strong focus on collaborative abilities. Bottleneck strategy offers the best ecosystem wide growth prospects but requires agility in achieving a careful and situationally adjusted balance between cooperation and competition. When successfully executed, it offers a great deal of control in the ecosystem, highest amount of value generation, and moderate degree of benefits from specialization.

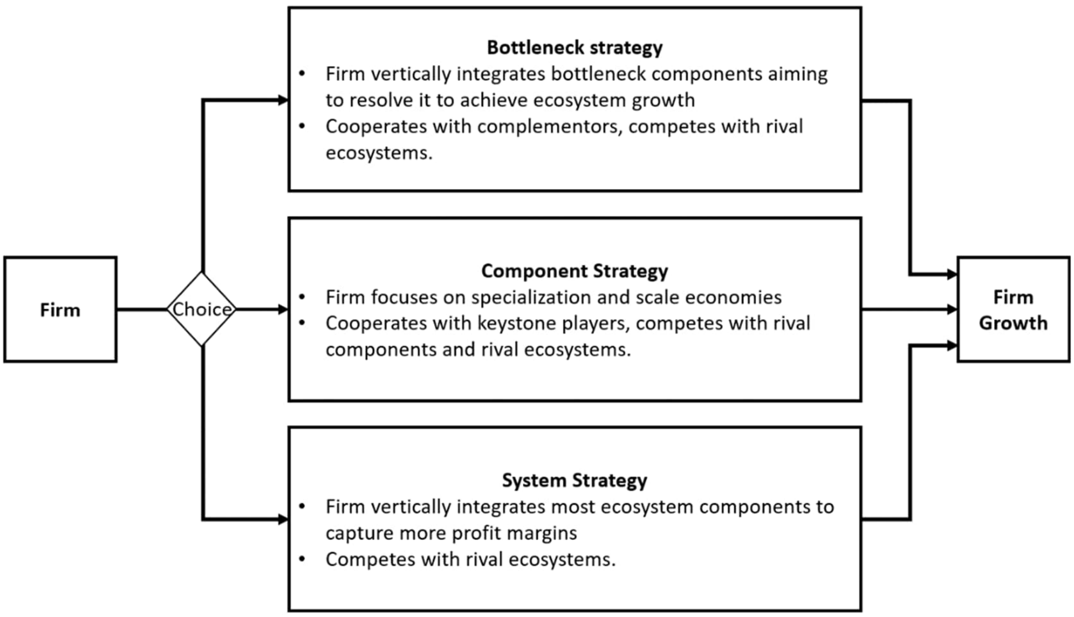


Figure 5: High-level ecosystem strategy choice for a firm (adapted from (Hannah & Eisenhardt, 2018))

3 Research material and methods

Like said in the introduction, in the interest of succinctness, the stages of literature reviews on timber construction civil engineering and TMC adoption, as well as market studies on timber usage in large scale construction are not elaborated in detail in this work. Therefore, this thesis moves on to presenting the methods for data collection and analysis to understand the challenges that main contractor firms, as key decision makers for frame type choice, face in adopting TMC.

Before planning and executing the interview study further, it was made sure that the reason for shortage of main contractor's viewpoints in previous research was not because they had been deemed unimportant already. For this, eight different timber construction element producers in Finland were contacted as informal sources. Everyone agreed that a meaningful shift to TMC happens only when existing general contractors come along. Therefore, the planning of an interview study of residential multi-storey construction main contractor representatives was commenced.

3.1 Interview study design

After directing attention of my primary research to general contractors, sampling of the interviewees had to be considered. From the literature, industry sources, and governmental statistics, it becomes clear that many Nordic and central European countries are in a similar early stage with regards to TMC adoption in residential multi-storey construction industry. Other than USA and Canada, timber framed multi-storey buildings are extremely rare outside of Europe (Svatoš-Ražnjević, et al., 2022). Even though LWTF multi-storey buildings comprise the majority of all multi-storey buildings in North America (U.S. Census Bureau, 2021), modern massive timber frames have been less often used there than in Europe (Svatoš-Ražnjević, et al., 2022). It would be interesting to study why LWTFs are so popular there, but then this study's considerations might be limited in terms of modern massive timber construction. In terms of assessing possibilities of construction products and methods, collecting varied perceptions from both the more traditional LWTF and novel massive timber products is likely more helpful for assessing the potential of timber construction as a whole.

Even in all European countries TMC is still quite marginal in the grand scale. The types of timber frames used in different European countries differ somewhat (Salvadori, 2021). Sweden and Norway have the well-developed TMC industries, but their construction industry is more characterised by use of light weight timber frames in timber framed multi-storey buildings than other countries. Central European countries use more GLT frames than elsewhere and hardly any LWTFs. In Finland, there are only a couple post-and beam (GLT, LVL) timber framed buildings, but LWTFs and panellised massive timber frames are practically equally common in Finnish multi-storey buildings (Karjalainen, 2022). Like in Sweden and Norway, a relatively large portion of timber multi-storey buildings in Finland are constructed in highly industrialized manner from prefabricated voluminous building modules, much more so than anywhere else in the world (Salvadori, 2021). In Finland, both LWTF and CLT-frames are used in voluminous modules, but CLT has been used more recently (Karjalainen, 2022).

Due to convenience, relevance to the locale of the author, the prevalence of both massive timber construction products and LWTF production facilities as well as the use of both of these in voluminous and panellised elementized forms in actualized buildings, and the high rate of industrialized prefabrication, it made sense for this study to focus on Finnish TMC and main contractors within and across Finland.

Previous research shows that construction cultures differ geographically even within a single country and lead to different locales preferring different frame types (Hemström, et al., 2016; Jacobides, 2008). Keeping that in mind, the aim for this study's sample was to get viewpoints all around Finland so that views from possibly different ecosystems would be accounted for. The goal was to understand the practical limitations and benefits of timber frames, so informants who actually grappled with either the choice or the execution of different types of frames were targeted. This mostly meant professionals who had good understanding of the actual construction activity but preferably also were involved with the decision-making regarding frame type choice. Inclusion of viewpoints from multiple levels of the company hierarchies would help in forming a complete picture from the practical issues to managerial and strategic issues. Firms of different sizes and ages were covered, some of which acted only locally and some had subsidiaries in a few locations or even all around Finland and abroad (refer to Table 3 for interviewees' and their firms' characteristics). Firms with different background brough context to the data and helped understand how different construction firms may differ in their preferences for different frame types.

Candidate main contractor companies to be interviewed were searched for from the internet and by contacting municipal building inspection officials all around Finland. Then, 40 contractor representatives were contacted directly by cold calling by phone. 27 relevant representatives agreed for a phone- or web-call interview, out of which 4 were not carried out due to schedule delays they would have caused to the thesis. This sample size was deemed appropriate at the time of conducting the interviews, as 23 interviews already showed significant saturation data (Bryman & Burgess, 2002).

Twenty interviews were scheduled directly on the spot during the cold calls, while rest were followed up by emails. Finally, the last business day before the interviews, as a reminder, each interviewee was sent a list of preliminary topics that would be covered during the interview. The first informant was interviewed directly on the phone during the cold calls. This functioned as a test interview, after which the interview guide was refined. All interviewees allowed audio recording. Four interviewees preferred to be interviewed by phone, rest were held through web meetings. Each interview was transcribed soon after conducting it.

Semi-structured interviews were chosen so that all the topics of interest would be covered systematically, but to still allow the emphasis of follow up questions in each interview to fit the individual informants' expertise (Adams, 2015; Barriball & While, 1994). The interview structure also allowed to achieve the benefits of unstructured interviews by allowing a conversative tone (Adams, 2015) , depending on the interviewee. The intent was to get natural and truthful responses, as opposed to holding a questioning that might prompt "rehearsed", "politically correct", "textbook" responses from the interviewees. A conversative feeling was kept up by not strictly following the order of topics in the guide, but instead by continuing with a follow up question or switching to another topic in the interview guide based on something the informant had said (Adams, 2015). Some interviewees had more to say, and they would often mention or even completely shift to other topics without needing to pose them many questions at all.

To build up trust between the interviewee, each interview started with a short intro, assuring anonymity, asking for permission to audio-record, and a courteous inquiry whether the interviewee thought they would indeed have one hour to spend on the interview as was preliminarily agreed on. If interviewees thought they had less time, less follow up questions were asked. Some interviewees said they are not in a hurry, so more details in their thinking could be drilled into. For first interview questions, easy "icebreakers" were asked, for which the interviewees likely had answered often previously or that were otherwise general enough that no deep thinking would be needed: background info about the interviewee personally and about the contractor they currently work for.

Relating to all issues of interest, open ended questions were first asked to give interviewees possibility to direct the conversation to the issues that they actually felt most relevant. Follow-ups were given to hear deeper reflection which helps build understanding on the reality of the matters. Like said above if the interviewee by themselves did not mention or move to topics that were intended to be covered, they were asked directly. For example, an open-ended question first was "How do you think residential multi-storey frames will be constructed in the future?". If the interviewee did not bring up issues like the upcoming legislative changes on Finnish construction, digitalization, or TMC, they were asked as follow ups. If the interviewee brought the issues up by their own initiative, the possible bias stemming from the phrasing of the question by the interviewee or the conveying of a feeling of leading- or motivated questioning were mitigated.

Unintentional associations were also attempted to be minimized, especially as the individual questions got refined after some interviews. For example, interview questions about innovation were adjusted to convey the question regarding innovation as relating to all possible forms of improvement no matter how generic or specific. This was because, based on their answers, it was suspected that interviewees thought of innovation in the common sense of technological gadgets. Another adaptation of the questions especially towards the end of the set of interviews was questioning of conflicting views between the interviewees and of specific ideas or explanations brought up by other interviewees (Zimmermann, et al., 2012). It would have also been beneficial to recontact all previous interviewees as well to ask about the ideas and explanations brought up by later interviewees, but schedule limitations for the thesis restricted this possibility.

After a few background questions, the topics under study were brought up. The topics and multiple possible follow-up- and specifying questions were written down to an interview guide as a reminder for the interviewer (Adams, 2015). Field notes were written down of details of interest and for possible follow up questions, trying to avoid interrupting the informant before they had finished their thoughts. The interview topics were planned to cover issues relevant for understanding the way in which current construction ecosystems function, especially regarding the choice of the buildings frame type. Specifically, topics like contracting arrangements and customer relationships; the frame choice process; supplier-, subcontractor- and outsourcing decisions; prefabrication; challenges with construction cost and quality; past innovation and research & development activities; future direction of frame construction; and suitability of timber frames in residential multi-storey projects were included in the interview guide. Only the last topic specifically dealt with TMC (and hybrid) construction, because many interviewees had most of their experience in traditional RC construction. Many interviewees brought up TMC earlier even without asking, which showed their interest or acknowledgement of TMC.

Most interviewees had little to no experience with TMC, and some of them did not have much to say on that topic directly. That was not an inconvenience though, as the overarching idea was not only to learn of main contractors views on TMC, but also to identify issues which affect traditional residential RC construction and look for convergences and connections to TMC. Outsourcing, elementization, prefabrication, weather protection and adoption of new construction methods were examples of issues that have clear connection to TMC.

All interviewees were asked about the use of prefabrication. Bathroom modules were talked about with every interviewee, but some brough up prefabricated conduits as well. Those are similar to timber elements in that they offer the possibility for a high level of factory fabrication. Therefore, impressions on use of the bathroom modules could likely be applied to prefabrication in general, and so also for TMC due to wide possibilities of prefabrication it offers. It was seen more likely that the interviewees had relevant experience and thoughtful insights on the bathroom modules' applicability to multi-storey construction than that of timber prefabricated elements', because bathroom modules have been used in the industry for decades longer (Bonava Suomi). Most interviewees indeed had experience or had seriously researched the use of prefabricated bathrooms (Table 3). Still, only five of them systematically utilize them in their projects.

The same tactic was used on topics about outsourcing in general, and comparisons of elementized and CIS-RC construction. Like said above, starting with open ended questions about outsourcing and elementized construction versus on-site fabrication allowed the interviewees to bring up any manifestation of those in their projects. As follow up questions, specifics like outsourcing raw material procurement, labour, design, element supply etc were advanced. Elementized RC construction meandered to different types of elements (floors, dividing walls, building envelope walls, balconies) and different degrees of elementization for the building frames (partly elementized, completely elementized). Then the comments given for these topics could be connected to the topic of applying timber frames, and through commonalities and differences in how timber versus RC is used, the possibility of finding hidden patterns could be opened up.

These proxies of prefabricated bathroom modules and conduits, outsourcing, and elementized RC construction, remove possible biases that main contractors who traditionally build mostly from RC may have toward using timber building frames, especially those of common associations to timber (flammability etc.). The proxies are not perfect, e.g. bathrooms do have differences compared to other types of rooms, like extensive moisture insulation, high amount of MEP, and a thicker concrete floor. Therefore, the generalizability to TMC of specific comments for the bathroom modules, outsourcing, and elementization will be assessed separately for each issue.

Three of the interviewed main contractors had both extensive RC construction and TMC experience, and two had more TMC experience than residential RC construction experience (cf. Table 3). Those interviews went into more detail with TMC. Still, to get more support for the TMC related findings, publicly available interviews, conferences, and seminars related to practicalities in executing TMC projects were utilized as additional data sources.

Seventeen different corporations were represented in the 23 interviews. From four large corporations, there were four, two, two, and two informants from the same corporation's different regional subsidiaries. Other interviewees were the sole representative from their company in this thesis. The interviewees have more than 500 years of building construction experience in total. The geographies from where majority of each interviewees' experience is from are only roughly presented to make anonymization stronger. It should be noted that for the geographical division of Finland, the now-obsolete 2009 provinces were chosen, in which the Western Finland province includes south-western parts of Finland, inner parts of Finland and western parts of

Finland below Oulu province. The western province covers many significant areas that have their own ecosystems (Turku, Tampere, Jyväskylä, Vaasa-Seinäjoki), whereas the ecosystems in all other provinces are more congruent, with the Helsinki metropolitan area perhaps being one-of-a-kind. Interviewees' employer-companies' revenues are shown divided to three ranges, instead of more precise numbers, for the same reason as for why the geographies are vague. In case of corporations consisting of multiple firms, the total revenue of the whole corporation is considered instead of the regional subsidiary's one.

Table 2: Interview information

Interview #	Interview length	Date
1	1h 35min	24.03.2022
2	1h 14min	05.04.2022
3	42min	05.04.2022
4	1h 1min	06.04.2022
5	1h 10min	06.04.2022
6	1h 6min	06.04.2022
7	1h 13min	07.04.2022
8	40min	08.04.2022
9	1h 32min	08.04.2022
10	38min	09.04.2022
11	53min	09.04.2022
12	1h 2min	12.04.2022
13	1h 19min	13.04.2022
14	1h 11min	14.04.2022
15	29min	14.04.2022
16	1h 9min	14.04.2022
17	47min	19.04.2022
18	56min	19.04.2022
19	1h 3min	21.04.2022
20	49min	21.04.2022
21	41min	21.04.2022
22	35min	22.04.2022
23	59min	25.04.2022

Table 3: Characteristics of informants. Entries ordered by geographic area of main experience (not in order of interviews)

Title of the interviewee	Experience	Geographic area of main experience (2009 provinces)	Corporation revenue	Prevalent contract types*	Main client type^	Prominent frame construction crew type	TMC knowledge	Prefabrication experience
Project/contract manager	22 yrs	Eastern- & Southern Finland	<145M€	Own	DTC	CIS-RC, subcontracted + inhouse	none, applied timber frames in low-rise buildings	limited research and application
Project/contract manager	24 yrs	Eastern Finland	145-400M€	Own, DB, DBB	DTC	RC elements, in-house	none	extensive company research, limited application
Production director	33 yrs	Eastern-, Western- & Southern Finland	>400M€	Own, DB, DBB	Public, REIG/T, DTC	unknown	none	extensive company research, limited application
Project/contract manager	12 yrs	Oulu Province	>400M€	Own	DTC	CIS-RC, in-house	none, except traditional LWTF facades	limited research and application
Project/contract manager	23 yrs	Oulu Province	>400M€	Own, DBB	Public, REIG/T, DTC	RC elements + CIS-RC, in-house	none, except traditional LWTF facades	limited research and application
CEO (production background)	30+ yrs	Oulu Province	145-400M€	Own, DB	Public, DTC	CIS-RC, in-house	none, except traditional LWTF facades	extensive company research, limited application
Production director	38 yrs	Oulu Province	145-400M€	Own, DB	Public, DTC	RC elements + CIS-RC, in-house	Company has applied TMC, completed a couple hybrid/timber frames	extensive company research, limited application
CEO (production background)	20 yrs	Oulu Province &Western Finland	<145M€	Own	REIG/T, DTC	RC elements + CIS-RC, in-house	Company research on TMC, participated in TMC tender	extensive company research, limited application
Regional director (production background)	18 yrs	Southern Finland	<145M€	DB	Public, REIG/T	RC elements, in-house	Company research on TMC, won TMC tender, cancelled due to financing	extensive application of prefabricated bathrooms
Production director	35 yrs	Southern Finland	145-400M€	Own	REIG/T, DTC	RC Elements, subcontracted	Personal research on TMC	extensive application of prefabricated bathrooms and facades
Production director	24 yrs	Southern Finland	145-400M€	Own, DBB, DB	Public, REIG/T, DTC	RC Elements, subcontracted	none	extensive company research, limited application
Developer director (production background)	18 yrs	Southern Finland	145-400M€	Own, DB	Public, REIG/T, DTC	RC Elements, subcontracted + inhouse	none, except traditional LWTF facades	extensive company research, limited application

* **Own**: Builder vendor; **DB**: Design-Build (turnkey, i.e. contract includes both design and construction); **DBB**: Design-Bid-Build (contract is based on a pre-made design)
^ **Public**: public housing, social housing, dormitories, etc...; **REIG/T**: Real Estate Investment Group or -Fund, i.e. often rental apartments; **DTC**: Direct-To-Consumer, i.e. homeowners and retail property investors

Table 3 Continues on next page.

Table 3 continues:

CEO	24 yrs	Western (& Inner) Finland	<145M€	Own, DBB	Public, REIG/T, DTC	RC Elements, subcontracted	Personal research on TMC	limited research and application
Regional director (production background)	7 yrs	Western (& Inner) Finland	145-400M€	Own	DTC	RC Elements, subcontracted	Company has applied TMC, completed a couple hybrid/timber frames	prefabrication not applicable to product
CEO (production background)	24 yrs	Western (& Inner) Finland	<145M€	DBB, DB	Public, REIG/T	Timber elements, in-house	Company is serious on TMC, completed multiple hybrid/timber frames	extensive application of prefabricated TMC
Regional director (production background)	18+ yrs	Western (& Inner) Finland	>400M€	Own, DB, DBB	Public, REIG/T, DTC	unknown	Company research on TMC	extensive company research, moderate application
Developer director (production background)	25 yrs	Western (& Inner) Finland	<145M€	Own, DBB, DB	Public, REIG/T, DTC	RC Elements, subcontracted	Company is serious on TMC, completed multiple hybrid/timber frames	extensive company research, limited application
Development- and quality director	15 yrs	Western (& Inner) Finland	<145M€	Own	DTC	unknown	Company is serious on TMC, none started yet	extensive company research, limited application
Building systems development director (production background)	11 yrs	Western (& Inner) Finland	145-400M€	Own	DTC	RC elements + CIS-RC, subcontracted	Company research on TMC	limited research and application
Building systems development director	15 yrs	Western (& Inner) Finland	>400M€	Own	REIG/T, DTC	RC elements + CIS-RC, subcontracted	Company is serious on TMC, completed multiple hybrid/timber frames	extensive application of prefabricated bathrooms, some prefab TMC
Regional director	35 yrs	Western (& Inner) Finland	>400M€	DB, Alliance	REIG/T	CIS-RC, in-house	Company research on TMC	limited research and application
Building systems development director (production background)	28 yrs	Western (& Inner) Finland	>400M€	Own	REIG/T, DTC	RC elements + CIS-RC, in-house	Company research on TMC	moderate application of prefabricated bathrooms, some prefab TMC
Site manager	37 yrs	Western (& Inner) Finland	>400M€	DB	REIG/T	Timber elements, subcontracted	Company has applied TMC, completed a couple hybrid/timber frames	some prefab TMC

* **Own**: Builder vendor; **DB**: Design-Build (turnkey, i.e. contract includes both design and construction); **DBB**: Design-Bid-Build (contract is based on a pre-made design)

^ **Public**: public housing, social housing, dormitories, etc…; **REIG/T**: Real Estate Investment Group or -Fund, i.e. often rental apartments; **DTC**: Direct-To-Consumer, i.e. homeowners and retail property investors

3.2 Thematic analysis method

As a formal methodology to inductive data dissection, thematic analysis outlined by Braun & Clarke (2006) was used. This methodology is used to help organize and explain the data in a systematic manner, with the aim of uncovering patterns of issues through identification, analysis and reorganization. The analysis also forms a strong ground for interpretation and on drawing further conclusions that may not be directly present in the data (Boyatzis, 1998). Thematic analysis method underlies many other qualitative analyses but is not itself bound to any theoretical or epistemological context like other qualitative methods may be (Braun & Clarke, 2006, p. 80). For example, the general pattern-finding method of thematic analysis is also used in different varieties of grounded theory, exemplified by the Gioia methodology (Gioia, et al., 2012), all of which ground themselves in the implicit aim of new theory generation. In this thesis aimed at increasing understanding on the challenges of timber construction ecosystems, theory generation was not the goal. Instead, systematic data collation, meaning pattern discovery among main contractors' views on the topics of interest was seen sufficient to reach that goal. The analysis could then be extended if fruitful discoveries presented themselves. On a few issues the analysis went further that thematic analysis to formulate the synthesized understanding combined from multiple themes and topics (Bryman & Burgess, 2002).

Thematic analysis starts off by reading through the data and creating initial codes for the content (Watson, et al., 2008; Braun & Clarke, 2006). The transcripts' codes for this thesis ended up being either sentence specific, or more often closer to full "paragraphs" that conveyed a specific thought. The codes were indeed like condensed versions of the thoughts each informant conveyed. Initially, all codes were mostly unique consisting of the specific phrases and lines of reasoning that the actual interviewee used. , like: "Before expanding timber element manufacturing capacity, the market needs to make it more profitable". After coding the entire dataset, all the unique interview-specific codes that conveyed the same thought were refined to one unified code. The initial code could also be split to two or more refined codes if the initial code actually included more than one thought, or if that particular code included an insight that was not mentioned by all other similar codes. The above-mentioned code-example was refined to "The TMC market must evolve before extending participation is financially wise", Figure 6 shows an example of how the coding from the initial read-throughs of the transcripts were refined to a smaller amount of coherent codes that were easier to analyse and use for thematization.

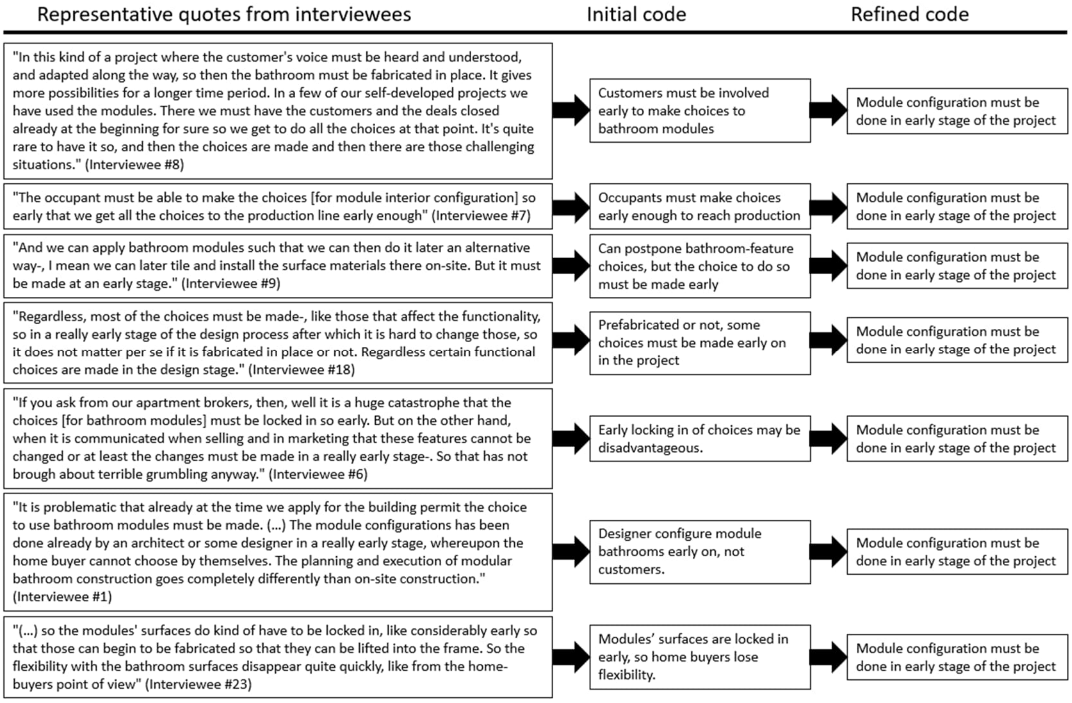


Figure 6: Example of coding and code refinement

After refining the codes, they were grouped to represent themes that were corroborated by multiple sources. Some themes could include only one code but would still otherwise be either objectively verified and/or linked to other themes as support to them or supported by them, and therefore deemed a valid part of a found pattern in the data. Most themes were formed from multiple codes though, like in Figure 7. Some publicly available conferences and seminars were also used as additional primary data to find support for some of the themes recognized from the interviews. Most themes were therefore supported either by multiple codes and/or multiple lines of circumstantial evidence that fit together among multiple sources. This indicates that the data was enough to saturate the uncovered themes to a sufficient degree (Boyatzis, 1998).

All themes were double checked against the original quotes to make sure the final conclusions would still be in line with what the informants had actually said. A couple of themes were then scrapped or rethought based on clear conflicts with the interview transcripts. Iterative analysis happened therefore in two stages of the analysis: codes were refined from specific to more generally descriptive, and themes were often rationalized from too general to more specific to ensure their better representativeness of the underlying data.

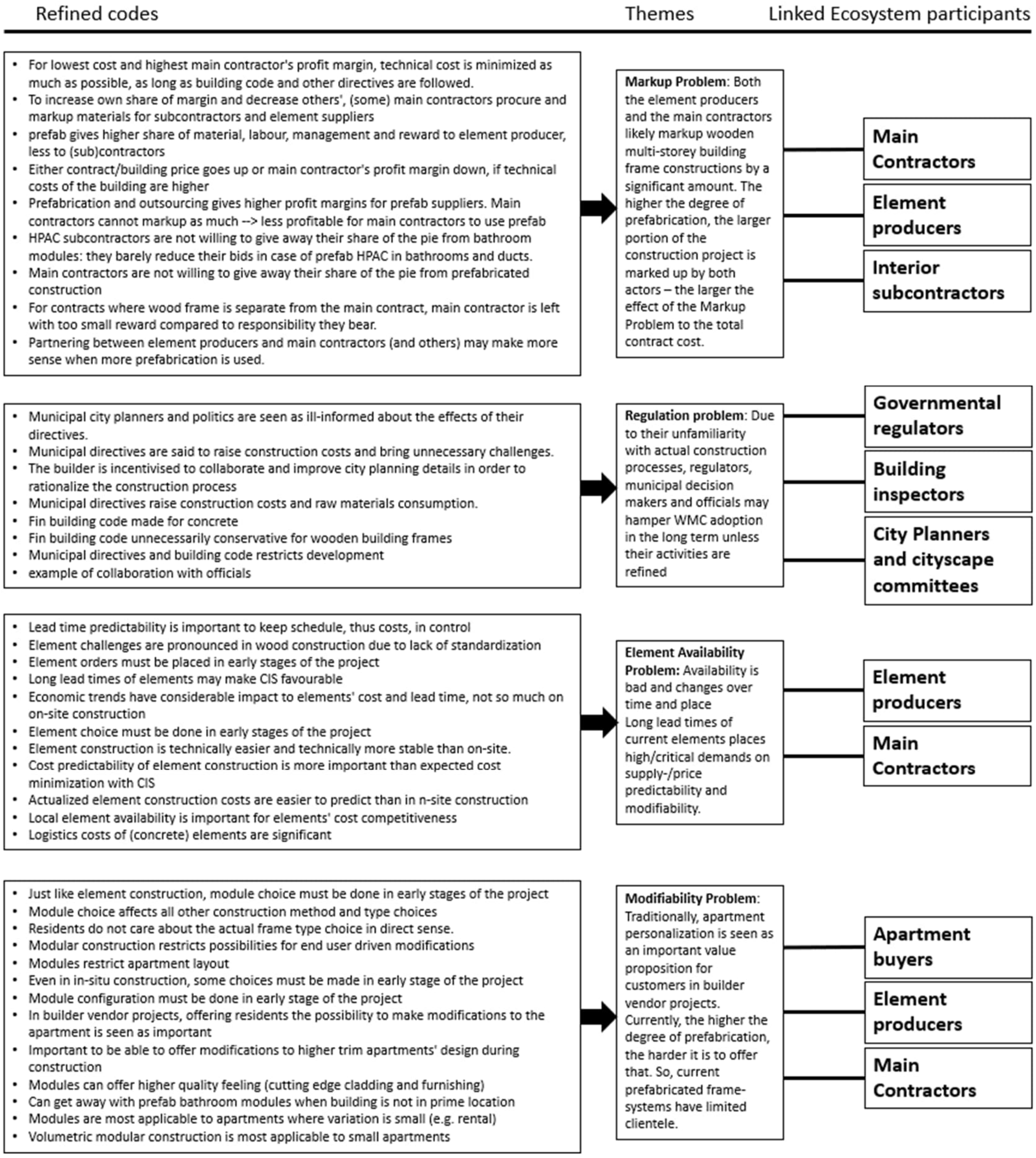


Figure 7: Examples of thematization of codes into problems related to TMC adoption. With links to ecosystem participants who uphold the problems.

The final step was to synthetize the findings, so the found patterns were illustrated as thematic maps (Braun & Clarke, 2006) or tables that show the links between themes, and in some cases, specific codes (cf. Figure 14, Figure 19, Figure 22). Most of the links between themes were communicated by the interviewees, but some themes were connected by logical relations and analytical reasoning by the author. A few supporting themes whose existence was deduced from the themes raised by the interviewees were also added by the author to complete the thematic maps. In the results section, the themes and links based on the author's conjecture are clearly denoted as so for better eligibility (Bryman & Burgess, 2002). In figures, this is done by use of legends, and within the body of text, such presumptions are qualified appropriately by use of phrases like “it seems like…”, “one could imagine that…”, “it is plausible that…”.

Dispersed throughout this thesis, representative direct quotes from the interviews are provided. Also, in the Appendix, a collection of quotes linked to the codes and themes derived from them are provided for the reader to evaluate. This is done to exemplify to the reader the unbroken link that the author attempted to keep between the interviewees actual sayings, the analysis, and the results. Multiple quotes or examples are provided in the body of text to help readers assess the validity and reliability of the base-level findings. Still, the most valuable insights may also be the rare ones borne by specific career paths- and positions-, or proclivities to share information-, of a small number of people. That is why triangulation and matching of different themes and patterns into a coherent whole, a “story-telling” approach, is also used when presenting the findings, to provide additional means of validation.

As an example of analysis that: uses the coding and thematization of the formal thematic analysis procedure; shows the “story-telling” approach for improving validity; and represents the power of interview methods afforded by semi-structured interviews, possibly the most significant result culminated from three different lines of inquiry (cf. Figure 14) and other circumstantial evidence (cf. Figure 15). One line of inquiry was the open question for why/why not RC element construction were used instead of CIS-RC construction, and about the preferred degree of prefabrication of façade elements. Another topic that shed light on the result was the open question about why/why not prefabricated bathroom modules were used in residential multi-storey construction. Questions about feasibility of contracting timber framed buildings then gave the final clues about the theme of The Markup Problem, which is covered in full in section 4.3. This issue was not a planned topic of the interviews but was uncovered by thematic analysis (Braun & Clarke, 2006) thanks to the semi-structured- and evolving nature of the interviews.

It should be noted that all the interviews were held and transcribed in Finnish. Representative quotes within the main body of this thesis’ text are translated to English by the author because they were seen essential for conveying the flow of thoughts to the reader. Still, due to inevitable losses in translation, paraphrasing was favoured unless exact quotes were used as examples or to strengthen the validity of the analysis, e.g. for rarely mentioned ideas. Similarly, translation was not done to quotes used in figures or tables outside of the body of the text to keep the link between the interviewees’ sayings and the analysis unbroken. This allows the reader to evaluate the coding and thematization applied by the author more realistically.

The range of topics related to the goal of understanding the process of frame type choice and adoption of new frame construction methods in residential multi-storey construction ecosystems was multifaceted. Almost all interviewees said this at some point: frame type choice is a complex issue that cannot be described completely. Because of this, the result of the thematic analysis was mostly disparate thematic maps with limited links between them. Each thematic map was named as a distinct problem, each of which were then treated separately in the results section of this thesis. The problems are the primary results of this thesis, and they are actionable by themselves for appropriate ecosystem participants. But an attempt to combine all the learnings from this thesis for a start of a complete description of frame type choice was also synthetized. This was done by additionally linking each one of the separate problems to interactions between construction ecosystem participants that were recognized as potentially significantly affecting the suitability of TMC frames. This ecosystem-wide view of the "appointed" problems then better conveys the totality of the challenge in adoption of novel construction methods as has been recognized based on the findings of this thesis. Then the issues that main contractors see in TMC adoption could be resented through the ecosystem lens, and a draft for a new TMC ecosystems could be developed in the conclusions section of this thesis.

4 Results: business problems in TMC ecosystems

Next, the major themes related to the choice of frame type in multi-storey residential construction will be laid out. The themes were the direct results that converged from the analysis of Finnish main contractor representatives' interviews conducted for this thesis. In the interviews, the themes manifested themselves as aspects that make applying certain frame types more problematic than others. Even though many of the themes were material-agnostic, they will be handled here as in how they relate to TMC adoption difficulties for main contractors; as TMC adoption problems. First, the residential multi-storey frame types that the interviewed main contractor companies mainly used are briefly presented for reference. Then, how the TMC adoption problems relate to the general form of existing latent multi-storey residential construction ecosystems and to different ecosystem participants is overviewed. Only the ecosystem participants who were brought up by the interviewees that could have a decisive influence on the frame type choice for a construction project are included as per the focus of this thesis. Regardless of these problems, it was learned that regional construction ecosystems in Finland have evolved to solve or live with the problems such that at least one frame type is practical and commercially viable in each area. TMC has not become one of these commercially viable frame systems anywhere in Finland. In order to understand the ecosystem bottlenecks hampering TMC adoption, the author termed the ten reoccurring TMC adoption problems as: The Markup Problem, The Regulation Problem, The Demand Fluctuation Problem, 71The Human Resource Problem, The Element Availability Problem, The Incompatibility Problem, The Innovation Problem, The Risk Problem, The Element Typology Problem, and The Modifiability Problem. These problems are briefly introduced in the end of this section and thoroughly covered following the next subsection of this thesis.

4.1 Frame types: Finnish residential multi-storey construction

Multi-storey residential buildings' frame types that, according to the interviews, are primarily used by the Finnish residential multi-storey sector are presented below in the extent that is necessary to follow along this thesis. For this end, it is sufficient to use only a couple basic typological concepts. In reality, there are dozens of alternatives on frame types and only the creativity and engineering prowess limits how to combine all the different solutions. As examples, Kotkavuo's (2022) master's thesis covers all RC frame typologies relevant to the Finnish context, and Salvadori's (2021) dissertation outlines all the mass timber frame types used around the world. Additionally, LWTF is the traditional way to use timber in building frames, and steel posts and beams offer another way to support a building. “Elementized RC” and “CIS-RC” are used in this thesis as generalizations of the prevalent RC frame types relevant for this thesis. It should be noted that, according to the interviews, elevator shafts and stairwells seem to be usually elementized no matter the rest of the frame. Also, balconies have highly varying structures, like pillar supported- or tension bar supported RC slabs. Roof substructures were said to often mimic the intermediate floors, but timber trussed frames are also used.

Regardless of the frame type, non-load-bearing dividing walls were often said to be metal-framed gypsum-sheathed walls, where metal framing is prefabricated and reinforced by LVL at openings. Bathrooms tended to be fabricated on-site with block walls or metal frames with water-sealed sheathing. Some builders use prefabricated bathroom modules in some projects.

4.1.1 Reinforced concrete frames

Elementized RC generally consists of concrete party wall elements, hollow core RC floor slabs, and RC sandwich perimeter walls, all prefabricated by element suppliers and installed (grouted) by a separate party on the construction site. Elementized RC was said to have the disadvantage of leaving much of the MEP, insulation, armament like doors and windows, and cladding to be fabricated or installed to the frame on the construction site. Sandwich perimeter elements are an exception, which can also have the insulation and outside cladding, sometimes even windows, ducts, and sills preinstalled.

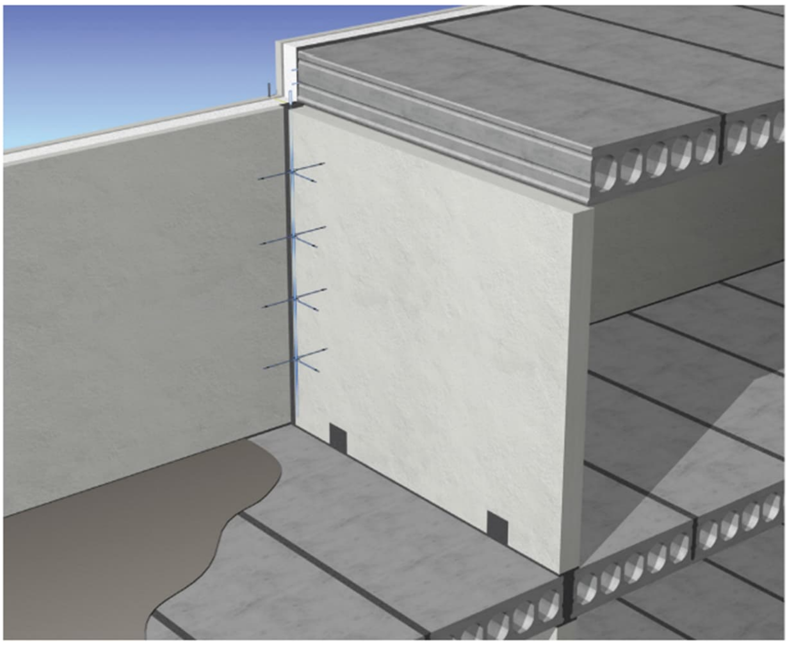


Figure 8: elementized concrete component assembly (Saint-Gobain Finland Oy, 2019)

Cast-in-situ reinforced concrete (CIS-RC) frames are on-site fabricated. The CIS-RC frame forms a unified continuous frame without joints. Different types of formwork are used to create the correct form for floor slabs and load-bearing walls. Rebar is placed to the forms as reinforcement to the concrete before casting to facilitate continuous load transfer and to take on tension stresses. Separate heaters or heated formwork can be used to accelerate curing of the casted concrete, so that the formwork can be circulated faster and to avoid freezing during winter.

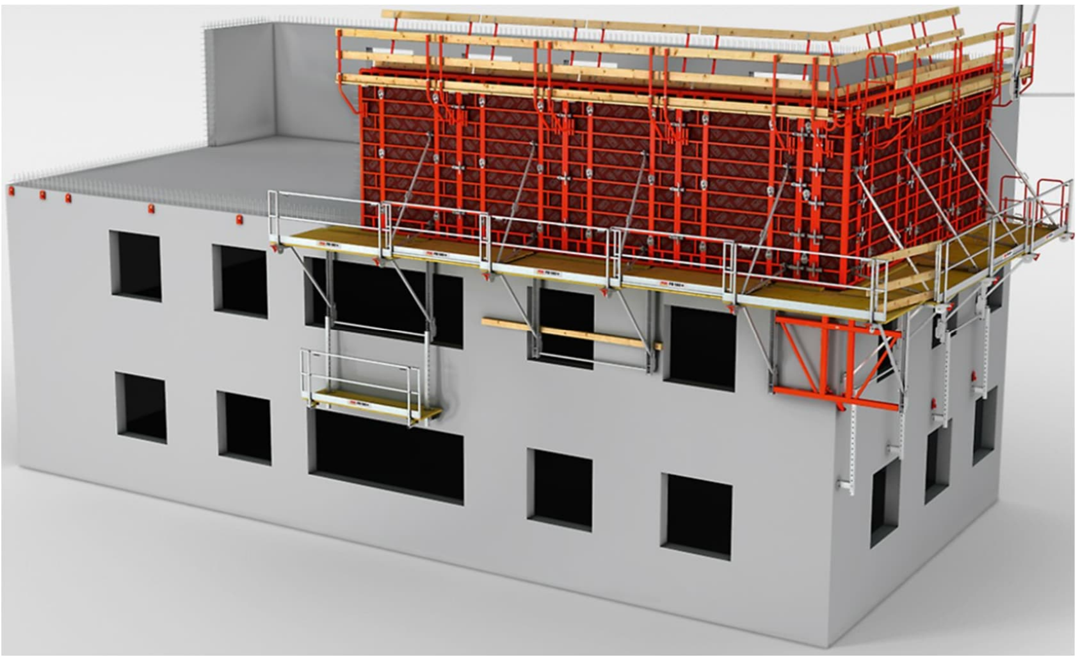


Figure 9: example of a CIS-RC frame (PERI USA)

Some companies also mix the two styles, like by using CIS-RC walls and hollow core RC floor slabs.

4.1.2 Timber frames

Regarding timber frames in the treatment of this thesis, it suffices to recognize light-weight timber frames (LWTFs), both on-site built and prebuilt, and CLT massive timber panel products, and that both of these can be prefabricated to voluminous building elements, i.e. (room) modules and MEP can be preinstalled into the walls and floors. This thesis does not handle post-and-beam frames, of any material, because they are so rarely used in residential multi-storey buildings in Finland. Only two interviewees mentioned in passing that it would be interesting to try post-and-beam structures in residential construction, but it was not an option they considered in practice.

LWTF's (see Figure 10) are assembled from studs of strength graded timber to form a grid-like frame. The spaces between the studs are filled with insulation, and additional layers of insulation, vapor barrier, sheathing and cladding are used to close up the walls. The sheathing simultaneously protect from fire, insulate sounds, and take on shear stresses applied to the wall (Tolppanen, et al., 2013). In multi-storey buildings plywood sheathing layers can be used for additional stiffening (Siikanen, 2016). As said, LWTF walls can be built piece by piece on the field or prefabricated into large panel elements or voluminous modules, with windows, MEP, cladding preinstalled. Usually, a “platform” structure is used, where walls stand 1-storey high installed on top of the previous storey (Tolppanen, et al., 2013). Studs and elements are connected to each other by using screws made for that specific purpose. Due to the layering of different materials and fragility of each component, LWTFs may be considered as complicated and intricate to build.

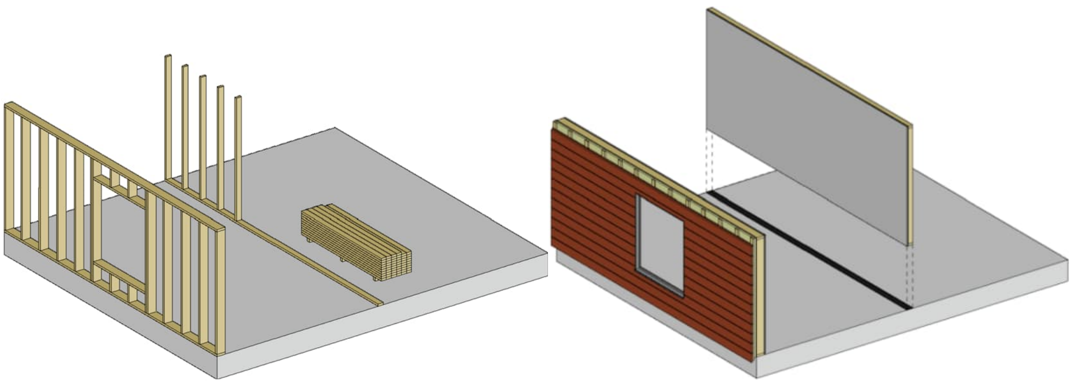
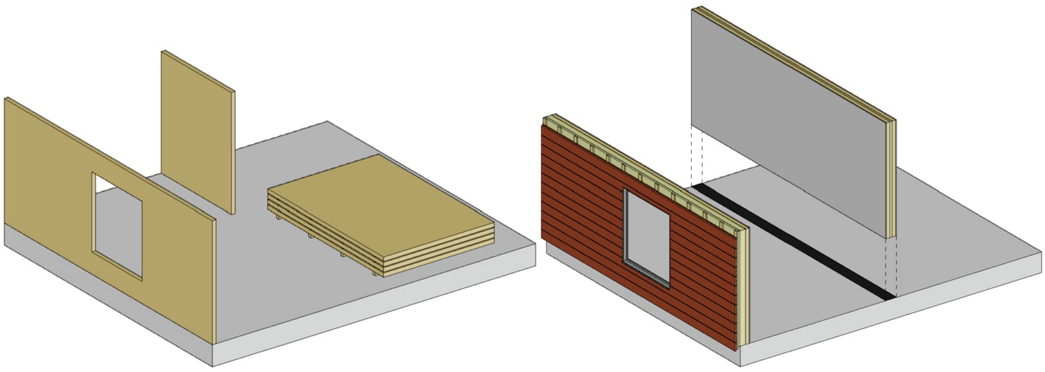


Figure 10: LWTF on-site fabrication (left) and elements with higher degree of prefabrication (right) (Puuinfo)

Massive timber panels are a more modern way to build from timber. Cross Laminted Timber (CLT) is the most common type. CLT consists of timber planks, stacked and glued in three to seven perpendicular layers into panels, which are manufactured in automated production lines to sizes up to 24 m by 3 m, and the thickness may be up to about 30 cm (Siikanen, 2016). These are cut to the designer’s specification using computer-controlled machining centres to include openings and shaping as needed. Insulation layers, vapour barriers, and additional sheathing are not necessary. The panels are more precise and stable in dimensions than LWTFs, have good shear resistance and load bearing capacities, have moderate temperature insulation, and are more robust to rough handling (Tolppanen, et al., 2013). The glue between the layers of timber provides films that hinder water vapour from passing through the wall. Still, the panels can be cladded from the outside and sheathed with plasterboard from the inside to protect them from the weather and improve fire resistance and as a sound suppression measure. Insulation can be added for energy efficiency. Like in LWTF, a platform structure is often used (Tolppanen, et al., 2013). Panels are connected by use of long strews or fixture plates, nuts, and bolts.



Massive timber element with low (left) and higher degree (right) of prefabrication (Puuinfo)

Volumetric timber elements are factory-made rooms or portions of rooms, “modules”, with some walls left open for extension (Tolppanen, et al., 2013). Wall and floor structures can be studded frames, CLT, or ribbed floors. Fixtures, MEP, cladding, appliances, flooring, etc. can all be installed in place in the factory. Their size is limited by viable transportation dimensions. The modules are transported to the site and lifted in place by crane, just as other elements are. Timber modules and elements can be lifted with lighter cranes than concrete ones. The modules are fixed together by use of screws and fixture plates, nuts, and bolts.

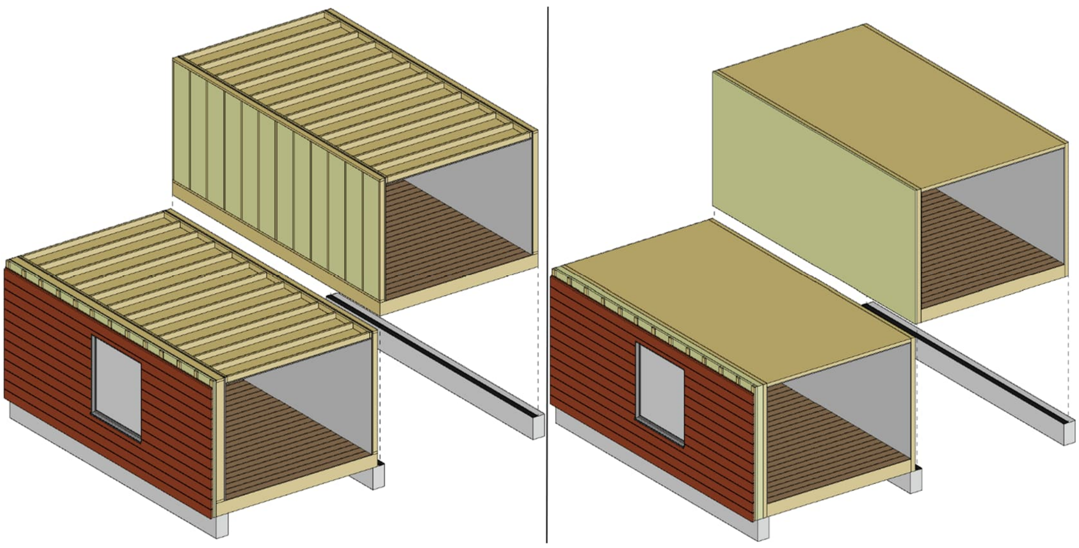


Figure 11: Volumetric timber elements (i.e. modules): LWTF on the right, massive timber on the left. Interior cladding, MEP, and fictures can be pre-installed. (Puuinfo)

CLT panels can also be used as floor structure, but additional mass or insulation as well as hung soffits made of plasterboard are added to reach soundproofing requirements (Tolppanen, et al., 2013). Ribbed floors are also common, where timber or LVL beams or joists support a wooden panel, and insulation is placed between the ribs (Tolppanen, et al., 2013). Additional layers of springed mass can be used for sound insulation.

4.1.3 Bathroom modules

Figure 12 showcases a modern bathroom module the like of which are used in Finnish multi-residential construction. All prefabricated in an external factory by a supplier, they usually involve RC floor slabs, light weight steel or timber framing with sheathing and waterproofing all around (Rakennustieto Oy RT 38784, 2016). Crucially, they usually include air conditioning units and ducting, drainage, the switchboard and electrical conduits, water plumbing, shower, faucet and fixtures, floor heating, as well as all tiling and surfacing in the interior (Rakennustieto Oy RT 38784, 2016). Most of the apartment-specific MEP is preinstalled in the module. The modules are transported to the construction site usually sealed in plastic covering and lifted to the building frame by crane (Rakennustieto Oy RT 38784, 2016). Appropriately for Finns, they can also include a sauna, ready for use.

Figure 12: Example of a bathroom module used in Finland. Note the amount of preinstalled MEP (Elementtisuunnittelu.fi)

4.2 The lay of the land: the latent multi-residential ecosystem

In the theoretical background-section, multiple different contract types were presented. All but the separate contracts -contract arrangement involved one key actor who was commissioned by the owner-client to execute the construction. In the case of separate contracts, the same single contract arrangement would usually repeat for each separate portion of the project. The key actor in question was either the main contractor or the construction manager. The totality of interviews conducted for this thesis confirmed that it is this one key actor who also chooses the general type of the building frame: they are the system integrator for the building and its frame. It did not matter which type of single contract -contract arrangement would be used. This solidifies the notion offered by the previous literature that main contractors indeed wield considerable power on frame type choice (e.g (Hemström, et al., 2016)).

The owner-client (or the developer) had also been recognized by the literature to house significant power over deciding the frame type, which was also supported by the interviews. In an extreme case, an owner-client could use separate contracts to procure the frame directly from the element producer to try to assure a specific frame type would be used, but this was said by a few interviews to dissuade the main contractor from taking on the rest of the project. In single contract arrangements, some interviewees implied that the owner-client or the developer can have preferences for the type of frame and may even demand a certain frame type. For example, the client may want to avoid trouble that water ingression can cause in hollow core RC slab floors, so they would prefer CIS-RC slabs. Usually though, the clients end up trusting the judgement, experience or at least the quoted contract prices of the contractors. In case of TMC, if the client is steadfast in their demands, many main contractors will ignore the project completely. So, it is up to the main contractor to price in the client's demands if they are willing to participate in such a project. One interviewee who had extensive experience as both a property developer (i.e. the client) and as a main contractor put it as follows:

Translated: "As the main contractor, we very strongly direct that what kind of a building it should become; different techniques, production methods, everything. But we indeed do outsource the actual creation of the design [of the building] in its entirety. We do not create that by ourselves. We are just the party who directs that. The city plan's specifications of course place restrictions and guide it already, but to be sure, we here then are principally the one who decides which frame construction method is to be proceeded with." (interviewee 19(13:30))

Just like previous studies found that the future residents of the apartment buildings do not have much influence on the type of the frame (Viholainen, 2021), the interviewees considered them uninterested and uninformed about the frame specifically. But the frame type affects the cost and modifiability of the apartments, which are of interest to residents. In builder vendor projects, frame solutions that allow apartment buyers more choice in the layout and features of apartments were favoured by most interviewees. Practically, this meant upping on-site fabrication. Apartment location was told to be a major factor in most buyers' choice, whereas sustainability aspects were thought by the informants as secondary relevance to most buyers' decision on apartments, all of which match the findings of Viholainen (2021, pp. 22-23). A couple of interviewees thought that many residents would think that timber frames are less durable and less safe than RC frames and would therefore prefer RC over timber.

As a summary of the primary findings and the centrality of main contractors in choosing the frame type for multi-storey residential buildings, Figure 13 below schematically depicts the traditional latent ecosystems, applicable to both elementized RC and CIS-RC, for multi-storey residential construction. This summary figure applies to all traditional contract arrangements. Elementized RC ecosystem differs from the CIS-RC one mainly in the added role of element producers and different frame crews. In latent ecosystems (Adner, 2016; Jacobides, et al., 2018), like the elementized RC and CIS-RC ecosystem are, all key players align their business to all other project participants following broadly acknowledged default division of roles. In addition to the influence of above-mentioned preferences originating from the main contractors, the clients, and the residents, additional influences on the frame choice stemming from interactions with other ecosystem players are presented in the figure. The players and the interactions are introduced in the following.

To begin with the overview on the latent ecosystem and problems related to frame type choice that interviewed **main contractors** face, main contractors' own internal issues are introduced. Majority of the interviewed main contractors' representatives said that there is little to no need to develop the technical solutions of traditional RC frame construction because they are so dependable and highly refined in application. This sentiment also related to the construction process, by many saying they are highly efficient already, but there were strongly differing opinions about the process side as well. Main contractors have little need to develop new frame types. In fact, trying new methods undermine the benefits they can reap from expertise in tried-and-true solutions. They lose the benefit of certainty by trying out relatively untested methods that have a significant effect to the end products that the contractors have judicial responsibility on. Lastly, high relative variation in contractor-specific local construction volumes make it hard to retain and manage labour and element production capacity. Suppliers and subcontractors can participate in all projects, not just for one main contractor, which makes their regional demand variations smaller.

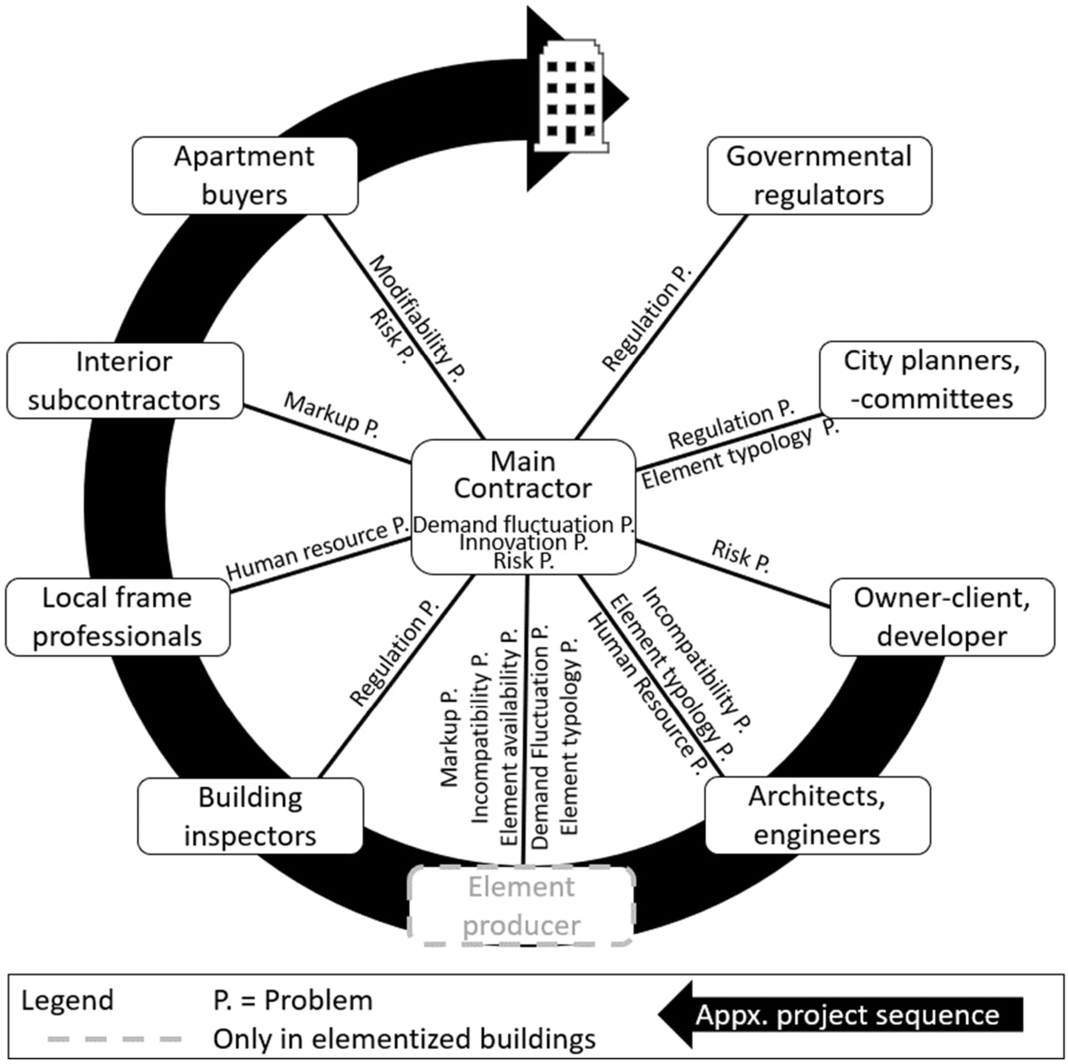


Figure 13: The latent multi-residential building frame construction ecosystem

Next, building code is literally the law of the land: all **governments** and even some smaller jurisdictions have their own climate, culture and tradition that have led to differing best practices between them (Jacobides, 2008; Nam & Tatum, 1988). The code underlies the industry logic by defining what the constructed buildings should be like based on regional best practices (Nam & Tatum, 1988). As said about innovation in the second main section of this thesis, building code can be seen to restrict innovation by requiring new solutions to achieve the same characteristics as traditional ones (Nam & Tatum, 1988; Koskela, 1992). This has an effect to TMC due to its novelty, to which it suffices to say that although the public body in Finland is supportive of TMC, the actual building code may still not be material-agnostic and for multi-storey construction may therefore unnecessarily favour the best practices of where it originates from: RC construction.

Some interviewees brought up **cityscape committees** and **city planners** as a route to influence on at least a part of the frame choice: perimeter walls, roofs, and balconies. For TMC, the influence may be more pronounced. Practically all TMC projects were said to be the result of political direction for using timber frames. But, their directions for the shape and size of the building, as well as for features of the façade, have resulted to ill-advised complications in the projects. Here as well, the practices of the municipal authorities seem not in line with the governments' principles for supporting TMC. As per the informants, the municipal decision makers are out of touch from construction practices for traditional RC construction as well. They were said to uphold façade requirements that fit poorly to modern element typologies and to commercially viable construction methods. This problem can also partly be said to be due to the constraints in the types of prefabricated elements that are available. Therefore, the builder must often fabricate the perimeter wall façade on the site. Some interviewees brought up cases in which they have collaborated in the zoning process of plots they own. This hints to the possible collaborative solutions to the problems.

As said above, the **owner-client** of the building to be constructed, or a **developer** that could be separate to the client, often prefer frame types that are least risky due to their long-term judicial responsibility on the building performance (Vanhala & Palviainen, 2008). It was mentioned that they may try to eliminate risks (e.g. ingressed water can cause trouble for hollow core RC slab floor, RC is more robust than timber) and/or lower costs (e.g. construction cost and maintenance of fragile timber) with their preferences. In the case of builder vendor projects, the main contractor itself is the owner and the developer and the only one responsible for the construction and building performance even long after project completion. Brought up often in the interviews, uncertainty on TMC performance the long-term responsibility leads to a significant impact to the risk premium required by the construction client. More of this will be discussed in a later subsection of this thesis. However, public housing clients for dormitories etc. are directed by the government to use more TMC anyways.

Building designers, e.g. architects, engineers, and specialized design consultants were mentioned only a couple of times to have an effect to the frame choice. Mostly the main contractor knew from experience what kind of structural solutions could be used without consulting the designers. Architects received some criticism for designing difficult-to-execute buildings, that could affect the frame type especially for the façade's part. Designers in general were seen out-of-touch from construction practicalities by some informants. The design process of TMC was said to require collaboration with the element producer, which was rarely needed in RC construction. It was said by a few interviewees that scarcity of competent designers for TMC was a challenge. Even specialized design consultants for sound and fire code provisions had to be used for TMC. A couple of interviewees also brought up that designers are often not aware of all the available frame solutions for TMC.

Element producers also affect the frame choice in three significant ways. First, the availability of elements affects their commercial viability through cost and lead time fluctuations and through logistics costs. This problem seems non-existent for CIS-RC construction but pronounced for TMC, which is why it is elaborated on as the Element Availability Problem further down below. Secondly, there is possibly a major tension between the element producers and main contractors: both play a key role in TMC construction projects, but if both are rewarded appropriately for their inputs, the total cost of the building may become too high to be commercially viable without subsidies. That brings us to the third problem where the producer is involved: main contractors prefer tried-and-true project arrangements they can efficiently follow through instead of new TMC project arrangements for which their businesses are not fit for. Large absolute fluctuations in volumes of construction are a fundamental problem for the entire construction industry (Nam & Tatum, 1988). It seems to largely define how element producers operate: there must be some way to buffer (Hopp & Spearman, 2011) the fluctuations. Lead time buffers seem the current choice. Finally, the element producers have a limited variety and features in the products that they provide, although the whole ecosystem from design to installation and to possible remodelling in the far future, must be aligned to make elements commercially viable.

Municipal **building inspectors** were mentioned by one interviewee as problematic in TMC projects due to the inspectors' inexperience with TMC. The experience and availability of dependable **local frame professionals** was the number one traditional driver mentioned for the type of frame selection by the main contractors. This was also often referred to as the local construction culture, which Hemström et. al (2016) call the "sociotechnical regime". But briefly, no matter if the contractor employed the frame crew in house or outsourced it, in locales where the crew or crews could construct CIS-RC walls (Oulu, Turku, (Kuopio, Tampere)), CIS-RC walls and CIS-RC slab floors were predominately used. If the available frame crews in an area were predominately specialized to RC element wall construction (most other areas), then RC element walls and hollow core slab floors would mostly be used. The experience of available site supervisors and managers was said to be somewhat less restrictive than that of the tradespersons in the frame crews. Some interviewees whose locale was more used to CIS-RC construction said that finding skilled tradespersons is problematic. Worsening availability of experienced local frame construction professionals, on who construction productivity is highly dependent, create a problem for human resourcing. This problem applies to both RC- and TMC, so it which will be covered later in this volume.

Interior subcontractors (MEP, cladding, fixturing), could sometimes affect the frame type choice. Primarily, MEP-subcontractors were mentioned to have an effect to the choice of prefabricated bathroom modules, because the largest part of work for those subcontracts happens in and around the bathroom. (Sub)contractors are not motivated to participate in projects where their work-share is smaller than usual unless they can recover their margins from additional markups.

Finally, as was already mentioned in the beginning of this section, in some projects the future **homeowners or private property buyers** can in fact affect the frame choice, although often only in small ways and indirectly. The will-be tenants of rental apartments even less so. In their own builder vendor projects, the main contractors usually aim to sell apartments, one-by-one, to end-users during or even before the start of construction. The buyers of the individual apartments can negotiate modifications to the layout, size, and trim level of the apartment. Also, to be able to offer a more compelling product, the builder vendor or the property developer may choose a frame type that they think the buyers would perceive to be worry-free over its lifetime and a type they know is more amenable to most modifications that the apartment buyer might want to do. Many interviewees said that prefabrication, like modular bathrooms, is problematic in this regard because most of the design must be locked in before the home buyer is involved with the projects.

4.3 The Markup Problem

As said in introduction, higher cost of construction has been recognized by many as hindrance to TMC adoption. The need for extra weather protection, heavier fire protection, inexperience of builders, unestablished structural solutions complicated by e.g. the acoustical challenges of timber, lacking scale and competition in timber element manufacturing were some reasons mentioned. The interviewees' views gathered for this thesis were concordant with these reasons. But a less-recognized insight to the cost issue could be uncovered from the interaction of responses to different topics covered in these interviews. The **Markup Problem** is potentially a significant explanator to the competitiveness challenges of TMC perceived by all TMC stakeholders, which goes as follows: a part-reason for TMC projects being more expensive compared to RC construction is likely to be that both the element provider and the main contractor place significant markups on the timber frame, a "double markup". If these projects are not subsidized or directed by authorities to use timber frames, the project earnings may remain too low to cover these markups. Therefore, either party may need to surrender a significant part of their markup to the other in "market priced" TMC projects, especially if the degree of prefabrication is high. So, unless the construction company can still get the normal reward for the responsibilities they bear as main contractors while the element producer gets their own share, it might not make sense for most main contractors to participate in TMC projects. This issue may imply a need for change within the industry, specifically the development of collaborative business practises.

The Markup Problem, was based on three lines of inquiry, which are covered in the following (refer to Figure 14 for an overview). First, main contractors may markup elements for the second time, which does not happen in on-site fabrication. Second, bathroom- and conduit modules decrease MEP-subcontractor's share of the project, making the projects with modules uninteresting to them unless similar earnings are provided to them as in traditional subcontracts. TMC projects may similarly be uninteresting to main contractors because the majority of the building frame is handled by the element producer. Third, even though in TMC projects' main contractors yield a large part of the project to timber element providers, they are still liable for the entirety of the project and thus are not motivated to participate in such projects unless similar reward is provided to them as in traditional contracts. Based on these, it is likely that both the element producers and the main contractors markup timber multi-storey building frame constructions by a significant amount. These insights constitute is the Markup Problem. In CIS-RC construction, there is no element producer to incur an additional markup. In elementized RC construction, markups of element providers are likely small due to commoditization (i.e. competition and operational efficiency), and the main contractor can also get away with smaller overhead. The higher the degree of prefabrication, the larger portion of the construction project is marked up by both actors – the larger the effect of the Markup Problem. The evidence for these three lines are covered next. Additional circumstantial evidence are illustrated later in Figure 15 as support.

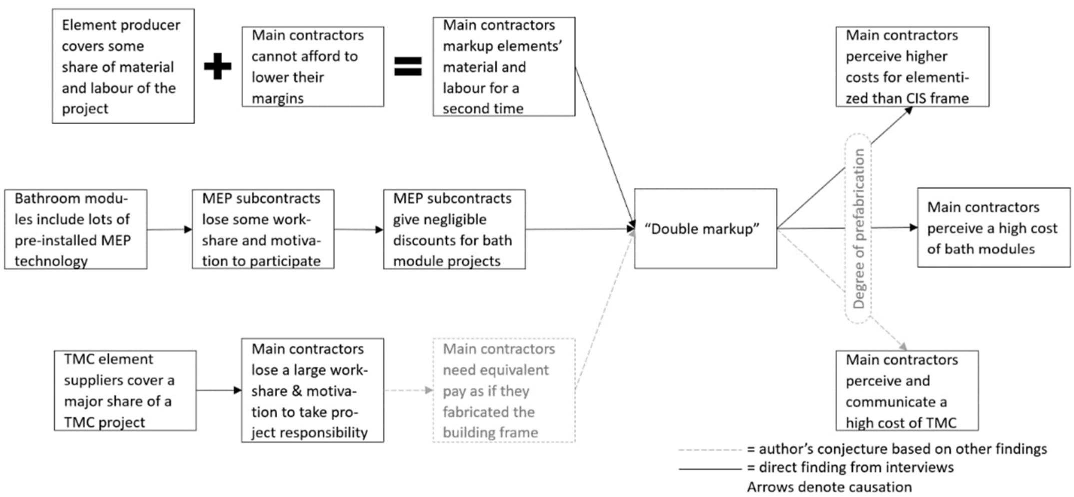


Figure 14: The three lines of inquiry: a thematic map of rationale behind the found reason for high cost and lack of motivation of contractors towards TMC

4.3.1 Primary evidence for the problem

In the first inquiry, when the interviewees were asked why they did or did not use RC element construction instead of CIS-RC construction, most said that whichever one they did use was simply the less expensive solution for them. There were many reasons why either elements or on-site built structures would be more or less feasible for a specific building, but the costs seemed to be mostly governed by issues not related to technical features of the building or the structural system. Instead, different kinds of interactions with complementors in the latent ecosystem were brought up repeatedly.

The bottom line is that CIS-RC construction was seen as the less costly and higher quality solution for residential construction, but only if the local latent ecosystem is fit to deliver it. For CIS construction, the main contractors need to have on hand several crews of highly skilled and versatile professionals to complement the execution of the majority of the whole frame from ground up to the roof. This usually means that the frame crew is employed in-house by the main contractor, which seems to be the way the biggest traditional contractors prefer to operate (cf. Table 3). Those who operate in geographic locations that have worse access to such a frame crew mainly use RC elements. They also usually operate in ecosystems where there is more fierce competition between the frame construction complementors – the specialized element installation subcontractors and RC element producers. Elements are thus well available and applicable. In this case, like in Southern Finland, the latent ecosystem has more complementors and the ecosystem participants seem more defined by competitive strategies rather than collaborative strategies. Thus, element producers' and frame crews' margins likely do not have much air in them and logistics costs do not become an issue.

A couple of interviewees said that, for element construction, the clients end up paying an extra markup from the materials of the element producer. It was also said that no matter if the building frame is made by an element provider or by the main contractor's own frame crew from ground up, the main contractor will add a markup including a risk premium to their costs. This extra markup from the element producer is avoided if the construction company operates in CIS-RC fraught ecosystems where the frame construction happens on-site. If the frame crew is in-house for the main contractor, also labour markup is saved. These CIS ecosystems exist in Northern- and Eastern Finland, as well as for some vertically integrated traditional main contractors using the system strategy in Southern Finland. The first clue for the Markup Problem was therefore that main contractors are said to markup the costs of outsourced RC elements, which could denote a widely wielded practice in the industry.

In addition to the latent ecosystem of elementized RC construction seeming more competitively rather than cooperatively oriented to force them to lower margins, it might be important to note that some main contractors likely have lower margin requirements as well, so the smaller margins would not be a problem for them. Co-specialization to outsourcing the frame likely means lower overhead and indirect operating expenses (SGA). The markups of the element producers may stay low due to competitive orientation and the use of component strategies (Hannah & Eisenhardt, 2018), and the main contractor might not need to markup the elements at all, or at least not by as much, to reach a desirable net profit. This is a plausible explanation for why the Markup Problem seems to not be a problem for every construction company in elementized RC construction. TMC ecosystems however, are not mature enough that the companies could use component strategies across the board and thus operate with low gross margin requirement.

As a second line of inquiry, a telling sign about the prevailing business practices in construction industry came from asking the interviewees about why do they or why do they not use prefabricated bathroom modules? Some of the reasons against using them are covered in later sections, but one follows here: Most other interviewees said that construction costs are usually higher when using prefabricated bathroom modules. As those have tiling, fixturing, and a large part of the MEP that each apartment requires preinstalled in them, the MEP subcontracts are less extensive than usual. This is effectively a disruption that bathroom modules have introduced to the latent ecosystems, which was also said to be present when using prefabricated conduits that have pre-installed MEP. Many interviewees had noticed that although the MEP-subcontracts' costs should accordingly be smaller, it is common that the subcontractors barely lower their contract price offers. A couple of those interviewees had concluded that the MEP-subcontractors may not be motivated to participate in these kinds of smaller contracts, and therefore quote a higher price than may be warranted by the actual extent of their contract.

So, main contractors recognize that subcontractors often feel it is not worth it to participate in smaller subcontracts, unless motivated to participate by a higher price than normal. It seems that because of the infancy of the TMC industry and the fact that TMC has often a higher degree of prefabrication than RC construction (Kesik & Rosemary, 2021), the main contractors could face the same incentive problem in relation to TMC as the MEP subcontractors face in relation to bathroom modules. TMC effectively introduces a disruption to the latent ecosystem, redistributing roles and possibly making some traditional activities or responsibilities obsolete. It could be that traditional main contractors may not be motivated to participate in TMC projects where a significant share of their contract is no longer under their direct management. For it to make sense for them to participate in such projects, they may require a comparable reward to what they would get from a traditional contract where they usually directly manage the design and execution of the building frame.

In TMC, the timber element producer manages a large portion of the design, production, and erection of the whole frame, which is the costliest item in the construction project (Pan & Sidwell, 2011). But the main contractor is still responsible for the overall project. In builder vendor projects, the main contractor also is their "own" client taking on the role of the developer. In Finland, a developer is liable for the building's performance for ten years after completing the construction (Ahonen, et al., 2020; Vanhala & Palviainen, 2008). Thus, even though their management-role is smaller, they might need an equivalent reward for the project because of their responsibility-role.

The final clues for the Markup Problem came when asking the interviewees about the commercial viability of TMC. Two high level managerial role interviewees, both experienced multi-residential production professionals in two of the most prominent Finnish construction companies that mainly utilize RC construction, directly mentioned the issue of redistributed margins when using prefabricated TMC:

Translated: "And then the fact that [in voluminous element construction] there the costs flow to the element producer to quite a large extent. (...) Then again when the element producer supplies everything completed, then all the margin goes there as well..."(interviewee 13(37:15))

Translated: "... [the separate contracts arrangement] is so harsh when the main contractor is the principal builder and the client [separately] procures the timber frame from a timber element producer, and the earnings remain really low even though you carry the risk-. And schedule and work site safety is managed by the main contractor with the lower reward, so in that case our motivation wanes really quickly. (...) But if we can build by ourselves and we also get the [frame] contract, then for sure. This is the thing that we have faced in multi-storey construction, that we do not get the compensation what would be deserved from carrying the responsibility and handling all the issues." (interviewee 9(37:30))

A third similarly credentialled interviewee also found it paradoxical that the main contractor is still supposed to be the principal builder even though the timber prefabricated element producer delivers most of the project.

The second quote refers to a situation where the owner-client procures a prefabricated timber frame in a separate contract from the main contract. When the frame is not included in the main contract, the main contractor cannot markup the frame, and is left with a significantly smaller reward from the project than if the frame was included. A separate contracts arrangement like this has been recommended for TMC (Ylinen, 2022; Kesik & Rosemary, 2021) exactly to avoid the second markup on the frame. Separate contracts may also make sense for the owner-client because of the novelty of TMC, so that the client can involve the element producer already in the concept design phase of the project (Segerstedt & Olofsson, 2010). Involving the element producer later in the project may lead to difficulties arising from low harmonization between different timber element producers' products.

If the frame was included in the main contract, as in DB ("turnkey") contracts, the main contractor could charge a higher price, as interviewee 9 said, but then the project costs may be higher for the owner-client. This is likely why many contractors said they preferred a DB single-contract contracting arrangement especially for TMC. It would also avoid the redesign of the building that may happen due to switching between non-harmonized element producers in DBB contracts. DB also allows the main contractor to contract with the element producer and markup its costs. In separate contracts the client deals directly with the element producer and could theoretically save money like that, but then it might be a challenge to find a motivated main contractor for the rest of the project.

Other circumstantial evidence are illustrated in Figure 15 below as support for the finding of the Markup Problem.

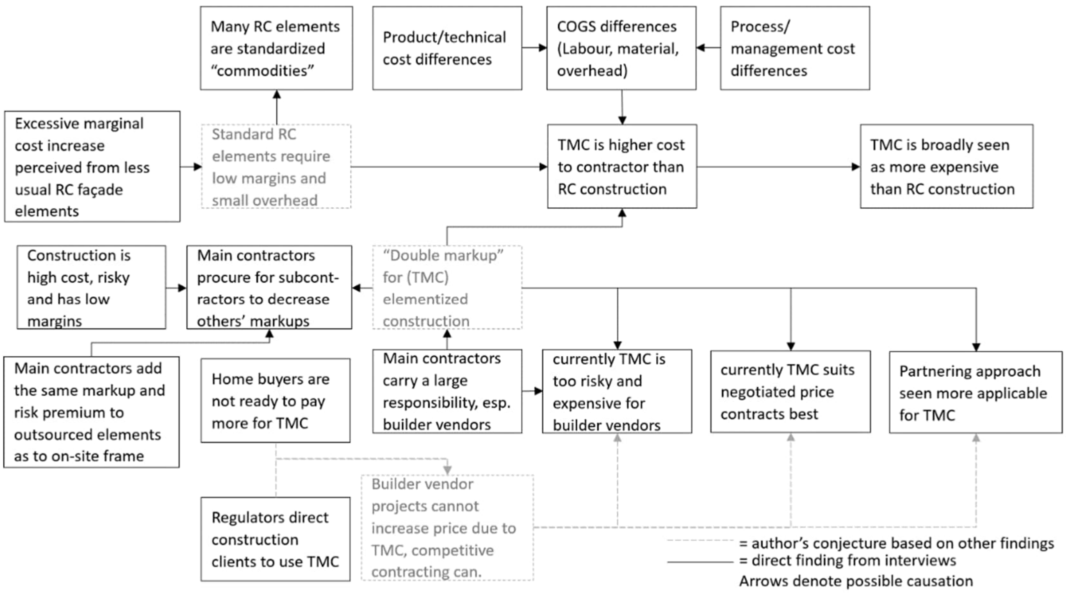


Figure 15: Thematic map of circumstantial evidence for the Markup Problem.

4.3.2 Consequences of the problem

A TMC building is expensive to the contractor partly because their technical costs already include the significant markup of the timber element producer. This could be fatal for the contractor in builder vendor projects where they must sell the apartments at market price, i.e. when they have little possibility to transfer the costs to the customer. In competitive contracting like DBB and DB, a TMC project is expensive to the owner-client partly because the total cost includes significant markups from both the element producer and the main contractor. Often, the owner-client is not willing to pay a higher price that would cover the margins required by both the main contractor and the element producer. Exceptions to this unwillingness are projects subsidized or directed by the Finnish public authorities. There, all competing bidders face the same markup problem and thus the client must accept a higher price. Generalizing this means that if not subsidized or directed by authorities to use timber frames, traditional main contractors may need to surrender a significant part of their markup to timber element producers in TMC projects, especially if the degree of prefabrication is high. So, unless they can still get the normal reward for the responsibilities they bear as main contractors, it might not make sense for most main contractors to participate in TMC projects.

The following figure (Figure 16) illustrates how the Markup Problem could be one of the explanations for why TMC is perceived as more expensive currently. The figure is qualitative; it is not based on actual numbers or rigorous estimates, but only showcases the concept of what kind of an effect the Markup Problem could have on construction costs. As a reference, some have estimated that materials and labour, overhead, and SGA cover 80%, 6% and 13% of main contractor's costs respectively (Mahapatra & Gustavsson, 2009). Gross profit is then derived by adding some operating margin to SGA. Without access to actual numbers from different stakeholders involved with TMC projects it is hard to evaluate how significant the Markup Problem is in relation to inefficiency stemming from direct material and labour that go into the actual fabrication of the frame.

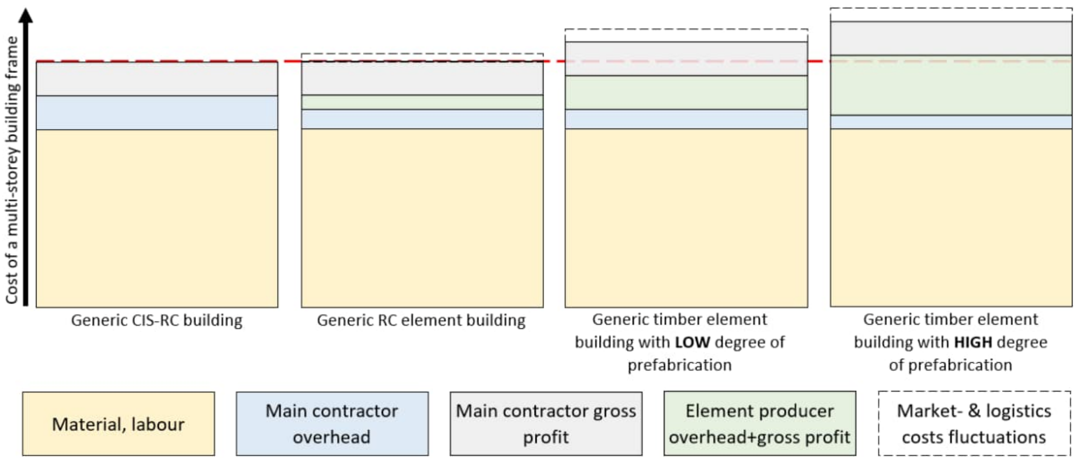


Figure 16: Qualitative illustration of how markups may affect total costs of a multi-storey residential building. Material and labour assumed invariable. Not based on actual numbers or rigorous estimates.

In Figure 16, gross profit of the main contractor, direct material- and labour costs for the frames are assumed equal in all cases to show more clearly how overhead and element producers' gross margins could tip the scale of total costs. In reality, there is likely always a difference between timber and RC frames' labour and material, currently often in favour of RC.

In Figure 16, "Market- logistics cost fluctuations" depict an increased effect of economic trends and logistics costs on elementized construction compared to on-site building fabrication that the interviewees communicated. This extra is more pronounced for TMC due to small number of producers. Then, effectively all interviewees said that elementized and prefabricated construction has a positive effect on the "Main contractor overhead" due to possibly faster schedule and less need for management compared to CIS construction. A few informants also said that elementized construction is easier to control and causes less variation in costs overall. Referring to "Element producer overhead+gross profit", overhead and the gross margin of timber element producers is likely to be higher due to their higher involvement in the project compared to RC element producers. The timber element producer's cut is even larger when prefabrication is taken further: one interviewee said the main contractor may only be left with the management of design and execution related to the foundation, the yard, some general site work, and sometimes the stairwell and elevator shaft, or the roof.

Timber frames can be less expensive than RC frames in some cases (Suuronen, 2021; Salonen, 2021). The consensus seems to be that currently it is most sensible commercially to use highly prefabricated modular timber construction in simple buildings that have low variation between the apartments and storeys of the building, like dormitories and low-cost rental housing. Many interviewees reported the same: modular construction costs the less the more identical module is used in the building. Simpler construction means cost savings across the board, and this effect is likely more pronounced in flow production in a factory setting than in on-site fabrication. For example, the effect of changeovers is huge in small lot-size production like construction elements are (Hopp & Spearman, 2011). The higher the degree of prefabrication, the higher share of production takes place in the factory and will benefit from serial production. The on-site installation is also made simpler. Lower costs mean proportionately lower gross profit. The result is that for a multi-storey "super-building" optimized for a timber frame, the timber frame may be the most affordable solution (Suuronen, 2021).

This far, varied evidence has been shown and their relation to the Markup Problem has been covered. As a summary, Figure 17 depicts the root causes that can be inferred from the evidence for why double markups and the Markup Problem exists for TMC and other non-standardized or prefabricated construction elements could exist.

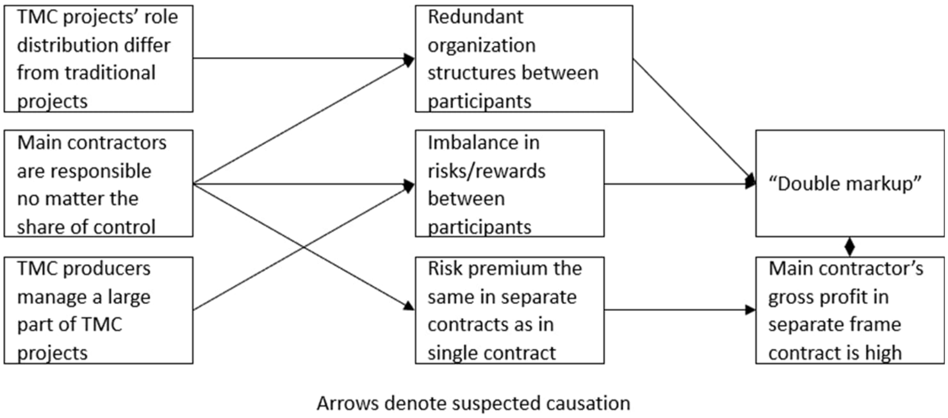


Figure 17: Thematic map of possible underlying reasons for double markups

It is of course as much the element producer's markup as the main contractor's markup that increase the final cost of the construction project. Both of them have an integral role in a TMC project. So, it is not the case that either of them would not be entitled to their reward. If the market is not ready to pay the margins, the companies must make do with less. For example, timber elements could be commoditized like RC elements, so element producers' costs would decrease. Or perhaps the main contractor could streamline their organization and save costs so that it could leave the whole frame for the element producer to worry about. Surely both parties could improve. This will be discussed further in the conclusions section.

4.4 The Regulation Problem

The regulation problem refers to challenges that TMC face in Finland from the directions of myriad of public authorities. Perhaps the form of regulation that has been most recognized by previous literature as a challenge to TMC is the building code. The challenges that were brought up by the interviewees stemming from authorities were broader than just about building code, though. Building inspection officials' influence and especially directives given by municipal decision makers and city planners were also cited as significant factors affecting the choice of building frame type. Through the synthesis of findings from individual interviews, the following insight could be drawn (cf. Figure 18): Due to lacking involvement in construction ecosystems, regulators, municipal decision makers and officials may unnecessarily rise construction costs and risks, especially for TMC, and increase consumption of natural resources. This is the **Regulation Problem** and the facets related to it recognized in the interviews are presented in

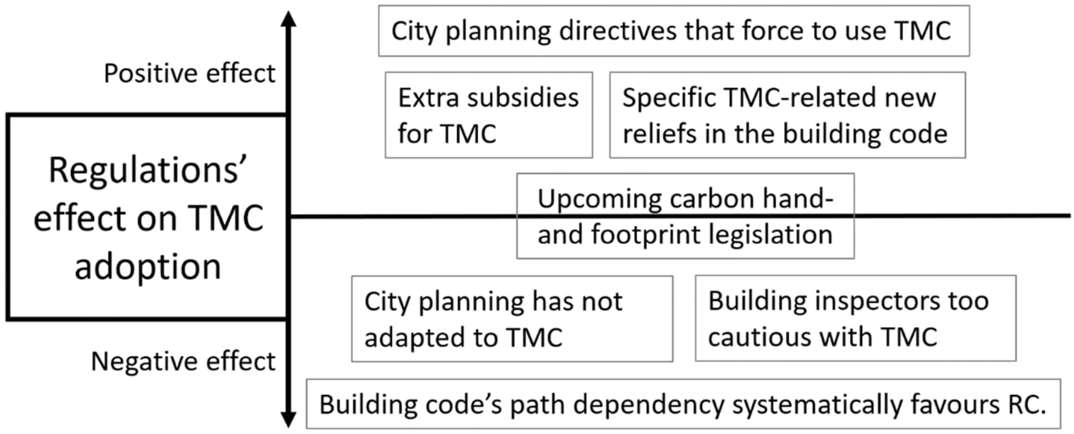


Figure 18: Counteracting forces of regulations to TMC adoption

The first part of the pattern of findings leading toward this conclusion relates to the building code. The exact issue of excessive fire protections required for timber was echoed by many of the interviewees. An interesting take toward the building code from interviewees 6, 9 and 18 was that just as the industry itself is configured for using RC in traditional multi storey construction, so is the building code. The code seems to have just abstracted away RC, and now requires all multi-storey buildings to inhold the properties that, for the most part, happen to be automatically reached with well-built RC constructions. So, path dependency on RC also reaches the building code which restricts commercially reasonable possibilities for adopting new construction methods, like TMC. This begs to question the intent of the building code: is our goal to build great RC (types of) buildings or is the goal to build great buildings in general?

One could imagine the counterfactual case where we had a construction tradition where TMC was dominant over RC. If the building code was configured for that, then, as examples based on material characteristics of timber, RC buildings would have harder time filling sound insulation requirements and noise, pollution and safety precautions on-site: it could be that concrete construction would require additional sheathing of walls and more field controls that are seen as extra costs for TMC currently. In that alternative world, it could be argued by RC advocates that those requirements are excessive; exactly the same situation we find ourselves right now regarding the building code, but with the tides turned. If regulators could somehow be freed form a material specific ecosystem's context, be it RC, timber, steel or otherwise, an outcome that also does not favour any material over the other by design would be reached. Each material would still have its advantages, but it would only be by the merit of the material itself that would make it more or less favourable in multi-storey construction.

Regarding the building code, TMC may or may not be supported more strongly by it in the future when environmental effects' provisions in legislation are revised. Most interviewees mentioned that the ongoing revision on regulating the carbon footprint of construction can affect the frame type choice in the future. It was said that TMC could then be more favourable, but most informants thought that the energy consumption of buildings during the usage-stage will dominate the environmental impact of the construction phase. Based on this, the favouritism in the building code does not significantly help TMC, but it is possible that this changes soon. But RC frames could remain the go-to method, and/or traditional contractors may focus more on renovation rather than new construction, as one interviewee said. In any case, even if TMC becomes significantly more favourable with the help of governments environmental requirements, the perceived impairments of TMC in the overall building code remain a burden.

Still, it should be recognized that thanks to some of the subsidies and directives placed by the public authorities, in the short term, regulators may be more of an enabler than an inhibitor of TMC. Effectively all interviewed main contractor representatives indicated that if it wasn't for the favouritism towards TMC by the authorities, most TMC projects would not exist. The favouritism comes in a few forms, and all of them help mitigate the Markup Problem and generally the high costs of TMC. First are subsidies that help cover some of the extra costs and risks associated with TMC by main contractors. Timber framed multi-storey buildings are allowed larger subsidies and better terms in largest Finnish cities for subsidised housing (e.g. (ARA, 2020)). Secondly, the contract terms that public construction clients use to favour timber frames or city planning directives that require timber frames creates circumstances where the quoted prices of the contracts do not have to be cost-competitive against RC construction, and the markup problem would be solved. Since the client had decided to favour TMC by using such contract terms, it was also likely that they were willing to pay to lowest of the higher prices. If the client would not be ready to pay the price, like in some projects that the a couple interviewees mentioned, the client would re-evaluate the grounds on which they would resolve the tender. The following quote illustrates the real positive effect that the regulatory favouritism has on TMC adoption:

Translated: "We haven't yet started using it (timber multi-storey construction) in our own builder vendor projects. In fact, we haven't seriously considered it other than pondered a little about the idea of applying also for those kinds of plots of land at some point, or that we would also think about projects for which the city plan has a requirement for timber multi-storey buildings. Those kinds of city plans have started to exist, especially in Tampere. It feels like the city of Tampere currently wants to somehow take the lead with timber multi-storey construction which has driven us in this region to seriously-. But we haven't yet taken those up in our own builder vendor projects." (interviewee 16(48:30))

But, even as in some cases TMC is favoured by the public bodies, other-, or even some of the same public actors also hamper the commercial viability of TMC. As explained already, the building code is a systematic way in which TMC is restrained, despite some concessions (e.g. 20% less protective sheathing (YMa 848/2017 24§, 2017) and lowered insulation requirements (YMa 1010/2017 24§, 2017)) . Then, construction project specific curtailments are also enacted by the building inspection officials, municipal decision makers and city planners.

A common thread among most of the interviewees is the fact that architectonic and cityscape-related demands from the authorities place considerable burden to construction in terms of costs and quality. This is a finding not specific to only TMC. Almost all interviewees said that cityscape-related requirements influence the frame of the building, but most of the effects related to the façade of the building. Interviewed main contractors' representatives felt that the cityscape is overemphasized at the expense of the actual building's end-user, who will have to carry the extra costs borne by filling the cityscape demands. As an example, the requirement that the seams between the building's shell's elements cannot be left visible was mentioned by almost everyone because it has a considerable effect to frame construction methods: cladding, windows, etc must be installed on-site, which requires scaffolding and lots of extra manual labour. The shape of the building, parking garages underneath the building, shape of balconies, positioning of windows, and shape of the roof are some other tangible examples that city planning controls and which often affect the frame of the building.

A few interviewees highlighted the effect of municipal directives on apartment distribution on commercial viability of multi-residential construction. They doubted the municipality's ability to determine what sized apartments and how many of them are needed in the market. One interviewee noted that requiring common areas and community spaces in the buildings could be adding unnecessary complexity to construction and be a waste of money and resources. He did not see the common areas being utilized much by the residents. Even though most of the city planning-related issues mentioned in the interviews related to RC construction, the situation may even be worse for TMC due to unfamiliarity to timber construction and its higher degree of prefabrication. It was said by few informants that usually the main contractor attempts to negotiate the requirements with the municipality and even bends the rules given to them as much as they dare to. Collaborative interaction with the municipal decision makers and officials was said to be key for rationalizing the cityscape demands. One interviewee told how they have employed a contract arrangement that successfully deals with this issue:

Translated: "We have quite many such [projects] where we develop the land-area and advance the city planning by actively discussing with the land owner, -with the municipality-, and then we look for property *investors or other actors who buys the plot and we will take care of the design and construction and all in a turnkey-principle". (interviewee #19(9:20))*

A couple of main contractors that are involved with TMC mentioned that massing (i.e. the shape) of timber multi-storey buildings is a problem. Even in city blocks designated for TMC, the massing is directed by the municipality to be the like that RC buildings have traditionally been, which may often not be commercially feasible for current TMC methods. The other interviewee, who is involved with both RC residential building construction as well as residential TMC, mentioned that in addition to harsh building code and challenges from the architectonic and cityscape demands, municipal building inspectors also exercise their own judgement on TMC more than would be warranted by their actual experience in it. His experience was that the building inspectors are not familiar with TMC and for that reason are unsure about themselves when inspecting such buildings. The inspectors feel responsible for the building's safety and thus, when in doubt, end up guiding the construction to be well on the safe side. The daily whims of the inspectors may end up requiring higher safety factors for TMC than the building code does, which make TMC more difficult and expensive. Therein again lies the same problem of inexperience and path dependence: timber frames are required to be RC frames.

Summarising, currently the building code, officials, and directives are often counterproductive towards encouraging increase in timber usage. The above findings on the Regulation Problem implies that although municipalities want to support TMC, they usually specify most requirements like they have used to do with RC buildings. Officials and decision makers seem to lack understanding of how buildings in general, especially TMC buildings, should be built without raising costs of living too much. Therefore, it seems like they are not be aware of how they could account for TMC better in their decisions. If the municipal decision makers seem not to be aware of the effects of their directives even on RC construction, how could they be aware in the case of novel TMC? A thorough re-alignment of the whole practising public body in relation to TMC could be needed if TMC is to be supported effectively.

4.5 The Demand Fluctuation Problem

The fundamental issue of seasonality, or high variability of demand (Nam & Tatum, 1988) was brought up by a few interviewees. The **Demand Fluctuation Problem** means that high relative variation in contractor-specific local construction volumes make it hard for the main contractors to retain and manage labour and element production capacity in-house. According to the interviews, it is not uncommon that locale-specific construction projects increase or decrease manyfold. Therefore, many informants preferred outsourcing their frame crews. Main contractors' in-house tradespeople are dependent on one builders' own projects but suppliers and subcontractors can work in all local main contractors' projects, which makes their regional demand variations smaller. Tradespeople were said to rather switch employers than travel for gigs, which amplify the problem. Considering that there were no questions in the interview guide related to demand fluctuation, mentions of it by the interviewees seemed crucial in terms of the feasibility of TMC, and elementized- as well as prefabricated construction in general.

A couple of interviewees said that due to high fluctuation of volumes of construction within a single firm and in local construction ecosystems, vertical integration of timber element production is challenging. It was also mentioned that only the largest main contractor firms can have enough construction projects to fill this demand required for element production factories, or otherwise they would also need to sell building elements to competitors. One interviewee said that it was seen as a good choice to sell elements to a competitor in the case that the construction market was booming, and the competing main contractor firms were willing to pay a great price for the elements.

For some timber element producers, even one delayed start of a project or other obstacles in construction schedules may be deadly, because TMC is such a low volume building system currently in Finland. However, such delays and fluctuations were said to be bound to happen in construction, so element producers need a way to deal with it. As an example, it was implied that the production rate of an element producer has to be sufficiently high to lessen the relative impact of single projects. Indirectly, through bringing up long lead times and large lead time fluctuations, many interviewees alluded to large time buffers that element producers use to shield them from the demand fluctuations.

In addition to posing capacity management challenges for element production, the Demand Fluctuation Problem also complicate human resource management. Many interviewees in traditional elementized construction ecosystems said that subcontracting solves this issue. Construction companies that have tradespeople in-house must place considerable focus on keeping the workers employed. Larger companies may have easier time doing this as larger scale will smooth out some of the fluctuations. Smaller companies must come up with ancillary jobs for their tradespeople to keep them employed. It seems also possible that a part of the low productivity in the construction industry is due to the employees compensating for expected shortages of work by lowering their work output, especially it they are paid hourly.

The Demand Fluctuation Problem was not covered much in interviews but is important to have in mind. Especially for a business model and an ecosystem design focused on a particular type of timber building system, there has to be some way to buffer or diminish this variability. Knowing about the

Demand Fluctuation Problem also gives the necessary background for analysing other problems that will be covered next.

4.6 The Human Resource Problem

As was already hinted at in the context of the Markup Problem, the competencies of locally available construction tradespersons and local supervisory- and managerial professionals is a significant factor in defining what frame types are used by main contractors in each local construction ecosystem. In the literature review, we saw that Hemström et. al ((2016)) recognized this effect in their research, calling it the "sociotechnical regime". The interviews for this thesis uncovered that the sociotechnical regime (local construction cultures) are just one facet of the influence that human resources have on frame type choice. As challenge for the adoption of TMC, the **Human Resource Problem** is that traditionally in multi-residential frame construction productivity has high dependence on experienced construction professionals, whose skills and availability vary greatly temporally and geographically, which limits the locally applicable frame types.

Analysis of the interviews of this study help to understand the facets of Human Resource Problem, including the construction cultures, actually mean, what causes the problem, what keeps it going and why it may be challenging to resolve. Disparate specialization opportunities, societal effects on workforce and on construction demand, situational personnel availability, experience driven construction efficiency, and novelty of TMC came up interviews as some of the facets that define the challenge that the availability of skilled personnel pose on frame type choice. These facets, as depicted in a thematic map in Figure 19,will be covered in the following.

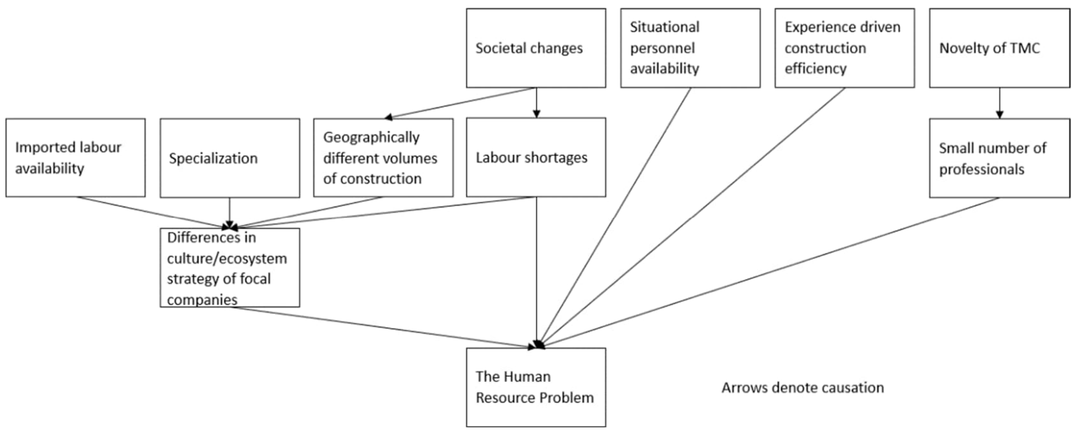


Figure 19: Thematic map of facets communicated by interviewees to create the Human Resource Problem for TMC

Effectively all interviewees stressed that experienced, skilled and dependable core personnel for the construction site are imperative for avoiding risks and staying in schedule with the construction project. This was the case also in Hemström et. al (2016) study of Swedish contract managers. Penalties for schedule-overruns for all contractors participating in a construction project are the rule in the industry. Schedule slips would therefore almost immediately cause financial burden that may not be recoverable. If one party is late with their contract, it may be a burden on other parties in the ecosystem. Accordingly, all of the interviewees brought out that the abilities of the field personnel, specifically the frame crews and the site supervisors/managers in the local ecosystem, are traditionally the number one determinant for the frame type used in that local ecosystem. If the available core personnel is adept at CIS-RC walls, then CIS-RC wall would mostly be used. Otherwise, elementized RC walls were used. CIS-RC walls were seen as more challenging for the tradespeople to construct, requiring adaptability, on-the-spot problem solving and generally a broader set of practical skills. RC Elements were said to be simpler for tradespeople because of clear division of labour among ecosystem participants like the element producer factory-work and the frame crew's on-site installation. Also, more emphasis is placed on standardization and advance design of the application of the elements in elementized construction ecosystems, which helps the professionals on the field.

This differential in personnel was depicted by the interviewees as cultures of construction that differed from locale to locale. Usually either CIS-RC walls or elementized RC walls are prevalent in each area. Some contractors do have in-house CIS-RC crews or use some specialized subcontractors that could built CIS-RC frames even if RC element walls were used by most other companies in that area. Additionally, a contractor that usually used CIS-RC walls in some area could sometimes also use RC element walls if they had no CIS-RC crews available for the project. Notwithstanding the local trends, floor constructions were more flexibly used; both CIS-RC slab floors and hollow core RC slab floors were used in all locations, and it was often said that even the same construction firm could use either one or the other in any location, but again depending on the frame crews available for each project.

It seems not necessarily the individual main contractor firms that intentionally uphold the sociotechnical regime. The interviewees implied that contract managers would not so much actively guide to using a specific type of frame by influencing or investing in the skills of the construction personnel. Even if they would do that, it was communicated that personnel mobility in construction is high making it expensive to retain the tangible investments into their skills. Rather, the interviewees portrayed the skill/cultural effect to frame type choice in such ways that it could be interpreted as a passive effect: the skills and experience of the personnel that happen to currently be available, in-house personnel or subcontractors, determine to a large extent the frame type that is cost effective to build. The availability of personnel depends on many situational factors that are outside of the contract manager's and even the whole construction firm's control. These issues are likely controlled by the organizations in a general sense: project scheduling, HR (hiring, training, incentives), frame choice policies, subcontracting practises, industry- and political influence, strategic choices, product focus etc. But, due to a huge number of other factors that lead to unpredictability in project schedules, it seems unlikely that the skills of a particular contract's construction personnel can be actively chosen.

Also in the construction industry, there are likely many reasons external to individual firms for why the locally predominant skills and cultures of the trade are such as they are. So, in addition to general preferences and choices actively made by the industry itself, the environment in which the industry operates would seem important to consider. Barely anyone interviewed for this thesis could give any answer for where the cultures have come from, or how have they formed. There were some thoughts, though, for what things set apart the locations with different construction cultures. These may be hints for why these cultures have formed such as they are right now. The thematic map in Figure 20 depicts the possible reasons for the differences in construction cultures, as uncovered from the interviews.

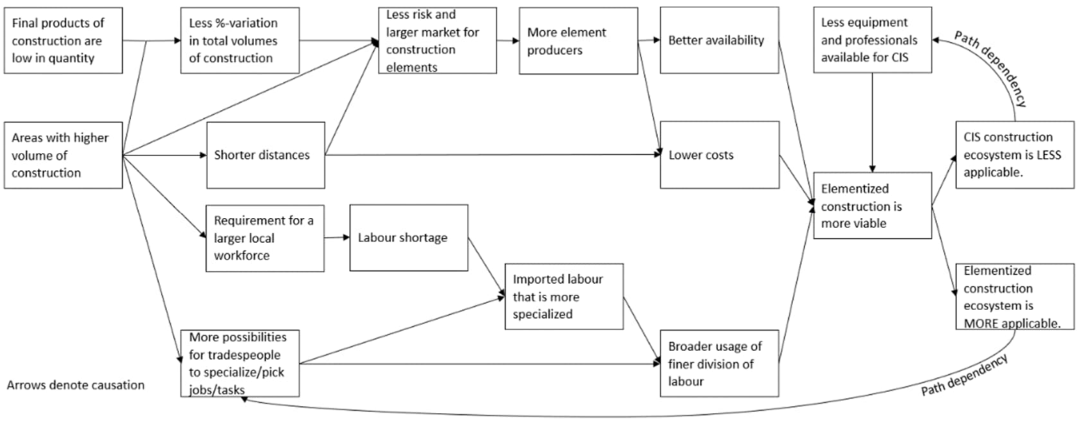


Figure 20: Per the interviewees, how different construction ecosystems were said to have emerged.

The first difference, and possibly the root cause for differences as well, is the fact that the intensity of construction differs geographically. Generally, in Finland, construction is more intense in Southern (and Western) Finland around centres of population growth and therefore the construction ecosystems can and must employ more people there than more north (or east) in Finland. The intensity has been so high in fact, that the interviews indicated a clear shortage of locally available qualified tradespeople. Some informants thought that because construction is seen as a more traditional industry, careers there have been less attractive for people than it used to be. This may explain why some main contractors' representatives operating in lower demand areas said skilled labour is in short supply as well. Three interviewees said that in the future, availability of experienced workforce will be a significant driver for the uptake of elementized construction, no matter the currently prevalent construction culture in all geographies, as it is easier to train people to the elementized construction ecosystem than to the on-site fabrication ecosystem. Labour efficiency was also said to be higher in factory production than on the construction site by some informants.

Some interviewees said that it has been normal to import labour to southern Finland from abroad to fill these increased manpower needs. This is the second factor given that sets some areas apart from others. Besides, importing work force seems less feasible the further up north construction sites are considered. Corroborating the Human Resource problem, an interviewee had experienced that personnel are becoming less and less keen to travel to construction sites that are not in the area of their domicile. It was also said that the labour from abroad was more specialized and more suitable for RC element construction that CIS construction. This is likely one reason why elementized construction is less feasible in the North, where the focal companies rely on the system strategies to keep labour in the ecosystem.

Stemming from the difference in volumes of construction and exemplified by the orientation of imported work force is the third difference between geographical areas in Finland: rates of specialization of the tradespeople. A few interviewees brought up that just the higher rates of construction activity in the South alone would enable the tradespeople to pick their jobs and focus their competency more precisely. The professionals can earn more by specializing, thanks to the piecework rates usually used in contracts. In northern Finland it is harder for specialized tradespeople to find enough work to live off just a narrow set of tasks. A problem finding specialized subcontractors there was indeed communicated by two interviewees, indicating that greatly increasing outsourcing might not be possible there.

Exemplifying the divergent rates of specialisation, one interviewee said that up to five times more personnel carry out work in their sites in southern Finland than in sites in northern Finland. Some others also referred to the fact that in some locales it is common to splice the subcontracts into smaller pieces than others. In Oulu, for example, it was said to be usual that the same frame crew performs the work for rebar, formwork, casting and even some detail designs of walls and floors, even the foundations, the timber perimeter walls from square one to finished walls, the lightweight dividing walls, they install the doors, windows and sills, and build or install the roof structures. In many elementized construction ecosystems in the South, all these parts of the building are built by different people and firms, often even further split between multiple complementaries, one of which prefabricates the elements and another one that installs them. Some of the largest construction companies seemed to make an exception in south and would execute their buildings more like the northern way, with in-house-employed frame crew. Unlike the smaller construction companies, the larger ones likely have enough capital and continuation of projects for the system strategy.

Benefit of specialization for elementized construction is one way in which the elementized construction culture and ecosystem is automatically reinforcing itself. Elementized construction inherently splits the fabrication and installation, which makes it a perfect fit for the opportunities for a finer distribution of work task between a larger variety of specialist complementors. Perhaps as a result from asymmetry of specialization, the local availability of RC elements was one clear differentiator between local ecosystems (cf. The Element Availability Problem). The final difference between construction cultures was the availability of proper formwork equipment for CIS work. It was said that in some areas, contractors either maintained their own specialized formwork equipment or they were better available for lease from complementor firms. In other areas, worse availability of specialized casting formwork meant higher barriers for expansion of the on-site fabrication ecosystem.

The last but not least finding relating to the Human Resource Problem is the challenge that the novelty of TMC poses also personnel-wise. One interviewee said that with RC elements, they could use something like 70 viable frame crew subcontractors in the traditional elementized ecosystem, but for TMC it is only about a tenth of that. The limited availability of skilled TMC builder crews may slow down the wide-scale adoption of TMC significantly. In addition, it was said that the if one was to aim to increase their usage of TMC, the initial TMC projects should be outsourced to more experienced crews and used as a learning opportunity for own crews to help with a transition to TMC. But, the tones of most interviews regarding TMC were quite uninterested. Learning TMC could be hard to pull off, like interviewee #9 said: “A concrete guy cannot really be turned into a timber guy.”

It is clear that the site-bound nature of construction is having significant effects to both the construction products and the construction ecosystems not only in general sense, but even more so locale-specifically. The labour shortage thus seems to affect the whole country’s multi-residential construction industry. Therefore, even for traditional RC construction, the sociotechnical regime was communicated more like a restriction or a problem, rather than a policy or a strategic or operational choice. From the point of view of TMC, personnel skills form a new problem: how to build timber frames if there are only a tiny number of skilled frame crews in the whole country, let alone locally? The dependence of frame type choice on availability of skilled personnel might thus be aptly called the Human Resource Problem in relation to RC construction, but especially for TMC.

As a final issue regarding human resources, the shortage of building designers for TMC should be brought up. This was cited by a couple interviewees to be a significant barrier for increasing the uptake of TMC. Other than mentioning it, this issue was not discussed much in the interviews. Perhaps this is because the design professions are not too familiar among the main contractors, but it is also likely that those professions are not under the influence of the same constraints and influences that drive the Human Resource Problem for the construction site personnel. A few interviewees even said that, even for RC construction, the designers of today feel out-of-touch from the actual construction activity. This may hint that the shortage of designers may be at least partly due to different reasons than the Human Resource Problem for the site-crews. Nonetheless, design is an integral part of the construction ecosystem, the deficiencies of which certainly seem an important issue to study and solve further.

To conclude the findings for the Human Resource Problem, there is a long road ahead to bring construction professionals' experience in TMC up to par with RC construction. It seems though that trends that have been set in motion a long time ago in traditional RC construction ecosystems, which may help TMC in accommodating the professionals in the construction site and the factory into using it. Elementized construction and prefabrication bring division of labour further along and are an answer to the worsening shortage of skilled labour brought forward by the interviewees. So, although the learning curve for producing timber structures from start to finish is huge for an industry familiar with RC construction, the curve can be split to a larger number of small curves that are much easier for individuals to conquer.

4.7 The Element Availability Problem

Issues related to element availability were brought up by many interviewees. Themes like long lead times, high transportation costs, cost- and lead-time fluctuations reoccurred in multiple interviews. These themes comprise the **Element Availability Problem**: the varying availability of building elements due to geography and market fluctuations was seen as a determinant for the commercial viability of elementized construction, including TMC. In addition to the previous section's Human Resource Problem, logistics costs and bad local availability of building element supply were reasons why elementized construction was not used by some of the main contractors.

It was said by most interviewees that the choice of element construction must be done in early stages of the project , which has been recognized as a factor influencing frame type choice in previous literature as well (e.g. (Segerstedt & Olofsson, 2010)). Due to changes in market condition, the lead time and cost of the elements may change significantly before the orders can be placed for elements. Transportation costs of elements are significant due to the high mass of the RC elements and limits to transportation dimensions and tonnages. So, in each local construction ecosystem, the feasibility of element construction depends on local availability of elements. This is a problem even in the mature industry of RC element construction, so even if TMC supply was similar to RC element supply, the problem could still be relevant. Lower mass of timber likely negates some of this problem, though.

Talking about market fluctuations, the element prices may fluctuate more than raw material and labour for on-site fabrication along with the general economic trends. First, the quoted prices of elements could be changed just because demand fluctuates. If order books are full, element producers could afford to offer higher prices for the future. One interviewee said that if the element production is in-house with the construction company, the market fluctuations do not manifest as significantly higher element costs. It is likely that if the raw material costs increase for the element producers, then along the lines of the Markup Problem, they may also increase their risk premium in anticipation of a downturn in the construction industry. If the elements would be utilized by the element producer itself, they would not have to worry about controlling the demand for the elements. Instead, they just need to cover the material cost fluctuations.

The lead times of elements may also fluctuate significantly due to the market condition. All of these effects seem negligible when CIS structures are in question. For elementized construction, lead times were said by many interviewees to affect the choice of frame type if elementized construction was the default choice in the local ecosystem.

Likely to counteract the demand fluctuation problem, element producers seem to utilize time buffering, e.g. long lead times, e.g. long order logs (Hopp & Spearman, 2011). According to the interviews, RC elements are sold for projects about six months forwards, but depending on the volumes of total construction, the order books can be as short as a few months or as long as a year, as an example. The long orderbook helps the element producers buffer the possible delays and cancellations of projects, by giving them time to resell the slot from the order book or reschedule other elements' production. Based on the interviews, CIS-RC construction seems to have trivial lead times for the materials used in the site-fabrication. This would not be surprising because the supplies are of a lower level of refinement, i.e. generic raw materials like rebar and concrete ingredients, that have much larger and stable market than concrete building elements have (all RC elements also use the same ingredients after all). Therefore, the CIS-RC construction material suppliers do not need time buffers as large as element producers.

Timber elements were communicated by the interviewees to have even longer lead times and more price and availability fluctuation, due to lower demand and lack of standardization. Voluminous TMC elements with high degree of prefabrication were said to have lead times up to a year. In these modules, the long lead times affected a larger share of the project. Interior cladding, fixturing and equipment were also said to be required to also be chosen early in the project.

Long lead times of elements are challenging to main contractors, especially the ones that are used to CIS-RC construction, for a few reasons. First, a few interviewees said that the hardest part of choosing a frame type is trying to predict what the market will be like a year from now, when the elements are ordered. Even if element lead times are six months, the choice of element construction vs on-site construction is one of the first decisions for the project that happen much earlier in the concept design phase. The frame type determines the design of the building and the resourcing for the project. The cost of element construction may change dramatically before the final order is placed, thus significantly affecting the chances of success for the project. Secondly, it was said that CIS-RC ecosystems are used to “design-as-they-go”, where they can make changes to the design to satisfy apartment buyers wishes even as the building is built. Long lead times make this kind of flexibility challenging.

Concerns of element availability are pronounced for TMC because the elements from different producers are not harmonized, and because there are fewer producers in total. Each timber element producers’ own frame type effectively has to do more work to convince builder of the availability of their products and build up a client base/market for itself. All RC element producers supply more or less the same client base, so the worries that builder may have on availability are diminished greatly, although still not completely.

In the previous section we saw how prefabrication or factory production could be beneficial for solving the Human Resource Problem. Now we can see that it also brings in challenges for the future in terms of element availability. Unless timber element production can somehow become larger scale than RC element production or as widely distributed as cement and concrete aggregate production or as sawmills are, lead times, market fluctuations, and transportation costs likely will become limiting factors in their commercial viability like they are in RC element construction. Even though the small mass of timber elements gives it an advantage in transportation costs, the advantage can be quickly lost if the majority of transported volume is empty space within prefabricated voluminous elements. Like one interviewee aptly put it: “In the worst case we take the bathroom module from Forssa to Kuhmo by truck, then install it into a voluminous timber module there, and then drive it back to Tampere to be installed in place on the construction site.” It is not only financially wasteful, also the environmental benefits of using timber frames can quickly be diminished in this kind of a rally. Long term, business development will likely continue to suffer from the availability problem even if TMC acquires such scale as RC elements currently do. So, apart from increasing scale of TMC production, innovative solutions for the availability problem could boost short term competitiveness and also be a source for long term competitive advantage in future TMC ecosystems.

4.8 The Incompatibility Problem

A challenge often communicated by the interviewees was that using a timber frame in a multi-storey residential project requires intense collaboration with a timber element provider. The element provider must be locked in for the project already in the beginning stages (see also: (Segerstedt & Olofsson, 2010)). This procedure is incompatible with main contractor firms that are used to act in latent ecosystems where dozens of co-specialized participant-firms who can design, deliver, and apply a commoditized means of production. This is the **Incompatibility Problem**.

Traditionally, the main contractor-led project execution is fitted to standardized construction methods with either CIS-RC or elementized RC ecosystems. Thanks to wide usage of standardized solutions, in these ecosystems, dozens of specialized firms can either design, produce or install the same product with corresponding levels of quality. Because the products and methods are familiar to everyone, the element producers do not have to be involved with the design or execution of the frame, designers can focus on delivering the design, and frame crews on erecting the frame. Approximate project sequences for CIS-, elementized RC, and TMC, based on the interviewees' verbal descriptions, are shown in Figure 21 below.

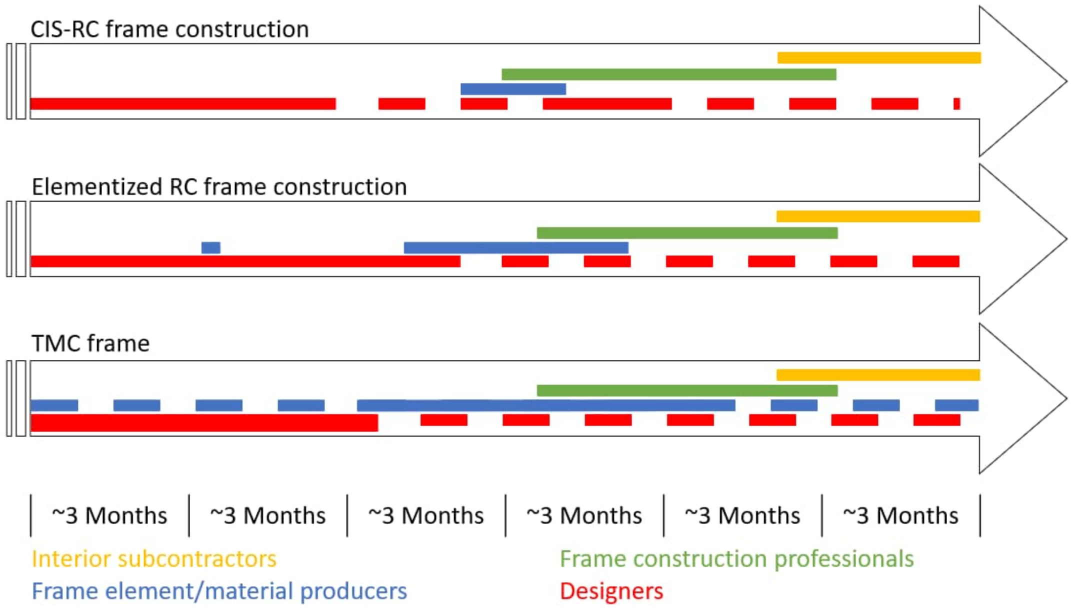


Figure 21: Estimates of frame-types' construction sequences' differences.

The main contractor usually chooses CIS or elementized RC based on preliminary price- and lead time inquiries from some suppliers, although often default choices-, that are ecosystem-specific-, are picked by the interviewees. Building design, handled by one of many separate design firms, is continued based on that choice. The design firms also know what kind of structural units can be produced and how to apply them in the designs. After months of design work, the main contractors will either order materials for CIS construction or tender multiple element providers for the delivery of the planned allotment of standardized elements. They also separately request for quotations from local frame crews for erecting the frame, or some may use in-house frame crews. The chosen element provider will produce the elements that will be delivered to the construction site close to when needed. The chosen frame crew will then erect the frame under the general supervision of the main contractor. The main contractor is to manage all these specialized separate pieces.

Early lock-in of timber element provider is due to almost every timber element provider having different element typologies and details, highlighted by many interviewees. So, it is impossible to design a TMC project with a generic timber frame and tender the element providers later; it is certain that no-one can offer that generic timber frame, so the design would have to be revamped. This can happen for example in single-contract DBB arrangements where the owner-client designs the building first, and then the main contractor is to tender the element suppliers, as couple of the informants said. This kind of a contract arrangement for TMC easily brings lots of redundant design work, but still seems to be an issue in the minds of some main contractors. The only practical way to choose the element producer was said to be to do it before designing the building. Then, the building can be attempted to be designed according to the chosen frame system. But designers that are proficient in novel TMC, let alone the specific frame system, are scarce, and the element providers themselves were said to not always have appropriate designers. Therefore, the design must be made in collaboration with the element producer.

The lack of proficiency in managing TMC was brought out by the main contractors as well. Even for traditional RC construction, many main contractors saw that it is imperative for them to strongly guide the outsourced design process of the buildings they will build. This helps the design firms realise designs that are cost effective to be constructed. The main contractors view was that they were the most competent ones to evaluate the "buildability" of a design and thus the ones who should make the design decisions that affect the buildability. So, it seems that many contractors indeed have an organization and business processes built to accommodate this kind of design and management expertise. But all that capability goes to naught when TMC is in question due to inexperience in guiding TMC projects.

Also, as came clear from the Availability Problem, elementized construction, especially timber elements and elements with high degrees of prefabrication, have long lead times. This poses a challenge to the main contractors that are used to on-site fabrication. On-site builders are used to designing the buildings "as they go", which gives a lot of flexibility in the timing of the design and for modifications during execution. This is seen as an advantage of CIS construction by some interviewees. For elementized RC construction, the element design must be completed much earlier, so the element producer has time to manufacture them. Prefabricated elements and some atypical RC elements require even more advance planning, because the project-specific materials must also be procured by/to the factory in time. Most TMC elements are still “atypical” and often far prefabricated, so they could have even longer lead times than RC-elements, thus being also problematic for RC element builders that are used to long lead times.

It is clear that TMC is currently incompatible with the main contractors used to doing business in the traditional ecosystems. Based on the literature and commonly held views, this is the number one problem standing in the way of TMC becoming mainstream in large scale, and The Element Availability Problem seems mainly thought of the root cause of the incompatibility. The argument goes that if there were more timber element producers and their products were harmonized, TMC would fit the latent ecosystem and the main contractors’ businesses would not have to adapt to intense collaboration with the timber element producers. This view is strongly supported by the interviews of this thesis. Should this view be challenged? In plain English, perhaps TMC adoption is more about the construction industry adapting to it, rather than adapting TMC to the traditions of the construction industry. This will be considered in the Implications-section of this thesis.

4.9 The Innovation Problem

Like said in the background literature, the construction industry is not so innovative and has stagnated in their productivity (Forbes & Ahmed, 2020; Ahonen, et al., 2020). Even though the products and materials used in construction have improved thanks to their traditional manufacturing underpinnings, the actual task of constructing buildings on the construction site are mostly based on traditional methods. Furthermore, the industry is said to exhibit strong path-dependency, focusing on risk mitigation by utilizing predictable, tried-and-true methods due to trust that the constructed products must garner. Here, this issue is elaborate on based on the interviews. **The Innovation Problem** based on the interviews for this thesis is formulated as: main contractors have little motivation to develop new frame types like would be needed in TMC, and rather, trying new methods for this critical building system undermines the benefits they can reap from expertise in tried-and-true solutions.

Most interviewed subjects did not see innovation or research and development activities as important, especially regarding frame construction. Most thought that traditional CIS-RC or elementized RC frame types fill all the needs of the contractors. It was seen that there is not much you could do to improve on long-standing best practises of the tried-and-true RC solutions. RC-construction was seen as the ideal way to build: simple, robust, predictable, inexpensive. Most main contractor representatives thought that MEP is the area of construction where innovation mostly happens. Many mentioned that continuous incremental improvements happen in an ad hoc manner in all stages of the construction process, but only a couple of the informants explicitly stressed the importance of decreasing waste and increasing efficiency of construction activities. This is surprising since Lean-methods have for long been recognized as a potent cure for the bad productivity in the construction industry (Koskela, 1992).

It tended to be the same few informants who highlighted bad productivity that also thought that there is a dire need to also improve the current frame construction methods. They saw that standardization and industrialization could achieve large benefits in construction. Most of them said that the improvements are best achieved by prefabrication specifically. But all this leads to a conundrum: if the majority of the people working in multi-residential construction thinks that there is no need to improve the frame, and only a few think that prefabrication specifically is needed, how could the industry be motivated to move to TMC for which prefabrication is one of the main benefits? Maybe the problem is that not enough professionals in industry are aware of the possibilities of productivity improvements and alternative solutions. It could be that path dependency shows its head here too. Professionals in the construction industry may not have experience from outside the industry and have thus become siloed not thinking about how elsewhere production may be done differently that could also benefit the construction industry.

It seems unlikely that the most traditional construction companies would take TMC seriously, as it does not complement their long existing competencies and competitive advantages. It seems like RC frames are all that they need. It could be that only the development of their own TMC building system is conceptually concordant with their existing vertically integrated businesses with high degree of direct control on the construction processes. But serious productivity increases in that space also seem unlikely because the long-lasting relative stagnation in the construction industry. It will likely require a more agile player that is willing to take the risk of renewal.

4.10 The Risk Problem

Construction is inherently risky due to the high social responsibility it carries (Nam & Tatum 1989). Some of these risks manifest themselves during the project delivery-stage of the construction and some in the usage-stage of the building. A few of the issues related to both of these stages' risks are covered in sections of this thesis that cover other problems. Those are only briefly mentioned here. Other risks that are not covered elsewhere in this thesis but came up in the interviews are laid out in more detail herein. Then an attempt to synthetise the findings to a more coherent understanding about the entirety of the **Risk Problem** is presented, which can be summarized as the outsized effect that unpredictability of applying novel construction methods like TMC have on construction project's risks.

It was said for the Markup Problem that for the main contractor, the absolute risk premium stays in line with the overall responsibility they must carry for the construction project even if a timber frame is contracted separately from the main contract. Then, it was noted there that builder vendor projects are riskier due to long-term judicial responsibility, which drives the main contractor to use conventional and safe frame types rather than novel ones. The whims of local building inspectors could pose a risk to construction costs as well, as brought up for the Regulation Problem. Also, market fluctuation risks were recognized as inherent in all current elementized construction ecosystems. Relating to the Human Resource Problem, it was also noted that traditional elementized construction is easier than CIS construction, which makes it more predictable and actually lessens the risks compared to on-site fabrication. But it was said there are only few frame construction professionals that could be depended on in TMC, bringing additional risk in its adoption.

It was common for the interviewees to express uncertainty and doubt towards long term performance of large-scale timber construction. It seems like fire protection does not cause as significant worries as general robustness does. The most highlighted concerns were long term durability and resilience to- and recovering from- accidents like water leakages. Fragility could risk high maintenance costs, especially for timber façades exposed to the weather. There were other doubts related to prefabricated construction that were not only specific to TMC. One interviewee brought up a concern about renovating or remodelling bathroom modules. Because bathroom modules have not been used for long, it has not become clear yet to them if the modules can be remodelled with sensible expenses if a homeowner would like to do that.

The common trend among most above-mentioned risks is the lack of experience and long-term examples from TMC buildings or buildings that use prefabrication. Examples would help show if these novel methods would maintain performance long-term and how to deal with possible issues. Mistakes and inadequate performance allowed by inexperience can lead to large financial impairments to the contractor. Especially builder vendor projects are sensitive to risks, which should be noted as it seems to be the most prominent housing construction project type according to the interviews (cf. Table 3). Many interviewees thought that timber frames were seen as riskier by clients and residents as well due to the same reasons: predictable, worry-free living is highly valued.

Hybrid structural members and hybrid construction, where different frame construction methods are combined in the frame, were seen both as a part-solution to the Risk Problem, but also as a further uncertainty that corroborates the Risk Problem. Using concrete to fill the critical requirements for durable, long-lived fire-resistant load-bearing structures and using more timber in less demanding parts of the building were seen by some interviewees as a more feasible way to increase usage of timber in multi-storey buildings. Hybrid construction could also avoid some of the more complicated details and layered structures that are needed in pure timber frames to achieve necessary sound- and vibration insulation. But much like with purely timber frames and structural members, most of the interviewees did not have experience or extensive knowledge about hybrid construction. Therefore, the existing latent construction ecosystems seem almost equally unfit for hybrid frames as for pure timber frames. The only exception could be the on-site construction ecosystem in Northern Finland, where non-load bearing LWTF perimeter walls were predominately used together with a CIS-RC load-bearing frame. The use of LWTF perimeter walls instead of RC sandwich walls were said to fit the ecosystem where there was little supply and competition in the local RC element market, as per the The Element Availability Problem. So, the reason to use hybrid construction in the North was not a technical one; it was due to the Human Resource Problem and the Element Availability Problem.

The example from the North shows that hybrid structures, especially prefabricated ones, face almost all the same problems as purely timber frames do. Higher costs and markups, regulatory upheavals, experience of the construction crew, element availability, project planning, path dependency, typology and modifiability problems must be considered in using hybrid as well. It seems like it is mostly the risk from applying unfamiliar materials in critical locations of the frame that could be lowered by using hybrid construction. Still, concerns were raised by interviewees that more complex combinations of different materials and features in structures leads to harder to control quality and unexpected issues. Many informants touted the simplicity of RC as a virtue, and some explicitly said that even simpler materials and construction methods should be favoured. Simplicity was said to leave less room for mistakes, to waste fewer natural resources and their performance is predicted more reliably. Complexity and fragility were indicated by some interviewees as a major downside of LWTFs, as an example. In effect, hybrid elements at least partly deal with the doubts toward fragility of purely timber frames, but new doubts on added complexity must then be addressed.

A risk brought forward by many interviewees was the timber frames' vulnerability to weather. Although they said the weather can be a problem in RC construction (water ingress to hollow core slabs, freezing of castings), quality control is seen adequate means to manage that. In timber frames, an integrated weather shelter may always be needed, as few interviewees expressed bad experiences with simple tarp-protection, especially in high-rises. The main concern of the interviewees seemed not be the damage that weather could cause to the building, but the delays that weather and weather protection can inflict on the project schedule. This may reflect their own experiences that may cover more nuisance from the weather cover than the weather itself. In any case, the risk and worries of schedule slippage are real and may be significant. Currently, TMC seems much more sensitive to rainfall and wind disturbances than RC construction. Low mass of timber elements is a disadvantage in windy conditions. On weather disruptions in a project where the integrated weather cover had to be opened for crane-work, an interviewee said they had to wait a full week for better weather so they could continue the installation, during which a frame of a complete floor level could have been constructed.

Some interviewees brought out effects that TMC and elementized construction have to decrease the risks relating to the project. It was said that element construction is generally safer than on-site construction: less need to climbing that may lead to falling, less need for fall protection and less people, equipment and activity in the construction site means smaller safety risks, even though rapid lifting of large and heavy elements does increase impact risks. The integrated weather shelters offer better controlled and more pleasant working conditions, which is also a benefit that timber frames itself give compared to RC frames, due to less dust and less noise hazards, for example. Additionally, the use of sprinklers decreases the fatality rate in building fires, which is a lower risk that applies to all timber-framed multi-storey buildings in Finland due to sprinkler requirements.

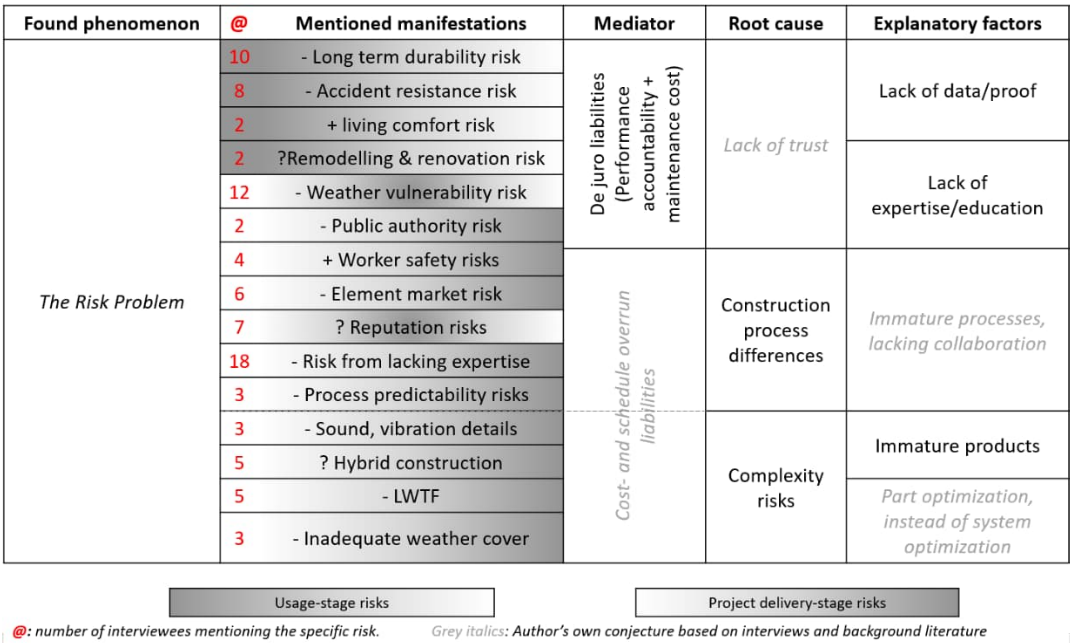


Figure 22: Found issues related to the Risk Problem

A few interviewees brought out additional risk reductions related to elementized construction. At least in the traditional RC construction ecosystems, elementized construction schedules and costs are easier to predict: material costs are locked in early and there is usually less need for fixing and adjusting the structures as there is in CIS construction. Informant #5 said “It is more important to improve predictability of costs than to try to achieve absolutely minimum costs.” It is debatable how large the benefit of predictability from locked costs for elements is however, because the Element Availability Problem showed us the cost and lead time of the elements can change more than CIS costs between the time a decision about elementized frame is made and when the order for the elements is booked. Figure 22 assembles all the mentioned manifestations of risks that were raised by the interviewees for TMC, and relates them to likely causes and mediators.

To conclude the Risk Problem, novelty of TMC means there is little data or proof for how timber framed multi-storey buildings will hold up in the long term. Construction processes have not been refined either, especially traditional (sub)contractors have little to no experience with TMC, which makes the projects hard to plan and predict. TMC is also often seen as more complicated way to construct multi-storey buildings, which further deters contractors from taking the risk of using new methods. Due to extensive contractual and judicial responsibilities, the impact of these concerns is magnified: possibility of large financial burden amplify the risks. And no wonder, since costliness is a fundamental characteristic that sets construction apart from most other industries (Nam & Tatum, 1988).

4.11 The Element Typology Problem

Many issues related to the geometrical properties of construction elements were mentioned by the interviewees. All of these could be thought of as technical problems that lead to lower applicability of specific frame types in specific contexts. These issue as a whole fall under the **Element Typology Problem**: limitations in variety and features of the products that element producers and the ecosystem can provide decrease the commercial viability of prefabrication. To compete with applicability of traditional methods, element typologies from design to installation and to possible remodelling in the far future must be aligned.

The most often mentioned issue related to prefabrication stemmed from the façade directives coming from city planning, as was mentioned in the section about the Regulation Problem. This is a simple one to understand, but seems a significant challenge in RC element construction. It was said by the interviewees that among the most difficulties and extra costs arise from the façade directives set by municipalities. RC element construction seems not apt to cover these directives. Many different types of cladding can be required, but the commonality between all of these is that the seams between the elements should not be visible. The interviewees said that usually prefabricated facades cannot achieve the most common requirements.

Related to facades, it was also mentioned by some interviewees that the shapes of roofs can also be defined in detail externally by the city plan and may exclude the use of some roof structures. Complex shapes are also slower to be built, which means in the RC frame construction case that the building will take longer to be covered from weather. A few informants mentioned that it would be efficient to use more prefabrication for the roofs, so that no matter the complexity of the roof, it could be lifted in place and sealed from water faster. Prebuilding the roof could be done concurrently with the rest of the frame, wherefore it would not extend the project schedule. As an example that some TMC projects have used, the roof could be prebuilt on site on the ground. This is also what some traditional construction ecosystems do for non-load bearing LWTF perimeter walls. Generally speaking, it seems like currently available elements or construction methods for roofs are not well-amenable to prefabrication of varying types of roofs.

Currently prevalent floor structures are CIS-RC slabs and hollow core RC element slabs. The advantage of the elements was said to be simple shaped buildings where the apartments are not too small. For a building full of small apartments, elementized hollow core RC floors consist of a large number of small pieces, which become laboursome to lift in place and be grouted. In large apartments however, each long slab can covers large spans, without the need to increase the thickness of the floor much. Conversely CIS floors need more rebar and become considerably thicker when they must cover longer spans, which becomes expensive. If apartments or the building perimeter are not shaped as right-angled, it was said that elements require additional cutting and fitting which may make elements too expensive compared to CIS floors. As opposed to floors, wall construction from RC elements was usually seen more flexible than CIS-RC walls. It was said that the massive, heated formwork for CIS may be too laboursome to install for small features, like short stump-walls, and in tight spaces. Elevator shafts and stairways were almost always elementized no matter the local ecosystem. So, depending on the typology of the elements in TMC, the frame type may be constrained in its commercial applicability to different types of buildings. This matters even for residential buildings, where sizes and shapes differ little compared to many other sectors of construction (source).

One issue raised by many for hollow core slab floors was that MEP could not be integrated in the structure as opposed to in CIS floors. This means that MEP installation cannot often be executed until the frame is partly completed, which elongates the project schedule. Also, conduits may need to be surface-installed and may also require separate fire protection. The often-quoted curing time disadvantage of CIS-RC construction was implied to be quite trivial by the interviewees. Hardly anyone mentioned it as a disadvantage. Heated formwork and overlapping casting sequence for adjacent floors was said to ensure that the frame is erected quickly, and interior work could be started as soon as the building envelope was closed, being no different in elementized RC- or TMC. Also, just like a weather cover allows faster interior work in TMC, the same applies for RC. But, these views may be affected by inexperience of TMC or other bias for RC. These are some downsides of currently widely used elementized products, which could be an opportunity for TMC product development. All these typology related issues may not be decisive in the choice of a frame type, but nonetheless do currently lead to additional challenges that increase costs.

In the future, an elementized construction system that can accommodate to these challenges will likely have a competitive advantage. It requires that the element typology is designed to be flexible or that the variety of elements is high enough to cover most use cases. The challenge will likely be creating designs, a manufacturing system and an ecosystem that can cost-effectively deliver such diversity. TMC offers the possibility for tighter tolerances than RC elements do (Kesik & Rosemary, 2021), so there is promise that timber frames as a product could technically answer to these challenges. But what should the ecosystem for delivering this product be like to make solving the Element Typology Problem commercially viable?

4.12 The Modifiability Problem

As the last theme of problems found relating to TMC adoption was another result of explorative probing in the interviews, not a pre-planned topic by the author. It was uncovered related to the topic of prefabricated modules as a frame solution for the apartments' bathrooms. Common to almost all interviews was a preference of builder vendor projects and focus on offering home buyers and retail investors personalized apartments as a value proposition. For bathroom modules and prefabricated construction in general, like TMC usually is, this brings up the **Modifiability Problem**: Currently, using extensive prefabrication limits the types of projects that are commercially viable due to significant extra costs that arise from variations and modifications in prefabricated elements.

The first issue brought up with regards to usage of bathroom modules by many interviewees was that the choice of using the modules, be it in otherwise elementized or CIS-RC building, must be made early in the beginning stages of the project (see also: (Segerstedt & Olofsson, 2010)). Each bathroom module producer was said to have developed their bathroom modules to be used in combination with a certain type of floor structure around and beneath the module. Also, through the core feature of integrated MEP in the modules, the orientation and placement of other rooms must be accommodated to the intakes and exhausts of the MEP conduits in the bathroom module. Therefore, many interviewees said that prefabrication leads to an inferior design philosophy: prefabricated elements drive the layout and design of the apartments, whereas in on-site construction, the layout and the design of the apartments can drive the fabrication. According to a couple of interviewees, this leads to a significant advantage on customizability and flexibility of design schedule for CIS-RC frames currently.

The same limitations of prefabrication seem to hold true for TMC as well. Especially the choice of whether voluminous elements are used must be made in the beginning of the building design due to extensive effects it has to what kind of structures are feasible and how the project is arranged. The section on the Incompatibility Problem explains the context for these choices. Direct effects of prefabrication , including timber elements, to the frame's modifiability are covered here.

The biggest communicated effect to the rest of the building comes from how the costs of the modules are constituted. Due to low piecewise production rates in building element factory production, lot-size increments in prefabrication become a significant determinant of the modules' production cost. The building should have as many bathrooms of the same kind as possible so that the contribution of startup- and stopping work, and changeover costs in the factory are minimized. One interviewee said that, in the context of an elementized RC construction ecosystem, five identical modules is the minimum lot-size from the cost standpoint compared to on-site fabrication. In CIS-RC construction ecosystems the Element Availability Problem is pronounced, which makes it likely that the minimum lot size is greatly increased, even so high that bathroom modules seem to be non-feasible in some of those ecosystems, according to the interviewees. The same effect of production lot-size applies for TMC as well; elementized timber frames are more commercially viable in buildings where more repetition of identical elements is possible.

The above-mentioned issues constrain the types of buildings that are commercially viable to be built as prefabricated compared to on-site construction. Generally speaking, elementized RC frames could be thought of as more constrained commercially than CIS-RC frames, bathroom modules more constrained than on-site fabricated bathrooms, timber frames more constrained than RC frames and voluminous elements more limiting than panel elements. This is exemplified by the commonly mentioned issue that bathroom modules are not used because they limit the types of apartments that are sensible to be built. This was also mentioned to hold to a lesser degree for element floors, as was covered in The Element Typology Problem-section of this thesis. As was mentioned for the Markup Problem, builder vendor projects are most profitable for main contractors and are seen by many informants to require end-user driven modifications Therefore, constrained building designs matter more for buildings aimed to be sold to homeowners than for rental apartments.

The buyers of the individual apartments, i.e. homeowners or private property investors, affect the frame choice in builder vendor projects in two ways. Most interviewees said that the main contractor more carefully evaluates what kind of apartments the buyers would want to buy to make it easier to sell them than in projects that are contracted by a separate owner-client. The separate client is usually a property investment company, real estate investment trust (REIT) or a public actor who all mostly lease/rent the apartments. In case of rental apartment buildings, many contractors said that the end users are not as demanding about the detailed features of the apartments. Likely the fact that tenants do not own the apartments also hampers their ability to influence the construction. The second effect is directly through the apartment buyers' negotiations with the main contractor. If the buyer is involved early enough, they can affect the layout and size of the apartment a lot. Many contractors communicated that it is important to offer the buyers this possibility to modifications, and thus may choose frame types that are more amenable to modifications to begin with.

A common thread related to the limitations of prefabricated frames throughout the interviews was that individual apartment buyers' chances to choose the layout of the apartment, and the surfaces or the equipment and the fixtures in and around the bathroom are greatly reduced. In addition, a large portion of the interior choices for the bathroom must be made months earlier than in on-site fabrication of the bathrooms. In practise, most apartment buyers are not involved early enough during the construction project that they could affect the bathroom modules at all, whereas in on-site construction, modifications on most features of apartment are possible up until the features are actually built. Many interviewees said that bathroom modules may make apartments harder to be sold because of that. Still, a smaller portion of informants said that this probably is a decisive limitation only in the highest trim-level apartments located in the most expensive areas of cities. For lower trim apartments, the cost of the apartment weighs more in the balance for apartment desirability, and modifiability weighs less. Therefore, it is also up to the strategic choices and distinctions in emphasis of the value propositions of construction companies that determine how suitable modular bathrooms are for the company's projects. Some companies focus more on rental apartments, others on owned apartments, some more on low costs, others more on higher valued apartments. As an example, one interviewee described how many RC frame construction methods, bathroom modules, and most TMC frame methods are not at all applicable to their product:

Translated: "We always fabricate bathrooms on site. (...) [Modular bathrooms] are not at all applicable to our apartment selling process. In practice, it would lead to a situation where the customer could not choose tiling for the bathroom and would not be able to do personal modifications to the extent that we would like to offer them. So, that is the main reason why haven't really even seriously considered those bathroom modules. (...) [Referring to RC construction:] We do have some exceptional features [in our apartments] (...) that other builders won't usually have. That is our signature demand to the element producers (...) We already know a bit from which [RC element] producers we can get them so we wouldn't have to [adapt sub-optimal elements]. (...) The first challenge [with TMC] was to find a frame system that would allow the realization of our [apartment concept]. (...) Then, a challenge was to find such a producer who can execute this concept of ours. (...) In practice, none of the voluminous timber element providers could offer the type of apartments we wanted to retail. (...) When we requested quotations from different [timber panel element] producers *based on specific architectural plans, we got very different quotations. They told us like 'this is the price, BUT the apartments should be like this, that, and this.' So there were long lists of 'buts'. That made it like challenging." (interviewee #5)*

Two interviewees highlighted the fact that modules are designed from the ground up and kept up-to-date by professionals. Professional designers were said to be better accommodated to the use possibilities of new materials, equipment, and technology, like line-wells, large tiling, wall toilets, in the modules, which can also be more challenging to install on the construction site compared to in a controlled factory environment. So, even though there is less possibilities for personalization, modules could offer higher quality. The small size of modules remain a fundamental limitation before element producers can offer a larger repertory, which was said to be really limited right now, and when logistics limitations can be unrestrained.

Based on the interviews, the above limitations do also hold for timber voluminous modules. A few informants communicated that the sizes of the timber volumetric elements strongly influence the commercially feasible sizes and shapes of the apartments as well. Thanks to the low mass of timber structures, volumetric timber-framed modules usually encompass the whole apartment. Therefore, an even larger portion of the apartment is prefabricated and harder to modify by the apartment buyers than with just bathroom modules; the design is locked-in in an early stage of the project. Modules can be combined to build a larger apartment, but then more distinct module types are needed which decreases scale benefits, and the installation and weather protection is likely more complicated. Modules can also be left unfinished in the factory, which allows the residents to choose the surfaces and equipment for the apartment, but the cost, speed, and quality advantages of prefabrication is then mostly lost.

To sum up, commonly mentioned issues that constitute the Modifiability Problem for prefabricated construction and TMC were covered here. It seems that TMC faces the same challenges as bathroom modules do. Therefore, understanding the challenges with bathroom modules could be useful for improving the TMC value proposition. Based on the issues covered here, prefabrication seems to currently be commercially applicable to a limited extent. First, the economics and typological constraints (small module-type repertories) of prefabricated elements are reasons for why the use of bathroom modules and volumetric timber modules in residential buildings is mostly limited to buildings that have a large number of small apartments. Larger buildings help achieve economies of scale. Bathrooms modules seem to be available only for small bathrooms, and volumetric timber elements are most beneficial for studio apartments where the element encompass the whole apartment. Secondly, there seems to be a niche where prefabrication can provide additional value that is not only based on efficiency of their fabrication: high quality, smaller apartments with highly efficient layouts that take advantage of the possibility to integrate some special features to the modules. Third, direct influence from the end-users to their apartments is at least currently greatly restricted in prefabricated construction. The limited modifiability makes their use less viable in builder vendor projects as it is likely to make the apartments harder to be sold.

5 Implications: a reason to reorganize?

The problems described in previous main section clearly answer to the goal of the thesis of understanding the challenges that main contractor firms face in adopting TMC. But how these findings could help in business- and product development is left mostly unanswered by the interviews. Still, there were some hints that point to a few alternative directions. These will be covered in the following, along with extensive contribution from the authors synthesis of all of the previous findings.

Most of the interviewees indicated that for TMC to become commercially competitive, there should be much more element suppliers, and common structural typologies and -details should be established. It has been said that industry-wide standards should be created that everyone could follow. This view coincides with using formal or informal regulations to mitigate the Element Availability Problem and the Element Typology Problem. In practise, timber element construction would be standardized and commoditized just like traditional RC elementized construction is. Then the traditional project arrangements and tendering practises could be used by project clients and main contractors. It would also be easier for them and designer firms to apply timber frames in multi-residential projects when the same solutions could be used in all projects. This kind of adaptation of TMC to the latent elementized construction ecosystem would indeed solve the Incompatibility Problem. The Demand Fluctuation problem would also be partly mitigated by separation of element production firms from element application firms and by creating common wider markets for standardized elements rather than fragmented markets for a wider range of proprietary timber element building systems. Finally, it would be easier to align all public authorities to the ecosystem and solving possible inconsistencies or biases in the regulations would have a wider mandate from the industry and society, which helps solve the Regulation Problem.

But a few ways that the sole focus on fitting TMC to the latent ecosystems falls short can be recognized. First, the interviews clearly brought out that even in the established elementized RC construction ecosystem, that could be taken as the goal post for TMC, some of the problems are still present. Depending on local construction ecosystems, the Markup-, Element Availability-, Human Resource-, Element Typology-, and Modifiability Problems hinder the use of elementized RC as well. The prevalence of preference on CIS-RC construction over elementized RC construction by main contractors, even in predominately elementized construction focused ecosystems, demonstrates this fact. It seems like some of the problems, like the Risk- and Modifiability Problems, are expected to be solved by themselves as time goes on, which will likely be the case thanks to gradual evolution and accumulation of experience. In fact, the second way that a focus on standardization and commoditization falls short is likely a lack of focus. It implies a seemingly passive grasp of problems by individual industry players: no-one seems to be responsible by themselves, but instead everyone is responsible together in moving towards a common building system. Third, the process of commoditization and the passivity of players in reaching the goal post of product harmonization between timber element producers likely mean a slow rate of development, as exemplified by the delayed realization of TMC adoption thus far. There is one last point that leads to question the sensibility of putting too much focus in accommodating timber element supply to the latent ecosystems' modes of operation as a solution to commercial viability of TMC. TMC offers the possibility of a paradigm shift in construction productivity through extensive prefabrication allowed by the low mass and the high fabrication precision of timber elements (Kesik & Rosemary, 2021). According to the Markup- and Incompatibility Problems, it may not be possible to utilize this possibility in existing ecosystems due to disruptions that prefabrication threatens for traditional roles.

As a supplement to standardization and commoditization of TMC, a new proactive TMC ecosystem development approach is outlined next in order to overcome the above shortfalls and to possibly help accelerate TMC adoption. Continuing with the ecosystem lens applied throughout this thesis, the literature on ecosystems provides a backbone for this new approach. Accordingly, this approach starts with a business-driven focus on solving the Incompatibility Problem by intentional strategic design of a new TMC ecosystem. Through new modes of co-operation, new solutions to the problems recognized in this thesis could be actively pursued, and the strengths of timber construction could be better capitalized on. Afterwards in another subsection, it will be elaborated why it might currently be important to divert more focus to adapting the multi-residential construction industry to timber construction by developing a new TMC ecosystem than adapting timber construction to the existing construction industry's modes of operation.

5.1 Ecosystem concept for proactive solving of TMC adoption problems

As said above, standardization and commoditization were seen as a long-term solution for commercial viability of TMC by the main contractor representatives interviewed of this thesis. As mentioned in the Markup- and Incompatibility Problem sections, five informants said though, that in the near term, the most sensible solution would be partnering up with a specific element producer for bidding for a DB contract. So, main contractors and element producers seem the key players in enabling TMC projects. It was said that then, right from the start of the project, the building design and project management could be accommodated to the specific element typology the producer can provide. Redundancies in project actualization would be reduced. It was not particularized though if they thought partnering would help in distributing margins and alleviating the Markup-, Incompatibility- or Risk problems. Project-by-project partnering is unlikely to allow for assimilation of the firms' operations, making curtailments to these problems doubtful. Also, due to the current situation where, with few exceptions, TMC is used only if subsidized or directed by the public authorities, the Markup Problem may be a non-problem to the majority who have no aspiration to use TMC otherwise.

Meanwhile, proactive firms interested in stirring up the competition and in the advantages timber construction may provide, could turn the short-term solution into a long-term solution. Two examples of companies that have integrated the two keystone roles were uncovered from the interviews. Both had vertically integrated the main contractor and the element producer roles into the same firm and gone further with aligning other frame construction ecosystem roles as well. These support the feasibility of the approach of adapting these two key roles with each other. Partnering up could be recognized as a possibility to immediately improve on the traditional contracting arrangements. If it is based on achieving mutual benefits from co-operation that continue throughout projects, the problems recognized for these players might be solved much faster than through standardization. This could also be the way forward toward a new kind of ecosystem, that is intentionally and strategically developed to fit the strengths that TMC can offer to construction. Long-term partnering could allow commercial viability also in market-priced projects, not only in projects subsidized by the government.

In any case, this hints us towards a new TMC ecosystem structure: the first bottleneck seems to be at the interface between main contractors and timber element producers. For a new TMC ecosystem concept, it therefore could make sense to build on those as the keystone roles and permanent ecosystem members. These two players also possess the core competencies needed for carrying out TMC projects: element producers are most acquainted with how to use the timber elements and main contractors are well versed in the management of construction projects in their entirety and in coordinating all the required players. The new concept is presented below in Figure 23. To resolve the Regulation Problem and ensure wide scale applicability of TMC in the long run, the public body should also be engaged persistently from the beginning. But since regulators are an unlikely role for spearheading business development and they must demonstrate impartiality toward individual businesses, the ecosystem cannot depend on those roles as keystones. Therefore, they are taken to be important permanent ecosystem participants along with the keystones. To provide a concept with minimal difference to latent construction ecosystems, all other frame construction stakeholders are left as temporary ecosystem participants, although they could also be permanent. Brief thoughts on how the keystone roles could interact by use of different ecosystem strategies and on solving the ten problems are provided in the following.

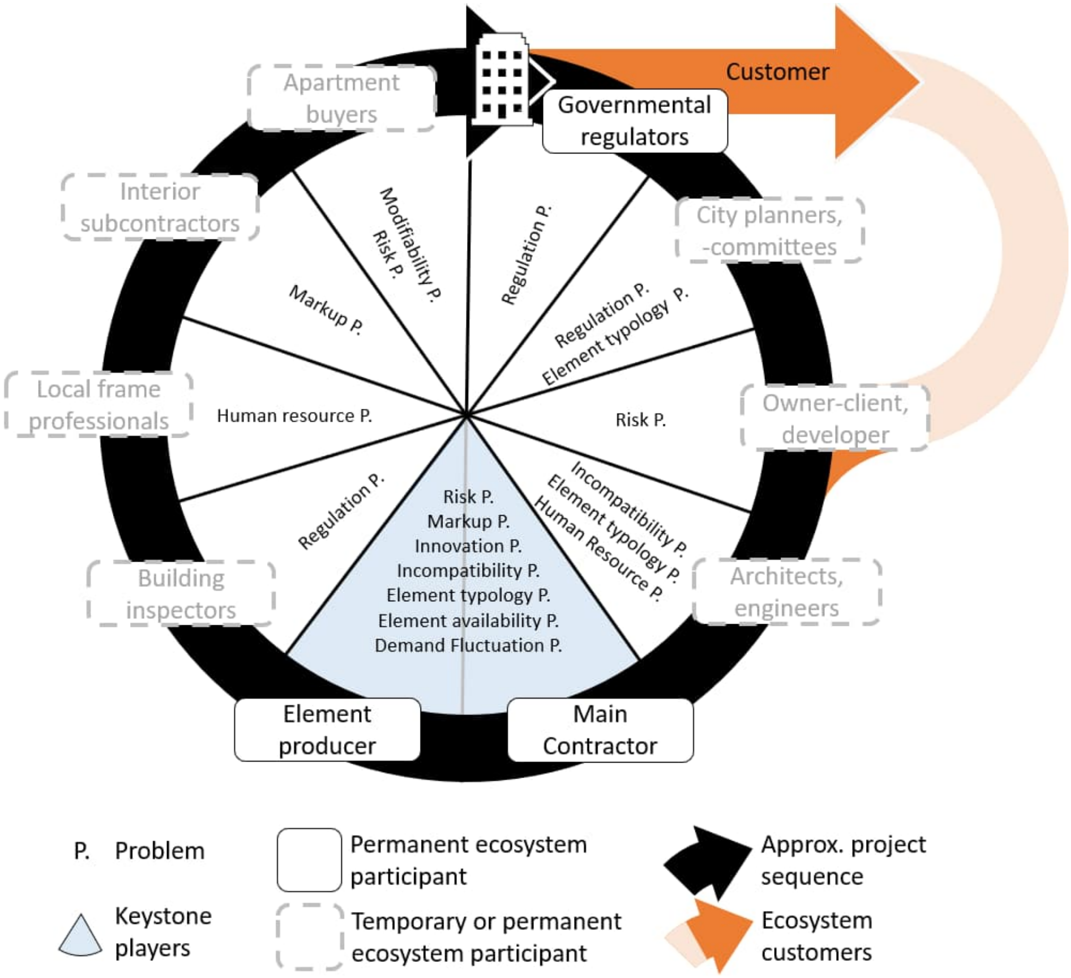


Figure 23: Concept for a new residential TMC ecosystem

Contrasting the proposed ecosystem concept to the traditional contracting arrangements presented in the background literature, two central ideas stand different: first, the concept ecosystem forms a recurring loop of project participation, as depicted by the arrow that denotes the project sequence. All ecosystem participants that are needed for realizing the novel TMC value proposition are involved in the recurring process of building delivery rather than project-based collaboration as in traditional contract arrangements. Even the temporary participants benefit from maturing of-, and co-evolving with the ecosystem. The buildings and the value provided to resident could also be enhanced by ecosystem benefits related to renovation and remodelling, as well as relocation services the ecosystem may offer to differentiate themselves. Furthermore, the governmental regulators and city planners should be considered as complementaries participating in every project. This way the effect of unfamiliarity to TMC of city planners could be diminished faster and the best practises of the TMC frame system could be transformed to provisions for the building code in due time. For example, "specialized"

TMC officials may be advocated for during the transition phase toward mainstream TMC, so that inconsistent and unproductive regulatory practises are limited and they can contribute to long term TMC development. Smaller municipalities may need governmental/regional support from locales where TMC is more prominent. Thus, the effect of the Regulation Problem may be diminished.

Second differentiator to the traditional project delivery methods is that some of the players involved with the ecosystem participate in every project. The governmental regulator is a unique complementor in that their role is a closed-off "monopoly", which means they should be involved in every project. In addition to filling the traditional roles, the keystone element producer and main contractor keep the ecosystem functioning by incentivising and coordinating all other players to participate in the ecosystem. As the TMC ecosystem matures and if other element producers and main contractor firms are allowed to join the ecosystem, the keystone firms could let the new participants to produce timber elements and manage the project while themselves remaining as ecosystem facilitators in those projects. As examples, the keystones can use standards, IP-rights, specifications, and formal contracts (Jacobides, et al., 2018) to do so.

Third, direction of contractual authority is not defined for the ecosystem and there is no one player in the centre that contracts with all other players. It will be up to the practise to decide how the ecosystem will be aligned, but bilateral contracting may not be the sole way to arrange the interactions in a effective new ecosystem. The partnering approach -type of team effort would likely include at least the keystone players, but also temporary ecosystem participants like the designer professions and the frame professionals. Modes of operation and ecosystem benefits could be agreed upon in that manner, but project-specific roles could be formalized in in the traditional manner by more familiar contracts.

5.1.1 System- and bottleneck strategies:

The keystone players' possible ecosystem strategies are covered in this section. There are two options for co-specializing the two keystone roles with each other: through vertical integration or long-term partnering, like hinted at above. Vertical integration would either mean a bottleneck strategy or a system strategy for the keystone players, whereas long-term partnering between an element producer and a main contractor firm represents component ecosystem strategies for both (Hannah & Eisenhardt, 2018). A system strategy would mean covering all or most of the ecosystem roles in one firm while bottleneck strategy limits the vertical integration to the keystone roles. Following the latter strategy would later lead the keystone to expand to the designer- or the frame construction crew roles as per the Human Resource Problem. A system strategy would capture all margins in one firm, making the Markup Problem obsolete, but it requires extensive resources and capabilities to pull off, as well as primary focus on capacity management (Hannah & Eisenhardt, 2018) to deal with the Demand Fluctuation Problem. Combining the supply for timber elements and labour with the demand for them under one firm is vulnerable to lows in construction demand, which was mentioned in the interviews as well. The problem could be amended with low fixed costs and by supplying elements (and labour) to competing contractors as well. The bottleneck strategy faces the same challenges but as less pronounced. It allows the firm to adapt to the challenges and increase vertical integration as their resources and capabilities build up, but meanwhile, it requires more effort for collaboration with separate ecosystem participants.

One of the firms that was said in the interviews to have developed a new ecosystem based on co-specialization of main contractor and element producer roles, seemed to utilize a bottleneck strategy in doing so. The company started as a main contractor with in-house field crew for frame construction. The firm quickly co-specialized with a specific timber element provider to apply that one frame system in all of their TMC projects. The frame construction crew grew proficient in that construction style, and later the main contractor started a subsidiary that would produce the timber elements for their projects from that point on. The next ecosystem bottleneck seemed to be building design, which was likely a natural expansion upstream from element design. For the interviewees that had experience from multiple TMC projects, finding proficient building designers seemed to be a topical issue. Even though the firm of the example brought building designers in-house, the Human Resource Problem was still said to be a nuisance. More recently, the firm was said to have shown interest in developing their own properties. After the frame crew, element production, and building design, this signals a possible next bottleneck at the client side as TMC ecosystems mature. Taking on builder vendor projects would mean tackling the Risk- and the Modifiability Problems head on.

Another example of a new TMC ecosystem based on integration of main contractor and element producer roles was brought up in the interviews. The keystone company vertically integrated these two key roles so they could control the majority of their prefabricated building process in-house. They also solved the Markup Problem of interior subcontractors by partnering up with multiple complementors from different regions where they operate, due to the immobility of construction products (Nam & Tatum, 1988). This allowed them to align the local subcontractors to the prefabricated process even as it left subcontractors with less work to do. An example of designer-driven system strategy is the StructureCraft Inc in Canada. The founders' design professions formed a strong foundation, on which the element production and main contracting business, together with on-site personnel, were developed (StructureCraft Builders Inc.; Fast + Epp). A designer-driven ecosystem could more easily solve the next likely ecosystem bottleneck of design capacity.

In principle, both the system strategy and the bottleneck strategy are simple solutions to the Markup-, Element Availability-, and Incompatibility problems: under the one roof of a single firm, they are mostly dealt with by fiat. Furthermore, one informant pointed out that with in-house element production, it is not necessary to consider market fluctuations in their pricing as long as raw material costs are covered. Logistics costs can be controlled by centralized planning. The Risk Problem is likely diminished by better understanding of the product and the construction process. Still, long term product testing, smaller scale pilot projects, comprehensive insurances and additional financial backing from third parties could be ways to combat this problem that also face the construction clients.

Human Resource Problem remains a challenge no matter if frame construction and design personnel are employed in house or provided by complementors. Retaining in-house personnel requires consistent stream of projects, which may be hard to provide if the tradespeople are specialized to a specific task in one type of construction like elementized frame installation. If the tradespeople are generalists like in CIS-RC ecosystems, then they could be employed from start to finish in each project. Ensuring that projects are conducted back-to-back would then be enough for retaining the workforce. This might preclude the strength of TMC in elementized construction and prefabrication, because of the division of labour to factory work and field assembly. Only large scale, and field personnel willing to travel for work, would remain as solutions for the Human Resource Problem for vertically integrated firms who apply extensive prefabrication.

5.1.2 Component strategy:

The approach of long-term partnering to co-specializing the keystone roles requires explicit design of how the two roles could co-operate to solve the problems in their interface. Partnering like this would entail a degree of exclusivity of the element producer's services for the main contractors to help solve the Element Availability problem. Therefore, supply and demand for timber elements would be coupled between the keystone firms, making the problem with Demand Fluctuation not much different to the case of vertical integration. Then, either multiple main contractors or one large scale player is needed in the ecosystem to provide enough demand for the element producer to cover their fixed costs.

Then, if the keystone players in a new TMC ecosystem utilize a component strategy so that separate firms fulfil the roles of main contractors and element producers, their operations must be co-evolved to utilizing their specific TMC frame system in order to minimize salary and other SGA costs and allow lower gross margins. It means that their roles must be clearly distinguished and agreed on so that all redundancies between their operations would be minimized. The details of Incompatibility Problem indicate that SGA or overhead costs, like procurement, tendering activities, building design (-guidance), project planning and management, and site supervision should be rationalized so that only one firm incurs these costs. As an example, if a main contractor has supply networks, -deals, and procurement capabilities in place, they could also procure at least the generic construction materials and components, like insulation, MEP, and cladding, for the element producer. This kind of a procurement practice was indicated by the informants to be used by some main contractors already. If the element design is carried out or directed by the element producer, it may make sense for them to also do the procurement at least for the element-specific materials like timber and fasteners. In any case, there should be a clear assignment of who procures what, and a goal of centralizing all possible procurement to one firm would direct the ecosystem towards lower operating costs as it matures. When the same thinking is applied to all other SGA and overhead costs, the Markup Problem will eventually be solved without decreasing the net profit of either firm. While the operational efficiency is being developed to that level, the keystone firms may take advantage on governmental subsidies and directives and agree to temporarily lower profits to deal with the problem.

If a traditional main contractor wants to seriously diversify to TMC, a separate organization and accounting is likely needed to rid of the burden of operating cost from traditional contracting. Alternatively, joint-ventures or spinoff companies could be created for this purpose. New and smaller main contractor firms would not only be weighed by the legacy cost structures as much, but they would also be more agile in adapting their organization and operations from RC construction to TMC, as the new ecosystem matures. Contract management firms that focus on project management and are used to outsourcing the majority of the project execution could also be well-positioned for aligning with a new TMC ecosystem. Still, the smaller the firms, the harder to balance solving the Demand Fluctuation and Element Availability problems.

Liabilities should also be clearly distributed. As said for the Risk Problem, even little doubt on product performance is consequential because of high levels of accountability in construction. Decreasing the doubts and convincing the different ecosystems participants of adequate performance of TMC for example by improving the product and/or performing more testing is not the only way to decrease the risks. Accountability could also be redistributed with the ecosystem participants or perhaps even to new participants. As was mentioned for the Markup Problem, the responsibilities of main contractors could be limited if a large part of the project, the building frame, is managed by a different company, like the element producer. If a firm is liable on other firm's doings, extra transaction costs will arise from trying to prevent adverse selection (Akerlof, 1970) and moral hazard (Arrow, 1965), e.g. from additional quality inspection and oversight. Transaction costs are also borne from disintegration especially if incentives and responsibilities are misaligned.

Keystone players who would outsource most of the field work would not have to worry about labour utilization in solving the Human Resource Problem so much, but instead in incentivising and finding subcontractors to co-specialize with the TMC ecosystem. Making co-specialization costs for the frame construction professionals trivially low could make realigning them much easier. As an example, this could happen by developing easy-to-assemble modular construction and an efficient on-the-job training program led by a small number of experienced professionals from the keystone firms. This is feasible for TMC thanks to simpler field work resulting from prefabrication and division of labour. Over time, a pool of capable subcontractors would be formed to cover all target geographies. They could be flexibly subcontracted as needed, like in the second example company mentioned above.

5.2 Addressing the adoption problems

The key to solving the Markup Problem is decreasing some or all of the components to gross margin requirements of companies: gross profit = operating costs + risk premium + target net profit . Operating costs are decreased by solving the Incompatibility Problem and the risk premium is decreased by addressing the Risk Problem. As said above, this should happen naturally in system- and bottleneck strategies through vertical integration, and through long-term planning and clear distribution of roles and responsibilities in component strategies for the keystone players. Lastly, especially in the near term as the costs and risks are worked on, keystones may need to surrender net profits in favour of ecosystem growth and development. Governmental support may offset some the losses.

Even though governmental support may help TMC in the short term, active and continuous engagement of the public body is important to make sure TMC is not curtailed by the building code and authorities in the long run. An ecosystem approach to this end was covered in previous subsection.

The demand fluctuation problem was also touched upon above, resulting in need for increasing scale of construction in the ecosystem and decreasing fixed costs of element production. To further combat the problem, an ecosystem approach can better utilize other means of variability buffering (Hopp & Spearman, 2011) than just lead time buffers, that seems to currently be in use by element producers, as per the informants. Inventory- or stock buffers may be used more effectively when the main contractor and element producer are co-specialized. Main contractor could better “bank up” projects and shift their schedules to fit the availability of capacity of the element production, and focus may be directed to realising projects that could utilize more make-to-stock elements and delayed customization. Even if a portion of each project must be made-to-order, a volatility portfolio approach (de Treville, et al., 2017) could allow element production's responsiveness to this. Extra production capacity as an additional buffer could also be backed up by the ecosystem approach.

The Human Resource Problem requires onboarding and training efforts by the keystones no matter the strategy employed. The component- and bottleneck strategies may offer more flexibility in human resource management by not employing the tradespeople in-house. As said above, the outsourcing approach is supported by the finer division of labour that TMC can allow. Designers also face many problems due to unfamiliarity with the material, but perhaps even more so because there are no established design solutions for timber frame systems, as many interviewees said. Therefore, providing comprehensive design solutions for them to use could advance solving the Element Typology Problem and the Human Resource Problem for the designers' role. Even though this could be a chicken and an egg situation issue where designers are required to produce the "design manual" for others to use, this likely does not require them to devote their business to the TMC ecosystem. Instead, it may be possible to engage with them as consultants.

Ecosystem approach could theoretically solve the Element Availability Problem completely as said above for all three types of ecosystem strategies. How this could lead to exacerbating the Demand Fluctuation Problem in practice was mentioned along the ecosystem strategies. Large scale and low fixed costs would help, but focusing on demand variability buffering, as just described, may be more actionable for a variety of possible TMC ecosystems. More realistic demand signalling up the supply chain could also be achieved through ecosystem collaboration, which avoids overreactions in element pricing caused by the "bullwhip effect" (Forrester, 1999), making project costs more predictable.

Solving the Incompatibility problem is the step number one in forming a new TMC ecosystem: how should the keystones operate? This was covered for system-, bottleneck-, and component strategies above. Based on the interviews with main contractors, it is not clear if the Incompatibility Problem is significant for design firms. It could be that the more intense involvement of timber element producers and more extensive advance design in TMC projects just means that the designers create closer-to-finished designs from the start instead of one portion- or one level of detail at a time with possible breaks in between.

The primary challenge for any ecosystem arrangement is likely to be overcoming the Innovation Problem. How to get capable established firms to change course? Maybe the solution is to find firms or portions of firms who are more prone to see the benefits of possible change. Even if the Innovation Problem characterizes construction businesses as a whole, there could be individuals or divisions of firms that are open to serious experimentation with new modes of operation. The problem could be sidestepped by engaging construction companies that have not established operations for multi-storey residential construction yet. Still, the benefits that TMC can offer must become more decisive to give builders a reason to use them instead of dependable RC construction. Long-term strategic benefits that a unique TMC ecosystem value proposition may offer could be related to features of the building-offering, marketing and branding, differential competency development and asset diversification, as examples. Prefabricated TMC, especially of the massive timber type, also enables more fool proof frame erecting, which lowers the dependency of frame crew's experience in productivity of frame construction. This can be used to help builders shift from routinized RC construction to simpler TMC. If the component strategies are used by both keystone firms, risk sharing may be one means of attracting main contractors. It may be easier to commit to pivoting their business to novel TMC if there is a partner-firm who takes some of the risk-burden off.

For the long-term view, the performance of the timber frame must be technically assured to tackle the Risk Problem. This may also require product development. Meanwhile, an ecosystem aligned for TMC could ward off risks for themselves and their customers better than disparately acting firms could. For the component strategy, it was indeed noted that sharing some of the main contractor's risks and responsibilities with the element producer could help tackle the Risk Problem. A joint venture between the two roles may be one way to do so. In principle, more comprehensive insurance taken by the element producer could also help, as well as additional financial backing from third parties. Additionally, increased familiarity with TMC and the specific frame system should help stave off the problem from the main contractor, especially for system- and bottleneck strategies.

Element Typology- and Modifiability Problems are first and foremost questions of prioritization and differentiation. Like the interviewees said, some firms may choose to focus on projects and buildings that do not require solving the problems. These problems were also said to be possible to be compensated by differentiators like higher quality features that prefabrication can allow. But eventually, if TMC is to become mainstream, these problems must be addressed. Like the Risk Problem, these two problems may also require product development. Still, even as the element producer is key in enabling a more flexible building system, the whole ecosystem must be equipped to deliver and apply the solution for it to be commercially viable. Ecosystem design might also help deal with modifiability challenges for example by reciprocal procurement between ecosystem actors, like hinted at in reference to the component strategy. Also, modes of operation that allow end users to be engaged earlier in the project, like extensive pre-marketing could be developed. Solving the Modifiability Problem could help motivate main contractors to participate in the new ecosystem by making builder vendor projects more tractable. In builder vendor projects, higher margins thanks to no seller intermediaries and market pricing of the apartments would then in turn motivate the contractors to develop the TMC ecosystem into more commercially competitive.

5.3 Why proactive ecosystem development?

Committing to a new construction ecosystem may be risky especially for main contractors. But without taking risks it is unlikely that changes will happen though, not in terms of TMC adoption, industry productivity, and not in terms of industry leadership or competitiveness of firms. Recognizing that even as timber elements cannot likely be made equivalent to RC elements, it is the same the other way around: RC elements cannot be made equivalent to timber elements. This could be made to an advantage in short term, but especially in the long term as regulations and TMC ecosystems mature.

For this to work out, right kind of ecosystem partners are needed, that could be ready to, in some projects, cede a portion of their gross profits short term towards working for the good of the whole ecosystem. To compensate for the lower gross profit, redundant and unnecessary activities for TMC could be cut collaboratively and cost savings from operating expenses and overhead achieved that way. As a return to lowering their profit margins, the participants would enjoy higher revenue and accelerated business development thanks to the ecosystem synergies. More significant returns to this investment would be collected later when the ecosystem has had the time needed for refining the product, the operative model, and the collaboration has become more streamlined. Some firms may be better positioned by their cost- and organization structure to participate than others. But currently, at least in Finland, it could even be possible to not compromise on any profits in some construction projects thanks to the subsidies from the government, which help sidestep the Markup Problem.

The end result could be almost the same as what would happen if timber element construction became commoditized through standardization similarly to concrete element construction. But through business driven TMC ecosystem development, it would likely happen faster, in a more focused, intentional manner, by incentivising all ecosystem participants to participate in developing and maturing the building system. In the long run, a successful ecosystem like this could also develop an outsized competitive advantage against industry actors outside the ecosystem, be they element producers, contractors, suppliers or subcontractors. It is possible to allow more and more participants into the ecosystem, and in the case of success, the ecosystem would eventually characterize a major part of the whole industry. Therefore, through constant refinement and standardization of products and processes within a growing ecosystem, timber element construction would become harmonized, with lots of competition among actors and a possibility to have an “open source” building system, similar to current RC element industry as the ecosystem grows. The difference would be that this would happen by design, gives more room for innovation and collaboration, with a better change to reach a more integrated end result that could bring the conservative industry of construction further forward than otherwise possible. The two routes to mainstreaming TMC and the order in which they solve the problems found in this thesis are depicted in Figure 24 below.

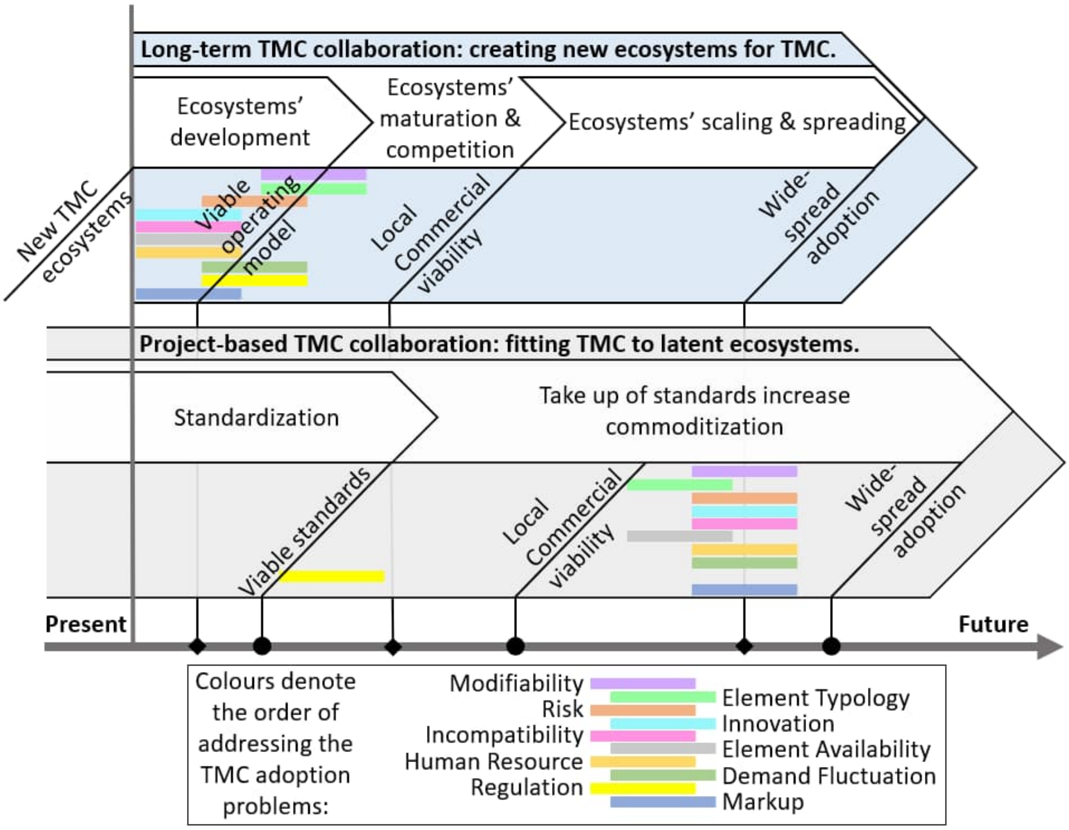


Figure 24: Two parallel routes to mainstreaming TMC

In reality, it is not either-or: commoditization versus active ecosystem development. Some firms will likely adopt TMC thanks to commoditization and some firms will be more proactive. But the argument here is that firms that take an active role developing a new TMC ecosystem and adapting construction projects to it could move TMC adoption faster and further. The more companies that participate in the ecosystem or develop competing new TMC ecosystems, the more likely the outcome of mainstreaming TMC.

There are at least a few reasons to not solely bank TMC adoption on commoditization and harmonization: first, at this moment, and in the immediate future, standardization will likely not help anyone. A new standard is novel anyways. So, it will take collaboration, time, effort, money and broader adoption before the harmonization will kick in and provide benefits to the industry. Standards are mostly there for guidance, but it is not enough to know what the intermediate products, the construction elements and modules, as well as the end result should be like. More companies must anyways gain competency with the underlying technology and the processes before the harmonized offerings can be applied effectively.

A second short term reason is that there may not be any stakeholders in the construction industry, that are incentivized to invest time, money and effort to meaningfully furthering commoditization of TMC and thus solving TMC's incompatibility to the industry practices. Game theoretically thinking (Besen & Farrell, 1994), existing (element producer) firms may wish to achieve standardization, but unless they are largely indifferent on which type of a frame system the standard is to be based on, it may be difficult for them to reach agreement on a common standard. Some firms may also want to retain their current competitive advantages against others and possible newcomers, which would discourage them from investing in open standardization. In effect, a company that meaningfully invests to industry harmonization, might do more to help their competitors than themselves. It is perceivable that prior-existing individual companies could benefit from industry harmonization only if they do not have to invest and use their resources for standardization efforts much at all, and if the standardized products and practices can be produced by their operations without much changes. Otherwise, only future companies or newcomers to the TMC space could get differential benefit from the standards in the short term.

The case of active TMC ecosystem development is contrary. Investing in and developing the collaboration between element producers, contractors and other ecosystem participants that is not aiming for "open source" commoditization is necessarily going to lead to differential competencies that may give a competitive advantage to the early bird doing so. All participants in an ecosystem like that, even if risky, could then have the short-to-long term incentive to meaningfully increase TMC uptake through their own business. If done wisely, short term competitive advantage could be even turned to long term competitive advantage.

A third, medium-term reason is that for a problem related to industry incompatibility due to lack of standardization among a large number of companies, it is not clear who is responsible to solve the problem. Blame for a common problem could always be put on someone else. A governmental intervention could help. Externally defined standards by the government, for example, could be non-practical for firms to adapt and may require a long time to be refined and adopted to make a difference. Like said above, businesses would in any case have to learn how to produce and apply an offering that is in accordance with a standard. The governments can also help with learning by providing training, consultancy and other material besides the standards, that help companies get acquainted with TMC.

The fourth reason why it may make more sense for the construction industry to adapt to TMC than the other way around is the dormancy of the traditional construction industry in terms of productivity. For a long time, scholars and practitioners alike have understood that there is much that the industry could do to improve the productivity (Forbes & Ahmed, 2020; Ahonen, et al., 2020; Koskela, 1992), as the interviews for this thesis corroborated. The Human Resource Problem highlighted how elementized and prefabricated production that fits TMC perfectly, could be ways to increase productivity and available workforce. At the same time, collaboration widens the possibilities for other project sequencing and process improvements related to procurement, design, modification, sales, and other activities that happen at the interfaces between different stakeholders. Collaboration, coevolution and co-specialization are ways in which a collaboration-focused ecosystem strategy in furthering TMC adoption may lead to long term advantage, at least in theory.

At any rate, incompatibility must be solved with collaboration even if the end result after many years is a traditional construction industry-like TMC ecosystem with harmonized products. Why not take the future into the companies own hands and make collaboration both the beginning and the end?

6 Discussion

By developing business models and modes of operation that account for this thesis' primary findings of the frame choice problems that main contractors face, it may be possible to accelerate TMC adoption. Residential multi-storey construction may have the most potential in the near term, due to the simplicity it offers in structural terms, at least. Also, the industry has developed myriad of frame solutions which are being applied already, although in a relatively small scale. Therefore, in the previous section, a draft for a new ecosystem concept for TMC in the residential section was advanced. Although the long term partnering approach is mostly untested, a the few encouraging examples already gave some merit to the concept as an answer to the subgoal of this thesis: How adoption of timber in large scale construction could be accelerated?

Next the yield of this thesis is summarized and put into perspective.

6.1 Summary and research contribution

Timber frames are seen as more expensive than RC-frames by traditional main contractors and many other stakeholders. One part of it is because of higher direct costs from inexperience of tradespeople and higher complexity of TMC stemming from additional drywall sheathing, sprinklers, and soundproofing, as examples. Nevertheless, the Markup Problem shows significant cost-inefficiencies in how the firms operate as well, especially when the degree of prefabrication is high. The Regulation Problem is one reason for complexity of TMC that leads to higher costs for builders and residents, although façade- and massing directives by city planners under-appreciate the cost-increase in RC construction as well. Still, the building code, city planning, and building inspection may reduce commercial viability of TMC compared to RC, seemingly needlessly because of their habituation on construction that is RC focused. The Markup Problem could be solved by vertically integrating timber element production and main contracting, but there are obstacles for doing that. One of them is the Demand Fluctuation Problem. Only the largest construction companies in Finland reach a scale large enough that a viable level of demand for the element production can be maintained within the firm despite the high variation in construction volumes.

The inexperience of construction professionals with TMC combined with the Demand Fluctuation Problem makes the Human Resource Problem severe for TMC. The few frame crews practiced with TMC may not be available when needed, but at the same time, TMC projects are too few and inconsistent to incentivize more professionals to specialize. The division of labour that pre-fabrication allows was said to possibly alleviate the problem by decreasing specialization costs. Unfortunately, using pre-integrated "sub-assemblies" poorly fits the traditional operating models of main contractors.

Main contractor's management- and procurement practices, be it for CIS- or elementized RC construction, seem suitable for integrating building components and materials from multiple harmonized suppliers. There are only a few timber element producers, and they offer inequivalent products, prompting a need to solve the Element Availability- and the Incompatibility problems advanced in this thesis.

The Innovation- and Risk Problems are other obstacles to main contractors for making significant investments to TMC, for example by vertical integration of element production. Only TMC projects where the operational inefficiencies and the risks of applying novel timber frames are somehow compensated seem to be taken up by main contractors, like in small and simple buildings and when the public authorities subsidize or only allow timber frames. Developing more robust timber frames to mitigate the Risk Problem is one technical product development task that could help TMC forward. Similarly, solving the Element Typology- and Modifiability Problems start from the technical design table, but also require an ecosystem around the product that can deliver the enhanced product cost-effectively.

The implications drawn from the data is that significant investments to vertical integration by traditional main contractors seem unrealistic as a solution to the found problems, at least while TMC is nascent. Element producers might not have resources or capabilities for expanding to main contracting despite of their motivation. Therefore, only when the problems recognized in this thesis are alleviated enough by industry development, will there be meaningful adoption. Most of the 23 interviewed main contractor representatives' implied that there should be more element suppliers and product harmonization, which was recognized as how the industry thinks TMC ecosystem should mature. This thinking has surfaced elsewhere as well. This will likely happen eventually as TMC evolves to better match to the traditional multi-residential construction ecosystems.

Based on insights advanced from the data, it was proposed that proactive development of a new TMC ecosystem would likely accelerate solving the found problems and the adoption and maturation of TMC.

A draft for a concept TMC ecosystem aiming to engage all the project participants who were recognized to affect the frame choice was introduced. Motivated by a possibility for a head start to competitive advantage in TMC, long-term partnering between an element producer(s) and a main contractor(s) as keystone firms could enable this. In addition to system- and bottleneck strategies for the keystones that involve vertical integration to one firm, component strategies (Hannah & Eisenhardt, 2018) that rely on collaboration between two or more firms in those roles was also proposed. The component strategy requires developing new modes of operation that remove redundancies and imbalances in rewards and responsibilities between the companies. A degree of exclusivity for the ecosystem benefits must be agreed on to make it enticing for both roles, but before reaching a large enough scale for the ecosystem, the players may need to act outside the ecosystem as well to balance solving the Demand Fluctuation- and Element Availability Problems. It was noted that despite the Innovation Problem, the shift to TMC-adapted operations could be managed better by some main contractor firms if an element producer is willing to partner up with them like this.

Governmental regulators, city planners and cityscape committees, and municipal building inspectors should be engaged actively by the ecosystem to ensure the Regulation Problem does not unnecessarily encumber the progress. Building code officials are especially important participants in TMC ecosystems due to their all-encompassing influence. Construction owner-clients, developers, interior subcontractors, and apartment buyers seemed largely interchangeable as ecosystem participants between RC- and TMC. Still, the new ecosystem should account for the problems found to alienate these ecosystem participants from timber construction. Offering them a differentiated value proposition through renovation and maintenance, for example, could offer further benefits to the ecosystem while simultaneously mitigating the problems.

The proactive approach to new TMC ecosystems would invert the logic that the prevalent industry approach projects. The conventional, mostly passive approach by firms would rely on industry-wide standardization and gradual growth of timber element producers and experience obtainment of (sub)contractors. Eventually TMC would fit the traditional ecosystems and the problems found in this thesis would be solved, making TMC a widely commercially viable option to RC construction. The proactive approach of building up new TMC ecosystem(s) would first tackle the problems and start expanding TMC helped by differential competencies gained in doing so. Through gaining new participants in the ecosystems and firm growth within the ecosystems there would be more supply for timber elements. More contractors would also become experienced in using the frame type standardized within the new ecosystem. The proactive route would lead TMC to similarly widely standardized and commercially viable option, but arguably it would happen faster thanks to competitive pressures, against RC and between different TMC ecosystems. If the new ecosystems can solve the problems and capitalize on the advantages in prefabrication, precision, quality, and aesthetics that timber provides, there will be strong reason for a large range of industry stakeholders to participate.

Through the lenses of ecosystems and organization design and leadership provided by an industrial engineering background, this thesis supplements the previous research and public knowledge on the adoption challenges that TMC face in the construction industry. By providing details and practical examples drawn from the interviews, this study highlights organizational and collaboration challenges which may have been overshadowed in previous literature by other challenges that may be more technical in nature. The findings and the implications drawn from the findings may also help industry stakeholders like regulators and timber element producers develop solutions that improve the TMC value proposition and rate of its adoption.

Although the application of ecosystem concepts in this thesis is perhaps rough and cursory theoretically speaking, this thesis strengthens the base of applied research for ecosystems theory. Like Viholainen (2021), Pulkka et. al. (2016), Jian et al. (2016), and Aksenova et al. (2018), this thesis found a particularly good fit between the construction industry and the ecosystem lens. Inherent in all constructed product's realization, the complexity and a large number and variety of players who compete and collaborate creates fertile ground for ecosystem development. When industry disruptions like TMC enter the picture, ecosystem analysis and design become a valuable tool for knowledge and solution creation. Future research directions in terms of ecosystems are given in next section.

6.2 Qualifications and Future Research:

The findings and implications are based only on main contractors' perspective, so they should be interpreted as such. It is not for sure that other actors would agree with them, although some of the previous research covered in this thesis includes findings from other actors and are compatible with this study's findings. The construct validity (Cronbach & Meehl, 1955) of the primary findings is improved by multiple corroborating data sources and multiple lines of inquiry that ft the conclusions. Even if only a small number mentioned some interesting facts, circumstantial evidence from other interviews that support the facts were plenty for most themes. To increase the reliability of the results, careful linking of the original data to the results showing the route of analysis was presented in the thesis. Furthermore, the raw data in form of transcribed quotes were provided for the reader to give them the possibility to verify the conjecture drawn from them and to challenge the interpretation of the author.

Although the implications drawn for the construction industry and TMC's future development are somewhat based on academic knowledge and professional experience of the author in business development, wood products industry and entrepreneurship, they also had several touching points to the interview-data. Also, the proposals do not go into high level of detail that would not be warranted by the general explorative nature of this study. Therefore, the proposals should be taken as informed suggestions that hint the readers to evaluating their applicability further.

Even taking the results as viewpoints of main contractors, they cannot be said to represent all main contractors. The sample size of 23 is likely not near reaching statistical significance on most if not all findings for this thesis in the Finnish multi-residential construction industry context. Usually contrasting views between the informants existed as well, and there was no attempt to relate these differentials to the explanatory factors listed in Table 2.

The generalizability of the results to other countries suffers due to the regionality of construction. Building codes, climates, available raw materials, and economic differences are examples of fundamental differences that are not only different contexts for the main contractors operating in different countries, also the technical applicability of different frame types is directly affected. For example, North American residential multi-storey construction is known to rely on LWTF to a large extent which may denote differences in underlying industry logic. It would be interesting to further study if this example would still fit the concepts found in this thesis: perhaps the main contractors there are long used to using timber for those types of building frames. They may also focus on capturing keeping most margins for themselves by using on-site fabrication instead of elementization and prefabrication, but with LWTFs instead of RC frames. Other Nordic countries have many similarities to Finland and the previous research has indeed shown similar findings from Sweden for example (Hemström, et al., 2016).

Few interviewees commented on the uninformed perceptions that the general public has towards construction, which also affects their RC frame construction methods. For example, on-site installation of perimeter wall insulation at the same time as the façade cladding was constructed instead of pre-installed insulation was said to be good for public relations of the firm, as passers-by would not see the insulation exposed to the environment. Using weather covers in RC construction and using CIS-RC slabs instead of hollow core slabs were also said to be good for creating a perception of better controlled construction, although none of exposed insulation, exposed concrete structure or water ingression to hollow core slabs are technically problematic. It is conceivable that construction professionals who have little or no experience or specialization to TMC could similarly have poorly justified perception to TMC just as many commoners were said to have toward construction in general.

It is also likely that the issues presented by the interviewees are highly dependent on personal experiences of the interviewees: what are the practises in their firm and their own personalities. Most of the interviewees had a hands-on practical background, and like the whole industry is path dependent, the viewpoints of the individual informants can be so too; their perceptions are likely dominated by a narrow focus on acting within their respective latent traditional construction ecosystems. It could be that many interviewees just happened to have bad experiences with city planners, or that a negativity bias (Kanouse & Hanson, 1987) dominates their perceptions. A clear example of the ecosystem focus is the view that there is nothing significant to improve upon in traditional RC frame construction because it has been used and refined for so long, that was communicated by most interviewees. It could be that if they had experience from other (manufacturing) industries, their views on improvement and innovation could be quite different. A couple of interviewees did recognize this issue, as is also known from the literature (Forbes & Ahmed, 2020; Koskela, 1992).

The strong linking of ecosystem concepts to practical issues mentioned in the previous subsection suggest a fruitful avenue for further research that applies the theories underlying the ecosystems lens. For example, transaction cost economics, agency theory, property rights theory, resource-based view, and incomplete contracts theory (Zhang, 2006) all have clear connection to the TMC ecosystem development context advanced in this thesis. As more practise oriented extensions to applying ecosystems, the roles in achieving coordination across the ecosystem (Jacobides & Kudina, 2013; Brusoni, et al., 2001) and how ecosystem participants could be incentivised to transition from the latent ecosystem to a new one (Jacobides, et al., 2006) could be analysed further.

Inefficiency of the nascent TMC industry may often be attributed to unrefined construction processes leading to unnecessarily high direct labour and material costs. This study has shown that a significant reason for the inefficiency could also stem from organizational structures and contracting arrangements that have unnecessary redundancies as well as from imbalances in risk/reward or responsibility/motivation positioning between the stakeholders. Therefore, it is not certain the most sensible outcome is achieved by developing the TMC industry and timber construction element producers towards a similar state where the current RC element construction industry is. It could be worth it to investigate this further to find out what are the possible efficiency improvements in both the construction processes and the operating models. How significant are the additional operating costs due to incompatibility of TMC to traditional construction ecosystems compared to the cost that actually go into constructing TMC buildings?

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Appendix: Representative quotes for themes

Theme: The Markup Problem: In timber frames compared to RC frames, main contractors must surrender a larger share of the project to the element producer. If the main contractor's responsibilities still stay the same, as it seems to be in many cases, they need the same gross profit anyways, which leads to more markups in the final product. This effect is more severe the higher the degree prefabrication	
Coding	**Representative quotes**
Prefabrication and outsourcing gives higher markups for subcontractors, so contractors cannot markup as much --> less profitable	23(4:40) "[kun] esivalmistusaste on huomattavasti-, elementointiaste on paljon suurempi ja, kyllähän se aina kun tavallaan työtä tekee joku toinen sulle valmiiksi ja siihen pannaan katetta päälle ja siitte kaikki kuljetuskustannukset päälle niin kyllä minä-. Sieltähän se sitten niinkuin juontaa se. (...) [kun] paljon tehdään omilla urakkaporukoilla tehdään näitä hankkeita niin, tuota, sun ei tarvi työstä maksaa katteita. Tuplakatteiden määrä on pienempi."
Prefab gives higher share of material+work+management and reward to element producer, less to (sub)contractor (Sub)contractors are not willing to give away their share of the pie	22(15:40) Vaikuttaako työn siirtyminen elementtivalmistajille elementtien houkuttavuuteen? "Onhan sillä jossakin määrin vaikutusta joo. Elikkä sanotaan sillä tavalla että, siinä törmätään taas niinku sellaiseen kulttuuriasiaan. Että jos ajatellaan että me joskus kilpailutettiin kylppärielementtejä ja laskettiin hintoja, niin haaste tulee siinä että kun talotekniikkaurakoita mietitään, niin talotekniikkaurakoitsijat on niin mustasukkaisia siitä omasta työsuorittamisesta koska nehän pitkälti saa sitä katetta siitä materiaalista mitä ne myy. Ja kylppärielementit jotka on tommoisissa kerrostalokohteissa niin kylpyhuoneisiin paljon liittyy sitä talotekniikkaa. (...) Kaikki se kun tehdään ja otetaan tietyllä tavalla siitä tällä hetkellä meidän perinteisestä LVI-urakasta pois, niin käytännössä ne ei oo hyvittänyt niissä kohteissa missä ollaan laskettu. Ne LVI-urakoitsijat on hyvittänyt hyvin nimellisen summan siitä että kun kylpyhuone-elementti tulee valmiiksi paikallaan. Sama juttu on hormielementeissä. Eli käytännössä kun hormielementeissä menee sitten putkia aika paljon että urakoitsijat sieltä on ollut hyvin nihkeitä hyvittämään koska ne tajuaa että heidän leipää syödään kun elementoidaan."
Prefab gives higher share of material+work+management and reward to element producer, less to (sub)contractor Partnering model may make more sense when more prefabrication	06(7:30) "Toki sitten on valtakunnassa niitä tilaelementtiratkaisupuukerrostaloja, joka ois niinkuin toinen vaihtoehto. Mutta tuota, siinä on sitten se tilaelementin tekijä, että kumpi siinä sitten oikeesti on pääurakoitsija, se grynderi vai se tilaelementin, siis joku perinteinen rakennusliike vai se joka tekee sen tilaelementin. Siellähän se kaikki tekeminen on pääasiassa siellä tilaelementissä. Pääurakoitsijalle jää siitten yleiset tilat ja porrashuoneet viimeisteltäväksi. Ehkä sit tommoisella kumppanuusajattelulla jossain kohtaa varmaan voi olla että sitte mennään. "
Partnering model may make more sense when more prefabrication	18(29:00) Kuinka hyvin LVISA urakoitsijat on osanneet mukautunut siihen että kylpyhuonemoduuleissa on tosi iso osa rakennuksen talotekniikasta valmiina? "Vaihtelevasti, mutta me pyritään siihen että meillä on tietyt vakiokumppanit joiden kanssa tehdään ja ne oppii tuohon meidän tapaan toimia ja sitä kautta. (...) Pyritään siihen että meillä on aina

	vakioidut kumppanit tai pitkäaikaisia yhteistyökumppanuuksia. (...) Kyllä me yritetään päästä niinkuin semmoiseen niinku kumppanuusmalliin monessakin asiassa. Siihen pyritään."
Prefabrication and outsourcing gives higher markups for subcontractors, contractors cannot markup as much --> less profitable	15(26:15) "[Puurunkoisten laattaelementtien kanssa käytettävästä sääsuojasta] tulee suuri kustannus, mutta moduulirahdit: nekin maksaa. Ja sitten se moduulitehtaan voittoprosentti tulee vielä siihen päälle. Että ei se-, se maksaa melkein se teltta-, no ei ihan, mutta se ottaa aika paljon sieltä pois ainakin. Ja sitten siellä on, mä voin sanoa että se on jopa nopeampi ratkaisukin. Mä voin luvata että se on nopeampi vaikka se ei kuulosta siltä, mutta se on nopeampi kun-, jos se konsepti on hyvin suunniteltu."
Either contract price goes up or contractor markup down if technical costs are higher For lowest cost and highest contractor margin, technical cost is minimized as much as possible	12(40:10) Tehtaalle suurempi palkkio, urakoitsijalle pienempi? "Sehän on tietysti tekninen hinta on aina mikä määrittelee sitten tehtiin se tuota elementistä tai paikalla rakennettuna niin määrittelee, ja se tekninen hinta on se että millä rahalla se pystytään niinku rakentamaan. Elikkä se raha tarvitaan jotta se rakennus voidaan tehdä. Sen teknisen hinnan päälle sitten urakoitsija laittaa riskien ja sitten se laittaa tavoitekatteen. Eli mikä se tuota hinta pitäisi olla ja mitä siitä pitäisi jäädä käteen kun se tekninen hinta pitää päällänsä. Tekninen hinta-, itse käytän sitä sanaa-, se pitäisi olla sellainen että se on silla rahalla niinnku järkevästi tehtävissä ja se on realistinen. Se on tuota napakka, ja se on tuota sillä tehtävissä, sitte se hinnoitellaan riskillä ja katteella siihen päälle. Se että valuuko se raha tuota elementtitehtaan laariin jos se lähtökohtaisesti hinnoitellaan tällä ratkaisulla, niin tuskin. (...) Sitten jos ajatellaan gryndiä niin sittenhän sillä on tällainen myyntihinta. Myyntihinnan ja teknisen hinnan välinen ero on olemassa myöskin. Esim jos ajatellaan että meillä on myyntihinta 1000 ja elementoidulla ratkaisulla tekninen hinta on 900, ja sitten jos tehtäisiin kaikki itse niin saatais teknistä hintaa pudotettua 800:n, sillä silloinhan sinne jä tuplasti enemmän väliin. Tästähän siinä on kysymys kun sitä rakennusta ja rakenteita ja sitä rakennustapaa optimoidaan on se että mikä se myyntihinnan ja teknisen hinnan välinen ero on ja millä tavalla me pystytään se tekninen hinta arvottamaa. Siihen vaikuttaa moni asia siihen tekniseen hintaan: rakennuksen muoto, valittu rakennejärjestelmä, asuntojakauma ja muut sitte myöskin."
Prefab gives higher share of material+work+management and price to element producer, less to (sub)contractor	09(37:30) "Ongelma tulee sitten, haasteet tulee taloteknisissä hinnoittelussa, elikkä talotekniikkahinnat ei, urakoitsijat ei niinkuin, sanotaan että talotekniikka hinnat ei huomioi riittävästi sitä kylpyhuone-elementin niinku taloudellista ongelmallisuutta. Se on selvä että heiltä jää aika paljon töitä sieltä pois. Sanotaan jos on talo jossa on lattialämmitys integroituna lattiassa, ja sitten on kylpyhuone-elementit, niin siellä ei taloteknisesti enää hirveästi ole niinkuin. Sähkömiehellä on pystynousut, vaakavedot sitten asunnon muut rasioinnit ja kalustamisen valaistukset ja käytävät. Putkiurakoitsijalla ei ole enää muutakuin ja jakotukilta lämpölinjan runkolinjan tuonti hormeissa pystykäytäville ja liittäminen jakotukkeille tuonteihin ja pesuhuoneisiin, ja sitte koepaineet ja IV-kone

(sub)contractors are not willing to give away their share of the pie for separate contracts, main contractor is left with too small of a reward compared to responsibility	ehkä yksi jos sellainen on. Sitten ilmanvaihtourakoitsijalla on sen yleensä IV-konehuone ja vesikaton kanavoinnit konehuoneelle. Muuthan on suurin piirtein moduuleissa valmiina. Tää on se minkä takia heiltähän huomattavasti jää töitä pois. Ei se ole kokemuksen puutetta hinnoittelussa, kyllä se vaan tosiasia on että he ei vain oikein pärjää kisassa. Ansainta on niin pientä siinä ja ehkä urakkarajojen ja riskien jakautumisessa. Kyllä heiltä paljon töitä jää pois ja se tarkoittaa että heidän urakkahintansa tulee putoamaan, ja se mielenkiinto sit lakkaa. Mää uskosin että se lisääntyy vaan tässä että pakko se on heidänki alkaa tätä hommaa niinku miettimään. Jotkut talotekniikkaurakoitsijat kyllä katsoo ja se hinta on ihan kohdallaan mutta kyllä se tällä hetkellä vielä mietintää on. 09(1:26:30) Vaikeuttaako oman runkoryhmän sidottu osaaminen eri rakennusmenetelmiin siirtymistä? "Joo kyllä se vaikuttaa, se on ihan totta että ei betonihenkilöstä ei puuhenkilöä helposti saa. Ja tuota, vaikka se on moduulirakentamista niin siinä on omat jipponsa ja se vaatii opettelua. Mutta en mä nää sitä esteenä että se on, miettii vaan että miten se lähtee menemään. Onko se alihankintana ensin ja sitten tulee omaa porukkaa opettelemaan mukaan ja sitten omalla porukallakin ihan hyvin onnistuu. Jos se tehdään itselle KVR:nä niin se on ihan jees, mutta sitte jos mennään urakkamuotoon niin meillä on urakkamuotona vaikka- ,tilaajalla on kunta tai joku muu toinen joka rakentaa puukerrostaloa niin yleensä se urakkamuoto on niin raaka että sitten se pääurakoitsija on päätoteuttajan roolissa ja sitten se tilaaja tilaa sen puurungon puutoimittajilta ja se ansainta jää todella pieneksi ja kuitenkin kannat kaiken riskin ja toteutusaikataulun kantaa se pääurakoitsija sillä pienemmällä palkkiolla, niin silloin se kiinnostus lakkaa aika nopeasti. Tässä on tää, elikkä puumoduulitoimittaja yleensä toimittaa puurungon joka on urakkasummaltaan kaikista isoin järkevin, ja sitten perustukset ja aikataulu ja työturvallisuuden ja muut vastaa sitte se pääurakoitsija, joka on kuitenkin sitten tavallaan, jonka alihankkijana tai sivu-urakoitsijana toimii tää puurakennetoimittaja. Niin semmoisessa urakkamuodossa ei niinku ole järkeä että lähdetään ottamaan vastuuta ilman kunnon palkkiota. Mutta sitte jos pystytään itse tehdään ja itse toimitaan ja saadaan myös se urakka sieltä niin tottakai silloin. Tää on semmoinen mihin tässä kerrostalorakentamisessa on törmätty että siitä ei saa sitä korvausta mitä sitä pitää saada siitä vastuun kannosta ja kun kaikkien asioiden hoitamisesta. Kuntien kanssa käy kyllä ihan jees kun kuntien kanssa tehdään tällaisia julkisia hankkeita niin se on ihan ok. Uskoisin näin että nää puurakenteet tällä hetkellä aika pitkään tehdään alihankintana, kyllä kun niitä tehdään niin kyllä meillä ei oma porukka niitä tee vaan kyllä se on alihankintana.
To increase own share of margin and decrease others', (some) contractors procure and markup materials for subcontractors (continues on next page)	13(37:15) Miksi LVIS urakat ei huomioi kylppärimodulia? "Tiedän että jotku rakennusliikkeet tosiaan ostaa vaikka vessanpöntöt itse ja IV-koneet ostaa itse ja näinpoispäin, että sinne jää vain vähän niinku sit työtä ja putkenvetoa. Sitten kylpyhuone-elementissä on vähän samalainen että siellä on ne vessanpöntöt ja IV-koneet valmiina hankittuna. Ja-ja, sitä kautta sinne jää sitä samaa putken vetoa sitten vaan että se on

Prefabrication and outsourcing gives higher markups for subcontractors, contractors cannot markup as much --> less profitable prefab gives higher share of material+work+management and price to element producer, less to (sub)contractor	ihan sama heille että kumpi hinta siinä on. Se niin riippuu vähän niistä hankintajutuista että kuka ostaa, mitä ostaa, ja kokonaisuuksista. Sitä on niinku vaikea sanoa että niin kenenkin kannalta. On niin erilaisia hankintatapoja yrityksillä. (...) Sanotaan nyt vaikka mekin niin vaikka noissa suurelementeissä niin kyllähän me niinkuin esimerkkinä se että me ostettiin itse ikkunat ja ne ikkunat toimitettiin sinne elementtitehtaalle ja ne elementtitehtaalla asensi valmiiksi niihin ja elementteihin he tekivät ne esimerkiksi ulkoa täysin valmiiksi pellityksineen ja kaikkine päivineen että niitä ei tarvinu alkaa nysväämään tuolla työmaalla, että kaikkee tämmöisiä on mahdollistaa toteuttaa." Miksi ei tilaelementtejä? "Ehkä siellä on isoin että se rajoittaa vähän sitä huonesuunnittelua, mikä sen niinkuin tehokkuus loppuviimeksi on. Ja sitte se että siellä varmaan se kustannus valuu aika paljon sinne tilaelementtitoimittajalle. Eli kun, kun-kun, jotku rakennusliikkeet haluaa ostaa ne materiaalit vaikka sen vessan pöntönkin haluaa ostaa itse, niin-niin ne ei anna sitä katetta sen vessanpöntön osalta sille LV-urakoitsijalle vaan ne saa sen sieltä itse. Kun sitten taas tilaelementtitoimittajalta tulee kaikki valmiina niin se katekkin kaikki menee sinne tilaelementtitoimittajalle, että siellä voi olla tämmöisiäkin juttuja siellä taustalla että kun joku haluaa ostaa sitä materiaalia ja muutakin itse, IV-koneita, vessanpönttöjä, laatoituksia, ja ostetaan vain työtä sitten niinsanotusti."
Prefab gives higher share of material+work+management and price to element producer, less to (sub)contractor	11(25:40) "Siellähän [kylpyhuonemoduulissa] on kaikki valmiina, ei tarvi kuin ulkopuoliset kytkennät." Sieltä jää paljon urakoitsijoilta työtä pois? "Kyllä sieltä jää jonku verran laattahommaa ja tämmöistä kaikkea. Se on jännä homma että se ei ihan mahdottomasti kuitenkaan näy talotekniikan hinnoissa. Urakkahinnoissa se ei välttämättä ihan mahdottomasti. Vähäsen se on halvempi kuin, mut jostain kumman syystä ne aina pystyy sen jollain perustelemaan että ei siitä nyt ihan kauheasti hinnasta lähde. Tietysti kytkennöissä on oma hommansa. Ja sit se et varmaan on sekin et ihminen on rahalle hyvin perso."

Theme: Regulation problem: Due to their unfamiliarity with actual construction processes, regulators, municipal decision makers and officials may unnecesseraly rise construction costs and risks, and increase consumption of natrual resources. Especially WMC is affected because officials' are even more unfamiliar with it.

Coding	**Representative quotes**
Municipal city planners and politics are ill-informed about the effects of their directives. Municipal directives raise construction costs and bring extra challenges. (continues on next page)	9(33:30) "Kyllä meillä paikallamuurauksia on. Tällä hetkellä kaavoitus haluaa jostain ihmeen syystä elementtien saumat piiloon. Ja tuota, sanoisinko näin että aiheuttaa tällä hetkellä laadullista tuskaa ja hinnallista tuskaa. Ja se että kaavan kautta tulee valitettavan usein niitä että, sanotaan että mehän sitä kaavaa välillä päästään ja ohjataankin aika usein mutta-, ja haasteet tulee sieltä että kaavoittaja ei päästä läpi semmosta pelkästään pesubetonisänkkärijulkkaria vaan sit siellä pitää olla rappausta, muurausta tai jotain. Pahimmissa meillä on kaikki niinku julkisivumateriaalit joissain kohteissa. Ne on niinku tosi vaikeita laadullisesti sekä niinku taloudellisesti. Tää on se mun mielestä se, tai

The builder has clear incentives to collaborate and improve city planning details	sanotaan iso haaste näissä julkisivumaailmassa, että liikaa säännellään, niinku kaupungin kaupunginkuvatoimikunnat ja virainomaispolitiikka, sanotaanko näin. Mä sanon suoraan että rakentajat ei pysty siihen juuri tällä hetkellä sanoon muutaku yrittää taistella sen asian kanssa. Tuossa yksi keissi on että 16krs talo sitä kaavoittaja halusi sen rapatuksi ja sanottiin et tää ei toimi ja meidän piti useita lausuntoja hakee siihen että todistaa että siinä on iso riski että se rakenne ei tule toimii siellä ylhäällä. Paineolosuhteet, ja kosteus tulee oleen niin valtava että se rappaus ei toimi siellä, et semmoinen iso riski. Kyllä nää niinku tosi raskasta on nää projektit kun pitää käydä sellaisia perusfysikaalisia asioita näiden kaavoitusarkkitehtien kanssa."
Municipal directives raise construction costs and bring extra challenges. The builder has clear incentives to collaborate and improve city planning details	6(2-19:15) "Ainakin Pääkaupunkiseudun kunnissa mistä mulla on nyt kokemusta niin tota kaavoittaja on aika-, tuota, aika kuningas kun se-, tuota, määrittelee että, että tällaisen talon, tänkokoisen talon tähän saa ja siihen pitää olla paikalla rakennettu julkisivu. Niin tuota, paikalla muurattu julkisivu, niin edelleen niin, niin tuota. Mut kyllähän me rakentajat sit koitetaan sitten niinku paikallarakentamisen käsitettä sitten niinku venyttää meille kustannusedulliseen suuntaan niin paljon kuin vaan kehdataan ja yleensä viel vähän enemmänkin. Jossain kohtaa se sitte raja tulee aina vastaan. mm"
Municipal directives raise construction costs and bring extra challenges.	8(15:40) "Kaava on siinä määräävä tekijä että sieltä tulee rajoitteita että välistä on on jopa muurattuja tiiliseiniä tai-, tai rapattuja ratkaisuja. Ne sitte muuttaa siinä tilannetta. Siis kyllähän sänkkäri, betonipintasänkkäri on, se on kestävä, se on kustannustehokas ratkaisu, mutta sitte siitä täytyy mennä eri suuntiin sitten, tuota, kaavan ehdoilla. Sänkkärissä on kaikki on valmiina tehtaalla. Et se on kaikki mitä kiivetään työmaalla ja tehdään, se aiheuttaa sitte kasilitteran härväämisen siihen. Siinä on kustannushaasteet, siinä on laatuhaasteet, siinä on, on niinkun työtyrvallisuushaasteet aina kun työmaalla kiivetään ja värkätään."
Municipal city planners and politics are ill-informed about the effects of their directives. Municipal directives raise construction costs and bring extra challenges. The builder has clear incentives to collaborate and improve city planning details	19(36:15) Mitkä on suurimmat haasteet runkorakentamisen kulujen hallinnan kannalta? "Kyllä se on nämä kaavoittajien erilaiset kotkotukset niin sanotusti, että kaavoissa viedään asioita liian yksityiskohtaiselle tasolle. Ja kyllä se niinkuin. Kaavoittajan ajatukset ei kohtaa ihan sen toteutuksen kanssa. Jos puhutaan ihan perusasuntorakentamista niin eihän siellä mitään monumentteja tehdä. Kyl se niinku ihmisillehän niitä asuntoja tehdään eikä niinkuin ulkoisesti hyvännäköisisä. Toki saa kaikki kohdata, mutta että asunto on hyvä asumiseen. Ja välillä tuntuu että se unohtuu, ja-ja kaavoittajaa ajattelee vain jotain kaupunkikuvaa ja miten ikkunat pitää sijoittua ja, se voi johtaa siihen että niitä asuntoja on älyttömän vaikea toteuttaa sen mukaisesti sinne talon sisälle. Että kaava on yksi iso tekijä mikä tuo lisähintaa tälle rakentamiselle."
Municipal directives raise construction costs and raw materials consumption.	14(54:10) "Siihen että mitä kehitysasioita tuohon kerrostalorakentamiseen ja runkoon liittyen. (...) Toivoisin että se niinku menis niinku sellaiseen yksinkertaisempaan muotoon tai että ei niinku haaveiltais sellaisista hirveen monimuotoisista kerrostaloista joissa tuhlataan paljon

	kaikkia raaka-aineita. Ja, ja, ja et kaupungit ja kunnat ei vaatis että rakennetaan hirveesti kaikkii yhteistiloja mitä kukaan ei käytä sitte, sitte koska se tuhlaa meidän luonnonvaroja ja ei se oo mitenkään kestävää rakentamista. Että ainaski niinku sitä, sitä niinku toivois että menis siihen suuntaan."
Municipal city planners and politics are ill-informed about the effects of their directives. The builder has clear incentives to collaborate and improve city planning details	YM. Sauli Ylinen pitkospuut (11:52) "Terveiset kaavoittajille. Me mielellään tullaan käymään toimialana teidän kanssa niitä asioita läpi, mitkä asiat vaikuttaa puurakentamiseen, ettei tulisi tämmöisiä... Joissain kaavoissa on mahdollista ehkä tahtomattaa on poissuljettu tiettyjä ratkaisuja, kun ei välttämättä ole etukäteen tiedostettu, mitä eri menetelmät vaativat. Samaan hengenvetoon on sanottava että kaavoittaminen palvelee koko yhteiskuntaa ja puurakentaminen on vain yksi osa tätä kokonaisuuden optimointia. Sitten on myös ne paikat missä sitä ei tule käyttää. Tällaisen dialogin tervehdyttäminen siihen että missä se oikeesti on yhteiskunnan etu ja missä se ole soveliasta käyttää, niin tällaista kaipaan enemmän."
Finnish building code made for concrete and may be unnecessarily strict for wood	6(15:30) "Kyl tuolla maailmalla, Sveitsissä ja muualla tehdään paljon toimistotaloja missä on, tuota, puisia pilareita ja puisia palkkeja, ja tuota, ja CLT-laatasta holvi minkä päälle valetaan sitten kymmenen senttiä betonia ja se toimii ihan vallan mainiosti, ja niin edelleen. Mutta ennen kuin me päästään siihen, niin tuota varmaan mun työura on taputeltu. Täällä on sitten meidän palomääräykset ja muut niin sitten tuota puukerrostalot on aina sprinklattava, ja niin edelleen. Niin tuota kyllä meillä siis betoniteollisuus on 60-luvulla saanut lobattua tämän maan siihen kondikseen että meidän määräykset suosii hyvin selkeästi betonirakentamista. Niin, että kyllä siinä muilla on paljon tekemistä. Että puu sinänsähän jos on massiivipuurakenne niin sehän kestää aika kauan kun se hiiltyy ja se hiili rupee suojaan sitä puuta niin sehän palaa entistä huonommin että sinänsä jonkulainen kantavuus siellä säilyy pitkään."
Finnish building code made for concrete and may be unnecessarily strict for wood	YM. Arttu Suuronen pitkospuut (1:20): "Mää oon sitä mieltä et siinä ei oo hinnan eroo, jos me mennään - kaks täysin identtistä taloa ja tehään ne niinku-. Jos me tehdään betonin ominaisuuksien huomioon ottaen niitten supertalo, niin tottakai puu on siihen varmasti kallis, jos se on betonin ominaisuuksiin hyvä [optimoitu]. Mut sit taas jos mennään siihen, et me tehtäis päinvastoin niinku puun ominaisuuden huomioon ottaen samanlainen betonista, nii mä oon ihan varma, että me saadaan puutalosta halvempi ku siitä betonitalosta." Oma: nykysäännökset ja kaavoitus on aivan varmasti kehittynyt sen rakennustekniikan perusteella mitä on ollut käytössä, eli betonirakentamisen. Eli säännökset varmasti suosii niitä betonin supertaloja.
Finnish building code made for concrete and may be unnecessarily strict for wood Municipal city planners and politics are ill-informed, -	18(44:00) "Mut sitte tosi isona haasteena on viranomaiset puussa. Et ei Suomen niinku rakennusmääräykset ja muut niin, on, öö, on niinku betonirakentamiseen soveltuvia. Ja puuta niinku pelätään. Et se niinku, määräykset tekee sen että se puurakentaminen on tällä hetkellä niin tolkuttoman kallista verrattuna betoniin et sitä ei niinku kannata useinkaan tehdä. Sen lisäks kaavotus kaavoittaa betonitaloja.

about the effects of their directives. The builder has clear incentives to collaborate and improve city planning details Municipal city planners and politics are ill-informed about the effects of their directives.	Puurakentamisessa on omat niinkuin, öö, lainalaisuutensa sen niinku kustannustehokkuuden suhteen. Että kun kaavoittajat kaavoittaa, niin monesti ne kaavat on sellaisia että sitä ei niinku voi puulla edes tehdä kustannustehokkaasti. Tähän niinku rakennusteollisuuden pitäisi päästä tai viranomaisten ja rakennusteollisuuden pitäisi yhdessä ratkaista se että jos halutaan puurakentamista kasvattaa, on se sitte niinku ekologisista syistä tai-, tai muista syistä, niin sitä yhteistyöstä pitäisi siinä kaavoituksen ja rakennusvalvonnan rajapinnassa tehdä tosi paljon että me saatais semmosia kaavoja, ja määräykset olisi sellaisia että puurakentaminen olisi mahdollista kustannustehokkaasti. Se on niinkuin suurin haaste puurakentamisessa tällä hetkellä." Mitkä ne on ne asiat mitkä vaikeuttaa puun käyttöä? "No, esimerkiksi tämmöiset niinkuin, öö, rakennuksen dimensiot, öö, tämmöiset kaavoituksessa monesti laitetaan esimerkiksi että sää et saa tehdä, tai sun pitää tehdä sisäänvedettyjä ullakkoja. Se muoto on niinku haaste. Sen lisäksi niinku joka ikinen rakennusvalvontaviranomainen tai rakennusvalvontaan liittyvä viranomainen on se sitten paloviranomainen tai LVI tai niinku ihan niinku rakennuspuolen viranomainen niinku ikäänkuin varmuuden vuoksi laittaa niin kovat vaatimukset sille puulle kun ne ei itsekkään niinku tiedä. Kun virkamies toimii virkavastuulla niin se pelkää sitä että jos hän päästää niinku tai tekee jotain niikun, ikäänkuin päästää läpi jotain sellaista mikä ei sit niinku olekaan niinku paloteknisesti tai rakenneteknisesti tai mitä vaan niinku toimivaa niin sitte hän on vastuussa siitä, vaikkei se niin tietenkään olekaan. Tää johtaa siihen että ne vaatimukset puulle on niin järjettömät että sitä puurakentamista on tosi hankala tehdä kannattavasti, kustannustehokkaasti. Elikkä meidän rakennusteollisuuden ja viranomaisten pitäisi yhdessä löytää ne keinot siihen että me voitais puurakentamista edistää täällä suomessa. Sitte vielä niin että kun ne keinot on löydetty niin niissä keinoissa myös pysyttäis eikä ois niinkuin kun yksittäisellä rakennusviranomaisella on tietynlainen valta, niin hän voi pyytä, tai niinkuin vaatia enemmän kuin määräykset ikäänkuin vaatii. Niin pitäisi niinkuin rakennusvalvonta ja myös olla mukana tässä kaikkien, sitä puurakentamista edistää. Tää niinkuin tää toimintaympäristö täällä Suomessa on tosi hankala siihen puurakentamiseen." Tulkitsenko oikeen, voiko sanoa niin että määräykset tulee siitä että minkälaisia betonirakennukset on ja mitkä ominaisuudet betonirakennuksilla on ja ajatellaan et juuri ne ominaisuudet mitä betonirakennuksella sattuu olemaan niin pitäisi kaikilta osin juuri samalla tavalla puurakennustenkin täyttää? "Käytännössä kyllä. Toi on ihan hyvin pistetty. Noin se on oikeesti." Entä huomioidaanko puukorttelien kaavoissa puun vaatimukset paremmin? "Olen ymmärtänyt että nämä puukaavat juuri on kaavoitettu niinkuin ne olisi betonia. Pitäis päästä niinkuin paremmin keskusteleen sen kans, rakennusvalvonnan ja ympäristöministeriön ja kaupunkien kaavotuksen kanssa siitä että mitä tämä puurakentaminen niinkuin vaatii jotta se on niinkuin mahdollista. Koska se-, monet yritykset ei tällä hetkellä halua koskea pitkällä tikullakaan siihen puurakentamiseen kun se on niin kallista. Kannattaa tehdä betonia kun se on varmaa ja sitä osataan ja määräykset, ja koko meidän rakennusteollisuus

	on ohjelmoitu siihen betonirakentamiseen." (...) Voitko antaa oman näkemyksesi erilaisten puurakennevaihtoehdoista? "CLT:hän vastaa niinkuin hyvin niinkuin tähän niinkuin määräyksiin, se on varmempi. Se on myös tehdasvalmisteisesti niinku parempi koska sen pystyy ajaa CNC-koneella niinku millilleen siihen kun se on ja se pysyy siinä. Rankarunkoisesta niinkuin on paljon enemmän haasteita kun CLT:ssä. CLT:ssä on taas se että se on tosi kallis se ratkaisu. Et, tuota, jos se ei olis niin kallis niin ei kannattais miettiä muuta kuin CLT:tä."
Finnish building code made for concrete and may be unnecessarily strict for wood	19(52:40) "Mää itse henk-kohtaisesti kannatan aika pitkälti betonia, koska se tuo aika paljon niinkuin sitä mukavuutta tullessaan siihen asumiseen, on hiljaista, on tavallaan turvalliset, paloturvalliset rakenteet, ja se myöskin niinkuin tukee tätä Suomen määräyksiä ja ohjeita miten täällä pitää rakentaa. Että kun tuntuu että ei niihin oikein höllennyksiä tule, kaikki vain tiukkenee koko ajan. Ääni ja paloasiat. Niin hybridiratkaisut on aika vaikeita. Et ne tekee sit sellaista että joutuu, tai siis puuta sit joutuu suojaamaan kipsilevyllä. Sama teräksen osalta, ne pitää täyttää betonilla tai suojata palonsuojalevyllä. Eli betoni on itsessään aika hyvä materiaali. En mää nyt sen enempää oo sen puolestapuhuja mut se on monta kertaa se helpoin ja kustannustehokkain ratkaisu. Varsinkin asuntorakentamisessa."
Finnish building code may be unnecessarily strict for wood	7(50:40) "Palopuolella on erittäin paljon kehitettävää. Se on mun mielestä nyt paikoin semmoista yliampuvaa ja-, ja ja tuota, hankalaa kun mietitään että meidänkin tapauksessa me sprinklataan aina kaikki. (...) Jotenki se tuntuu että tällä hetkellä on-, on niinkuin tuplavarmistettua kaikki siitä että ensiksi suojataan rakenteet palolta voimakkaasti ja sitte sprinklaus siihen lisäksi. Se tuo taas todella paljon kustannuksia ja vaativuutta siihen tekemiseen."
Municipal city planners and politics are ill-informed about the effects of their directives.	1(5.3.7) ”väitän että suomalaisessa betonielementtiteollisuudessa on eväät tehdä pirun hyvää toimivaa rakennetta, mutta kaavottajat ja arkkitehtuurilla ymmärrys siitä että minkälaisisa massoja ja hahmoteltuja rakennuksia kannattaa tehdä jotta pysytään turvallisessa rakentamisessa. Jos halutaan suuria lasipintoja ja sekarakenteita ja monimuotoisia kattoja ja parkkihalleja, vinoja seiniä, niin vaikka parhaan kyvyn mukaan tehdään, niin ihmiset tekee aina virheitä varsinki jos ei ennen ole tehty. Ja suunnittelukaan ei välttämättä vastaa todellisuutta."
Municipal directives and building code restricts development	9(1:09:00) Varovaisuus kehittämisessä? "En tiedä onko se varovaisuutta, varmaan liikkumavarakin on jollain tavalla semmoinen rajattu. Mutta siinä mielessä on se [varovaista], että täytyy ottaa huomioon määräykset ja ohjeistukset ja tuotannon tehokkuus ja talous. Tottakai meidän pitää miettiä koko ajan että me pystyttäis tekeen parempaa tuotetta, laadukkaampaa edukkaammin."
Example of collaboration with officials	19(5:05) "Urakkamuodot on menny aika pitkälti siihen että on tällaisia 2-vaiheisia projektijohtourakoita eli ensiksi neuvotellaan siitä että minkälainen tarjouspyyntö sieltä tilaajalta tulee, ja mennään referenssien kautta päästään sisälle. Ja sen jälkeen ruvetaan käymään

	keskustelua siitä tavoitehinnan/projektijohtopalkkion suuruudesta. Ja niissä on semmoinen kehitysvaihe joka voi kestää noin puoli vuotta jossa suunnitellaan se kohde aika valmiiksi ja sen jälkeen vasta annetaan se sitova tarjous, mikä on niinkuin riskien hallinnan kannalta ihan hyvä tapa. Siinä myöskin niinkuin autetaan tilaajaa siinä että se hanke saadaan heidän budjettiinsa. Esim me tehdään aika paljon sitä suunnittelu- ja sitä tuotannonkehittämistyötä että saadaan asiat kohdalleen. Tämä on yleistynyt mutta on ehkä tullut tuonne julkiselle puolelle sellaiseksi-. Mää luulen että heillä ei oo niinkuin resursseja siihen, ei aina osaamistakaan, niin he sitouttaa urakoitsijat hyvin aikaisessa vaiheessa ja sellaiset tahot joilla on niinkuin resurssit siihen hommaan. Kaupungin kanssa ollaan varmaan kolmessa hankkeessa ja sit on tässä niinkuin pari muuta tämmöistä nyt vireillä ja toivotaan että päästään maaliin. Ovat myöskin enemmän tai vähemmän julkisia tahoja." "Me vain ja ainoastaan urakoidaan. Mutta meillä on aika paljon siitä huolimatta sellaisia että kehitetään maa-alueita, viedään kaavoitusta eteenpäin, ollaan aktiivisesti siellä niinkuin maanomistajan kanssa keskustelussa: kaupungin kanssa. Ja sit me haetaan siihen sijoittaja tai joku taho mikä sit ostaa sen tontin ja me hoidetaan se rakentaminen ja suunnittelu ja kaikki avaimet käteen periaatteella. Eli me ei käytetä meidän omaa tasetta ollenkaan maan ostoon. Mut meidän liikevaihdosta tänäkin vuonna tulee varmaan 50% pelkästään tällaisista kohteista. Eli me sitoutetaan tavallaan itsemme ja se maanomistajakaupunki ja sit seuraa joku tilaajataho siihen hankkeeseen ja me viedään se sit niillä määrätyillä parametreilla maaliin mikä siinä sitten on niinkuin-, minkä tapainen hanke mihinkin sopii. (...) Me yritetään myydä ja tähdätään siihen että me myydään niinku enemmän palvelukonseptia tässä, ja me hoidetaan kaikki. Pyritään pääseen eroon siitä 'vain urakoitsija' -maineesta ja tyylistä, ja tuodaan siihen hankkeeseen lisäarvoa meidän osaamisen kautta."

Theme: Element Availability Problem: the varying availability of building elements due to geography and market fluctuations was seen as a determinant for the commercial viability of elementized construction, including TMC.	
Coding	**Representative quotes**
Lead time predictability is important to keep schedule, thus costs, in control	11(49:20) Mitkä on suurimmat haasteet kulujen hallinnan kannalta? "[Normaalitilanteessa] kyllä se tuota, no siis, toimitusvarmuus on, kun nythän rakennetaan niin kovasti niin se toimitusvarmuus on ykkönen. Ja sit tietysti aikataulun hallinta. Kun kerrostalorakentaminen on semmoista että aikataulun hallinta on tärkeämpää ja se on paljon nopeampirytmistä kuin esim liike- ja toimitilarakentaminen ja ei oo yhtään vaihtomestaa tuommoisessa pienemmissä hankkeissa: täyty mennä kerralla nappiin. Ne jos myöhästyy, riskinä on kustannuksien karkaaminen."

Element challenges are pronounced in wood construction due to lack of standardization	6(12:05) "Sitä puurakentamistahan pitäisi mahdollisimman pitkälle elementoida. Sit jokaisella puuelementtivalmistajalla tuntuu olevan vähän oma detaljiikkansa liitoksista ja niin edelleen. Et se ei oo ollenkaan se puurakentamisen detaljiikka ohjeistettu ja harmonisoitu kuin betonirakentamisessa. Ja mitoitukset ja laskelmat, niin jokainen tekee niitä vähän omalla tavallaan ja vähän soveltaen niin edelleen."
Choice of element construction must be done in early stages of the project Long lead times of elements may make CIS favourable Logistics costs of (concrete) elements are significant Economic trends have considerable impact to elements' cost and lead time, not to on-site construction Choice of element construction must be done in early stages of the project Element orders must be placed in early stages of the project	1(1.3.3) ”Elementointi vai paikallarakentaminen? se on varmaan monilla muillakin strateginen valinta. Olet nyt just ytimessä siitä että mitä valintoja meidän pitää tehdä tällä hetkellä ja painitaan niiden kanssa jatkuvasti. Pitää arvata hinnat ja saatavuus vuoden-parin päähän koska valinnat lyödään lukkoon silloin kun aletaan ensimmäisiä suunnitelmia tekemään” 3(9:30) "Kun mietitään paikallavalua tai elementointia niin kustannukset on tietenki yksi merkittävä. Toinen on sitten se että kun mietitään mikä on se toteutusaika/toimitusaika. Että varsinki kun välillä, niinkuin nytkin, elementtien toimitusaikataulut on niin pitkiä että onko se järkevämpi tehdä paikallavaluna. (...)Onko se nyt kuukauden pidempi rakennusaikataulu vai ei niin, sillä nyt ei välttämättä oo merkitystä. Toki se vaikuttaa kustannuspuolen vertailuun että onko se järkevää. Sitte mitä on mietitty paikallavalua että toisaalta elementtien toimitusaikataulut voi olla niin pitkiä että päästäisiin aikaisemmin aloittamaan jos tehtäisiin paikallavaluna. (...) Kyllä aina kaikki elementit kilpailutetaan kohdekohtaisesti. Toki niinkuin aina monesti, niissäkin on kuljetuskustannukset sen verran merkittävät että kyllähän ne painottuu monesti näihin lähialueen tehtaisiin mistä ne tulee. (...) Tällä hetkellä, viimeaikoina tuo markkina on vähän ollut silleen että nuo hintavaihtelut on aika isoja, että siinä mielessä kustannusten ennakointi kun hankintoja tehdään että mikä sen projektin niinkuin kokonaiskustannus on niin se on ehkä semmoinen niinkuin isoin riski aina että missä markkinassa ollaan. Mitä ne sitten-, ennen kuin se hankinta on tehty, -mitä ne esim elementit maksaa ja mikä niiden toimitusaika on. (...) Pitää oikeassa vaiheessa kilpailuttaa elementit, mikä tarkoittaa että pitää olla hyvissä ajoin tekemässä se varsinki jos tulee-, tuota, toimitusajat on niin pitkiä että pitää jo melkein siinä vaiheessa kun suunnittelu on vielä kesken-, tuota, pyrkiä saamaan suunnittelu siihen vaiheeseen että tuota, saadaan elementtisuunnittelu liikenteeseen. Kyllä monesti jo tehdään ennen rakennuslupaa tehdään ehdolliset tilaukset elementeistä. Tällä hetkellä on pakko tehdä, kun niiden toimitusaika liikkuu tuolla kymmenessä kuukaudessakin."
Choice of element construction must be done in early stages of the project Element challenges are pronounced in wood-	13(14:10) "Rankarunkoisten suurelementtien toimittajia on tietty toimittajakunta joka tekee sillä, ja sitten on tietty toinen toimittajakunta kuka tekee esim tilaelementeillä. Tämä päätös kummalla runkoratkaisulla me lähdetään hankkeeseen pitää tehdä hyvissä ajoin jo ihan siinä luonnossuunnittelussa että kumpi runko valitaan. Sen perusteella tulee ne yhteistökumppanit että kuka on se runkoratkaisutoimittaja on heti sit seuraavassa kättelyssä. Se eroaa siinä suhteessa siihen

construction due to lack of standardization	betonielementtirakentamiseen kun sitä kautta tulee niitä vaihtoehtoisia toimittajia on erilainen määrä. Että kun betonielementtitoimittajia saattaa olla 70kpl ja sitten kun valitaan rankarunkoinen suurelementtijärjestelmä joka niin sanotusti noudattelee tuollaista normaali betonirunkotoimitusta, niin siinä on huomattavasti vähemmän niitä toimittajia, puhutaan varmaan kymmenesosa mitä on betonielementtitoimittajia. Sama juttu tilaelementeissä."
Element challenges are pronounced in wood construction due to lack of standardization	13(44:10) "Se [puurakentaminen] ei ole niin standardoitua. Kaikki rakennetyypit on niin elementtitehdaskohtaisia. Ei ole sillain kun lähetän tuonne elementtitehtaille niin jokainen melkein tietää minkälainen on niinkuin väliseinä betonielementistä tehtynä tai minkälainen on ulkoseinä betonielementistä tehtynä. (...) Se on vaan niin erilaista, se on toimittajakohtaista että mitä on tyyppihyväksytty ja näinpoispäin, mitä ne on hyväksi havainnut missäkin."
Choice of element construction must be done in early stages of the project	13(1:10:40) "[Kylppärielementtien toimitusaika] taitavat myydä tällä hetkellä 7-8kk päähän. Eihän ne nyt varmasti sitä heti tarvi sitä laattatietoa mutta niin sanotusti hyvissä ajoin varmasti niinkuin täytyy olla puolta vuotta ennemmin tiedossa että mitä laattoja ja mitä vessanpönttöä sinne on tarkoitus ottaa ja tilata että saavat ne hankintansa tehtyä."
Element construction is technically easier and technically more stable than on-site. Cost predictability is more important than expected cost minimization Actualized element construction costs are easier to predict than on-site. *(Continues on next page)*	5(5:45) "Meillä on vahva ajatus ja kantava ajatus että me elementoidaan sitä rakentamista niin paljon kuin mahdollista. (...) Siinä se kantava ajatus on se että me on nähty se niin että kuitenki se ikäänkuin rakentaminen siellä stabiileissa olosuhteissa on helpompaa kuin siellä työmaalla. Elikkä ajatus siitä että jos mietitään vaikka seinää että kun valetaan työmaalla vaihtelevassa keliolosuhteissa vaihtelevien tekijöiden kanssa versus se että tehdään siellä tehtaalla pitkälti samat miehet tekee siellä pitkälti niitä elementtejä ja stabiileissa olosuhteissa. Me ollaan niinku nähty se järkeväksi että se esivalmistus kannattaa viedä pidemmälle kuin sillain että työmaalle tulee sitä rautaa ja kuraa ja [inaudible]. Yksi niinkuin tärkeä asia on tavallaan se hintavarmuus. Nyt on vähän poikkeukselliset ajat just tällä hetkellä mutta sanotaanko aiemmin me ollaan tiedetty hyvin että paljonko se elementtirakentaminen, maksaa paljonko elementit maksaa, ja paljonko asentaminen maksaa, niin me ollaan pystytty hyvin luotettavasti ennustamaan sitä, ja sit me ollaan nähty että jos me lähetään siellä työmaalla tekemään paikallavaluna niitä rakenteita niin siinä on ehkä enemmän sit niitä muuttuvia tekijöitä, että miten siinä urakassa onnistutaan ja miten siinä aikataulussa pysytään kun sitä työtä työmaalla on enemmän. Että tämmöinen seillä on niinku se kantava ajatus siellä taustalla että me tiedostetaan se että välttämättä se ei ole se absoluuttisesti se halvin tapa välttämättä tehdä elementeillä, mutta me tiedetään se etukäteen. Se ennustettavuus on niinkuin hyvä. Ja sit se tavallaan laatu-, laadun ylläpitäminen tuolla systeemillä niin se on niinku helpompaa, se on tasalaatuisempaa se meidän rakentaminen. Aina hinta on oleellinen asia, niin se nähdään että vaikka se ei ole aina absoluuttisesti halvin niin se on ennustettavaa. Tavallaan se ajatus sitten pidemmälle, sitä kautta kun se on ennustettava niin tiedetään että se

	maksaa tän verran, niin se riski siitä että se kustannus paisuu jonnekin on pieni ja pienempi kuin siinä paikalla tapahtuvassa rakentamisessa. Että tavallaan pohjimmiltaan niinku uskotaan että vaikka laskennallisesti vaikka laskisit että nyt se paikallavaluholvit ja seinät olisi halvempi, niin sitten monesti kun se hanke on toteutettu ja katsotaan että mitä se maksoi, niin lopulta se kustannus on helpommin ryöstäytynyt käsistä kun sitä työtä on tehty siellä työmaalla ja ollut niitä muuttuvia tekijöitä. Eli ajatus siitä että keskimäärin sitten kun katsotaan niitä hankkeita taaksepäin, kun vähä erilaisilla porukoilla, eri kokemusmäärää omaavilla työnjohtoporukoilla tehdään noita hankkeita, niin keskimäärin se elementtirakentaminen olisi halvempaa."
Local element availability is important for elements' cost competitiveness Actualized element construction costs are easier to predict than on-site.	8(13:05) "Seinärakenteissa (...) on tilanteita että on elementtien saatavuuden kanssa ongelmia, hintojen kanssa isoja haasteita (...). Sitten taas tullaan siihen että mikä on hallinta-aste, mikä on saatavuus. Paikallavaluseinien hallinta-aste on-, siinä on muuttujaa, siinä on sitä kasilitteraa, työmaan käyttöyhteiskustannusta niin paljon enemmän jonka hallitseminen on vaikeampaa kun taas elementtikauppa kun on kiinni niin siinä on selkeä asennus ja se on siinä. Ei siinä oo hirveästi sitten ylimääräistä leikkiä."
Local element availability is important for elements' cost competitiveness Logistics costs of (concrete) elements are significant	18(15:55) "Oulussa tehdään puurunkojulkisivuja ja muualla pääosin betonielementeillä. Siinä on kaksi syytä: Oulussa on osaaminen siihen puutouhuun. (...) Sit Oulussa ei saa tällä hetkellä betonielementtejä hirveän hyvin. Se markkina ei niinkuin-, siellä ei ole tehtaita niin paljon kuin muualla Suomessa. Niin se on niinkuin toinen asia. Että siellä kannattaa tehdä puusta niitä, se on halvempaa. Muualla Suomessa markkinat on niinkuin, on paljon helpompi saada betonielementtiasentajia kuin puuelementtiasentajia. Ja sit taas niinkuin tehtaita on niinkuin paljon, kilpailua on paljon, kilpailu tehdashinnoissa on parempaa. Niin se-, käytännössä just tehtiin laskelma siitä sillä ei oo oikeastaan väliä et onko se puuta vai betonia et saman hintaista suurin piirtein on se tekeminen, niin silloin kannattaa betonia ottaa. Ihan siis, jos asiakaspuolelta ajattelee, niin moni niinkuin haluaa elinkaarinäkökulmasta betonin mieluummin kuin puun."
Local element availability is important for elements' cost competitiveness Logistics costs of (concrete) elements are significant	22(6:00) "Pohjois-Suomessa on käytännössä niinkuin Rajaville on ainut elementtitehdas joka on Oulussa, sit seuraava onki jo Pellossa. Niin aika paljon on ollut se ongelma varmaan ja mikä on vaikuttanut tähän meidän ratkaisuun on se että meillä ei oo oikein ollut elementtipuolella semmoista järkevää kilpailua tai tarjontaa mikä ois niinku sen hintatason kautta tullut järkeväksi vaan meillä on ollu pitkään se että myöskin taloudellisesti on nähty että paikallavalettu kantava väliseinä on meillä halvempi kuin että me ostettaisiin sitä elementtinä. Kylpyhuone-elementtien kanssa on ihan sama homma. (...) kun ne tehtaat on Etelä-Suomessa-, se on se rahti niin kallis kun niitä lähdetään tuomaan pohjoiseen. Sen tietää että se rahtikustannus on niinkuin iso."
Economic trends have considerable impact to -	22(10:45) "[Elementtien kannattavuus] on suhdannekysymys myöskin. Että suhdanne vaikuttaa vahvasti elementtien hintoihin. Silloin kun

elements' cost and lead time, not to on-site construction	kysyntä on kova niin elementtien hinnat kasvaa kanssa. Silloin paikallarakentamisen edullisuus korostuu. Mutta silloin kun suhdannekuva on se että elementtejä on hyvin saatavissa ja hintataso on kohtuullinen, niin silloin se elementtirakentamisen ja paikallarakentamisen ero on pienempi. Se eron suuruus sanotaanko että suhdannetilanteessa ollaan suht-normaalissa tilanteessa, niin elementtituotannon osalta se saattaa olla lähellä hintatasoltansa paikallarakentamista, niin elementtituotannossa jotta sää pysytyt hyödyntämään sitä elementtiratkaisua taloudellisesti järkevästi niin sun täytyy ottaa hyötyjä myöskin sitten sen työmaan aikataulussa."
Local element availability is important for elements' cost competitiveness Logistics costs of (concrete) elements are significant	17(23:05) "Oulussa niinkuin ontelolaattoja ei saa muualta kuin Rajavilleltä. Sitten kun ne ontelolaattojen toimittaminen tuolta etelästä, niin tulee niitä kuljetuskustannuksia, niin nehän on kaikilla Oulussa Rajavillen ontelolaattoja."
Choice of element construction must be done in early stages of the project Element orders must be placed in early stages of the project	19(30:00) "Hankintojen aikataulutus on vähän semmoista kaksivaiheista. Että kun me sitä hanketta viedään eteenpäin niin kyllä me pyydetään niinku ennakkotarjouksia elementtitoimittajilta ja tavallaan varmistetaan että me saadaan niitä elementtejä. Se tapahtuu siinä yhdessä sen suunnittelun kanssa kun meillä alkaa olemaan ensimmäisiä tyyppielementtikuvia niin voidaan jo lähteä esittämään pyyntöjä elementtitoimittajille. Mutta lopullinen valinta normaalimarkkinassa tapahtuu vasta kun se on suunniteltu se niin pitkälle ja meillä on varma aloituspäätös ja sit pistetään uudestaan kilpailuun ja haetaan se lopullinen hinta. Mutta jotta me saadaan se budjettihinta kasaan niin meidän on pakko pyytää niitä ennakkotarjouksia. Se ei niinkuin normaalimarkkinassa ole vaikeata hinnoitella niitä ilman ennakkotarjouksia mutta tässä markkinassa on ihan ehdoton edellytys kun hinta tuntuu olevan joka päivä eri, varsinkin kun se tuntuu nousevan niin tää on vähän vaikeeta. Mut, elementtien hankinta yleisesti on sellainen haastava. Se pitää aika aikaisessa vaiheessa tehdä, normaalimarkkinassa varmaan kolmessa neljässä kuukaudessa saa elementtejä, tällä hetkellä puhutaan kuudesta viiva yhdeksästä kuukaudesta varmaan."
Logistics costs of (concrete) elements are significant	9(59:45) "Mä näkisin että tullaan enemmän siirtymään siihen esivalmistusasteen nostamiseen, ja logistisen-, nyt varsinkin kun maailman tilanne on mikä on, ne logistiset kustannukset alkaa oleen sitä luokkaa että ei yhtään ylimääräistä kuormaa kannata ajaa. Elikkä nyt pitää miettiä tarkkaan että mitä sinne työmaalle tuodaan. Tää liittyy siihen esivalmistukseen sitten."
Choice of element construction must be done in early stages of the project Element orders must be placed in early stages of the project	23(33:15) "Onhan meilläkin tutkittu sitä asiaa [kylpyhuonemoduuleja] ja mietitty ja muuta-, ja miettii että minkä verran niitä moduulien tekijöitä on Suomessa. (...) Se [tilaus] pitää tehdä melko aikaisin, niin tavallaan siihen ei ole rakennuslupaakaan eikä mitään, saatikka aloituspäätöksiä kun pitäisi tehdä se tilaus."

Module choice must be done in early stages of the project	6(12:05) "Jos joku rakennuttaja haluaa itselleen puukerrostalon niin sen kannattaa pyytää KVR-urakkana, jolloin se urakoitsija valitsee jonkun kumppanin ja sit sen niillä detaljeilla suunnitellaan. Jos se rakennuttaja piirtää ne kuvat valmiiksi että tämmöinen puukerrostalo, ja siellä on kaikki kuvat valmiina, niin siellä on yleensä jonkun toimittajan detaljit olemassa siinä rakennuksessa. Tai sitten ne on jonku rakennesuunnittelijan niinkuin omasta päästä. Ja sitten kun siihen tulee puuelementtitoimittaja niin se sitten muokkaa niitä oman järjestelmänsä mukaisesti. Ja sitten aina kun jotain muokataan niin hyvin helposti sitten jää jotain asioita huomaamatta, ja tulee virheitä ja tulee puutteita tai tulee huonoja liitoksia tai-, tää on huono tapa. Siinä rupee olemaan niin paljon muuttujia että se sisältää sitten eri tavalla riskejä."

Theme: Modifiability Problem: Currently, using extensive prefabrication limits the types of projects that are commercially viable due to significant extra costs that arise from variations and modifications in the types of elements used in the building

Coding	**Representative quotes**
Modular construction restricts possibilities for end user driven modifications Module configuration must be done in early stage of the project In builder vendor projects, offering residents the possibility to make modifications to the apartment is seen as important	8(6:10) "Kylppärielementit ei oikein oo päässy vielä valtaan. (...) se on sellainen kytevä. (...) Se on sellainen asiakasrajapintaratkaisu. Sehän on kuitenkin marginaalinen asukasmuutoksille ja personoinnille. (...) Tälläisessa kohteessa missä asiakasta pitää oikeasti kuulla ja ymmärtää ja muuttua siinä mukana niin se pitää tehdä paikalla se kylppäri. Se antaa pitemmän aikajänteen enemmän mahdollisuuksia. Muutama gryndi on siitä tehty, siinä tietysti se että meillä pitäisi olla asiakkaat ja kaupat tehty jo heti alussa että päästään siinä kohtaa tekemään kaikki valinnat. Se on aika harvoin niin ja sitten niitä valintoja tehdään ja sitte on niitä haastavia tilanteita."
In builder vendor projects, offering residents the possibility to make modifications to the apartment is seen as important Modules restrict apartment layout Modules are most applicable to apartments where variation is small (e.g. rental)	4(34:30) "Kyllä se tulee varmasti tällainen niinkuin kylpyhuonemoduuli. Mekin sitä ollaan-, mutta meillä on tällainen niinkuin-, ei ole niin samaa blokkia joka kerros välttämättä että-. Tottakai pyritään että kylpyhuoneet menee mutta sitten tulee asukasmuutoksia jonkin verran kun tehdään kumminkin niinkuin asuinrakentamista niin sanotusti kovan rahan kohdetta, RS-kohdetta niin, niin tuota-. Se on varmaan enemmän se moduuli ja tuollainen blokkirakentaminen enemmän varmaan missä tehdään sitten enemmän vuokratuotantoa sun muuta, missä niinkun hyvin identtisiä-, pieniä muutoksia tulee rakentamisen vaiheessa, niin soveltuu varmaan paremmin sinne sitten kun tähän meidän niinkuin ydintuotantoon. (...) Meilläkin on tarjota niinkuin asuntojen yhdistämismahdollisuuksia ja muuta että-. Tehdään pohja että, jos varhaisessa vaiheessa on mukana-. Kyllä melkein joka taloon tulee vähintään yksi sitten tällainen asuntoyhdistäminen, niin se ei taas oikein palvele sitä

	moduulirakentamista: tämä niinkuin puoli, niin siinäkin on varmaan yksi syy minkä takia ei olla siihen sitten niinkuin lähdetty."
Module choice must be done in early stages of the project Module choice affects all other construction method and type choices Modular construction restricts possibilities for end user driven modifications	1(1.3.9.1) ”On ongelmallista että samaan aikaan pitää olla jo päätös elementtikylppäristä kun hakee jo rakennuslupaa, niin pitää koko suunnitteluprosessi tehdä kylppärin ehdoilla, hormit ja niin edelleen. Mun mielestä asiakkaalle ei tule etua siitä että tehdään kylppärin perusteella koko rakennus, mutta se voisi sopia jos myydään vain jollekin sijoittajalle joka vuokraa asuntoa, mutta ei lapsiperheelle koska ne ei pääse vaikuttamaan kylppärin pintoihin, materiaaleihin, yleensä myös keittiökin on sidottu kylppäripakettiin. Asiakkaat haluaa vaikuttaa keittiökalusteisiin, vesikalusteisiin, lattioihin, pintoihin. Moduulivalinnat on tehty jo arkitehdin tai muun suunnittelijan toimesta jo tosi aikaisin, jolloin asiakas ei pääse valitsemaan itse. Moduulirakentamisen suunnittelu ja toteutus menee täysin eri kaavalla kuin paikallarakentaminen.”
In builder vendor projects, offering residents the possibility to make modifications to the apartment is seen as important Modular construction restricts possibilities for end user driven modifications	5(2-0:10) "Me rakennetaan kylppärit paikalla aina. Meillä oikeastaan yksi iso syy on tuo asukasmuutosasia. Nyt kun me myydään asunnot ihan yksitelen pois, niin se tilaelementin tavallaan päätöksentekoprosessi, että missä vaiheessa täytyy valita laatat esimerkiksi kylpyhuoneisiin ja muut asukasmuutokset tehdä, niin ne ei sovellu tähän meidän asuntojen myyntiprosessiin laisinkaan. Niin käytännössä se johtaisi siihen että asiakkaat eivät voi valita laattoja kylpyhuoneisiin ja tehdä asukasmuutoksia siinä laajuudessa kuin me halutaan tarjota. Niin se on niinkuin pääsyy miksi me ei olla edes harkittu niitä esim kylpyhuone-elementtejä."
Modules are most applicable to apartments where variation is small (e.g. rental)	7(31:30) "Eikä me nyt olla siis, varsinkaan nuissa opiskelija-asuntokohteissa, me ollaan oltu jo halvempia kuin betoni. Elikkä se, missä tulee sitä moduulin toistoa ja tulee sitä tietyntyyppistä tekemistä niin se on ollut kyllä älyttömän hyvä-, hyvä niinkuin kustannuspuolelta."
Module configuration must be done in early stage of the project	7(34:30) Tilaelementit gryndissä? "On koitettu miettiä sitä, koitettu kehittää sitä prosessia silleen että se toimisi myös tuossa gryndissä. Me ei olla siinä kyllä vielä onnistuttu, että se on vielä aika huonolla tolalla kyllä. Se lähtee sieltä prosessin ymmärtämisestä. Sen asukkaan pitää niin hyvissä ajoin pystyä tekeen niitä valintoja että me saadaan sinne tehtaan tuotantolinjalle tarpeeksi aikaisin ne kaikki valinnat. Se on siinä se kynnyskysymys mikä siinä tulee vastaan. Me ollaan itse ajateltu se alusta lähtien kun lähettiin tuota gryndiä kehittämään, sen prosessin kannalta, että sen prosessin pitää olla niin selkeä ja hyvä siellä tehtaalla ja kaikessa siinä tehtaan tuotantoon liittyvässä tuotannossa että me voidaan tehdä-, tuota, tehdä myös niitä valintoja sinne että ne tulee oikeaan aikaan ja sillä ei ole oikeasti merkitystä kun se tuotannon työntekijä tekee siellä tehtaalla että lyökö se siihen harmaata vaiko tuota-, ruskeata parkettia. Että sillä ei oo niinkuin sen työn kannalta merkitystä, vaan kun se prosessi on siihen asti tehty niin aukottomasti että kun se tietty moduuli on siinä tuotannon alla, että siihen tulee oikea-aikaisesti oikea tuote minkä se lyö eikä sen tarvi sen työntekijän sitä miettiä vaan se on kaikki tehty valmistellen sitä sitten niinku oikeeseen aikaan."

In builder vendor projects, offering residents the possibility to make modifications to the apartment is seen as important Modules are most applicable to apartments where variation is small (e.g. rental) Module configuration must be done in early stage of the project	9(45:30) Moduulien muuntojoustavuuden vaikutus rakennevalintaan? "On yksi asia, mutta tällä hetkellä ratkaistavissa kyllä se on. Ja kylpyhuone-elementtejä saadaan mietittyä niin että ne voidaan sitten myöhemmin ottaa vähän erilaisella vaihtoehdolla-, tarkoitan että ne voidaan myöhemmin paikalla laatoitetaan ja tehdään pintamateriaaleja sinne. Mutta aikaisessa vaiheessa se pitää tehdä. Mutta se riippuu vähän kohteesta. Jos on gryndikohde ja tehdään valintoja, niin täytyy miettiä että mikä se vaihtoehto on, tää on se yksi haaste tietysti, mutta niihin on ratkaisut olemassa. Ja tietysti se hintaan vähän vaikuttaa kun, jos se tehdään paikalla taas siellä niitä kylpyhuoneen laatoituksia, mutta tuota-. Sitten on taas kohteita missä ollaan varmoja että ei tule muutoksia, tämmöiset sijoittajakohteet tai muut jotka tulee vaikka julkiset kohteet jossa on valmiit mallit ja niitä ei enää muuteta vaan tiedetään että nämä tulee ja pysyy. Mutta kuluttajakaupassa tietysti tottakai halutaan asiakkaita palvella ja antaa niille vaihtoehtoja. Se aiheuttaa semmoista pientä mietintää siihen että mikä on se valmiusaste ja miten niitä voidaan sitten lukita missäkin vaiheessa kiinni. Me tehdään paikalla tällä hetkellä kaikki. Me tutkitaan nyt sitä kylpyhuonemoduulia ensimmäistä kertaa mut me tehdään tehdään paikalla tällä hetkellä. Uskon että jatkossa tullaan ottamaan niitä kylpyhuonemoduuleja."
Residents do not care about the actual frame type choice in direct sense.	9(59:45) "Asukkaalle-, kuluttaja-asiakkaalle ja asiakkaalle se ei juurikaan siitä näy, samanlaista runkoa heille tekee oli se esivalmistettu tai ei. (...) Ottaen huomioon se, että me tullaan kehittämään sellaisia asioita jotka tuo jälleenmyyntiarvoa sille asunnon ostajalle, ja asukasviihtyvyyttä sille asiakkaalle. (...) En usko että runkoihin sillä on hirveästi merkitystä."
Modules can offer higher quality feeling (cutting edge cladding and furnishing) Module configuration must be done in early stage of the project Can get away with prefab bathroom modules when building is not in prime location	6(23:40) "Ollaan nyt useampikin kohde jossa meillä on kylpyhuone-elementit moduuleina. Niin tuota, kyllä mä sanon että kyllä siitä niinku paljon hyötyä on. Ja tuota, kylpyhuonemoduulitkin kehittyy koko aika ja ne on niinkuin ajanmukaisempia ja enemmän ajan hermoilla hyvin helposti, ja sitten niissä pystytään vähän niinkuin-. Puhutaan vaikka perinteisestä lattiakaivosta versus linjakaivosta. Niin tuota, linjakaivossa on työmaalla omat haasteensa että se saadaan oikeeseen korkoon ja se pysyy oikeassa asennossa, mutta sitten tuolla moduulituotannossa se on aika helppo ja-. Sitä kautta se mahdollista niinkuin vaikka lattiassa vain ison laatan käytön kun se lattia kallistaa vain yhteen suuntaan ja niin edelleen. Sieltä on niinkuin helpostikin löydettävissä sellaisia positiivisia vaikutuksia joilla voi niinkuin vaikka niinkuin myytävyyttä edistää ja jonkunlaista laadun tuntua. Ja toki mun mielestä niin, kun se tehtaassa duunataan niin on se laatu on tasaisempaa. [Muuntojoustavuuden pieneneminen], jos kysyt meidän asuntomyynniltä, niin tuota se on ihan hirveä katastrofi kun ne pitää lyödä niin aikaisin lukkoon. Mutta taas toisaalta kun se siinä myytäessä ja markkinoinnissa kerrotaan että näitä ei voi vaihtaa tai ainakin pitää nämä hyvin aikaisessa vaiheessa tehdä päätöksiä. Niin ei siitä nyt hirveetä purnausta kuitenkaan oo tullu. (...) Silloin kun ei olla ihan niinsanotusti tuolla niinkuin ytimessä ihan prime-paikalla, niin silloin se muutostöiden osuus ei tuo niin paljon painetta

	siihen tekemiseen tai asunnon myyntiin, niin silloin se näyttää pelittävän."
Module configuration must be done in early stage of the project Important to be able to offer modifications to higher trim apartments' design during construction	13(31:50) Kuinka paljon teette kylpyhuone-elementeillä? "Oiskohan puolet ja puolet, tyyliin. (...) RS-hankkeita ajatellen niin meidän täytyy kylpyhuone-elementteihin tehdä hyvin aikaisessa vaiheessa kaikki laatta- ja kaikki valinnat, ja niiden muutostöiden tekeminen on siellä niin sanotusti-. Niitä ei hirveesti siellä tehdä. Elikkä ne valitaan hyvissä ajoin hankkeen aikaisessa vaiheessa lyödään lukkoon. Sitten kun on tuommoinen paikalla tehtävä niin sää pystyt siellä asiakkaan kanssa-. Jos on nyt vaikka tämmöisiä isoja kohteita ja näinpoispäin, ja tulee vähän tämmöistä kalliimpaa tekemistä esimerkiksi että ei lyödä ihan 25m2 yksiöluukkuja täyteen, niin siellä pystytään sitten niihen asiakasvaatimuksiin ehkä vastaamaan paremmin ja tekemään niitä muokkauksia ja kaikkea muuta vastaavaa että niitä laattoja pystyy sitten vielä vähän myöhemmässäkin vaiheessa vielä valitsemaan ja vaihtaan ja näinpoispäin."
Modules are most applicable to apartments where variation is small (e.g. rental) Volumetric modular construction is most applicable to small apartments	15(23:10) "[Puisia tilaelementtejä] olen kyllä käynyt katsomassa kun ne rakentaa niillä, ja ne sopii jos on semmoinen sama-, hotelliin ja sitten opiskelija-asuntoon, jossa on samantyyppisiä ja aika pieniä asuntoja. Olen käynyt katsomassa kohdetta missä ei ole pieniä asuntoja, ja sanoin kun menin pois sieltä, että olisi kyllä vaikea olla vastaavana mestarina siellä kun vesi valui sisään vaikka siellä oli yritetty peittää hyvin. (...) Tietysti jos se on että yksi moduuli on yksi asunto, sitten mä sanon että se on ok. Muuten se on, tuntui olevan aika huono konsepti. Oikeastaan se on sama konsepti mikä meillä on, mutta me siirretään se tehdas siihen teltan alle siinä työmaalla. (...) Se on mun ajatus, mutta siellä on monenlaisia ajatuksia, ja niin pitää ollakin."
In builder vendor projects, offering residents the possibility to make modifications to the apartment is seen as important Modules are most applicable to apartments where variation is small (e.g. rental) Module configuration must be done in early stage of the project	23(33:15., 38:40) "Kyllä meillä on aika vähäistä se [kylpyhuonemoduulien] käyttö. Me ollaan kuitenkin se-, paljon tehdään tuota RS-tuotantoa nimenomaan kuluttajille ja yksityissijoittajille, niin moduulinhan tavallaan pinnat pitää lukita niinkuin huomattavan aikaisin että niitä pystytään alkaan valmistamaan että ne voidaan nostaa sinne runkoon. Että se joustavuus niiden kylppäripintojen kanssa katoaa aika äkkiä, niinkuin asukkaiden näkökulmasta. (...) Jos liikaa se modulointi alkaa ohjaamaan sitä tuotetta tai asuntopohjia tai muuta, niin kyllähän se aika paljon rajaa sitä ostajakuntaa. Ehkä tuommoisissa kerrostaloissa mitä myydään vaikka sijoittajille kokonaisuutena, siellä se ehkä ei ole niin-, sä voit pystyä sitä ehkä painamaan kuluja jonku verran alas ja myydä halvemmalla sitä tuotetta. Se on tavallaan jokaisen vähän oma strategia että minkälaista tuotetta haluat myydä ja kuka se sun ostajakunta on. (...) Pitää kuitenkin muistaa että Suomen rakentamisen markkina on kohtuullisen pieni, -maailman mittakaavassa. Ja sitten jokainen hanke on omanlaisensa."
Important to be able to offer modifications to higher -	18(25:50) "Pääsääntöisesti kyllä [käytetään kylpyhuonemoduuleja]. Elikkä on ihan ne erikoiskohteet sitte jossa ei, ja saatetaan kohteen sisälläkin jokunen kämppä tehdä paikalla tehdyillä kylppäreillä. Jos se

trim apartments' design during construction Module configuration must be done in early stage of the project Can get away with prefab bathroom modules when building is not in prime location Even in in-situ construction, some choices must be made in early stage of the project	ei sovellu se kylppärielementti niinku semmoiseen-. Että, meidän tavoitteenahan on tehdä hyviä asuntoja-. Jos jossakin asuntolinjassa tai puhutaan jossain Helsingin ykköspaikasta ja halutaan tehdä ylimpiin kerroksiin joitain hienompia asuntoja niin sitten se kylppärielementti ei sinne välttämättä sovellu niin tehdään silloin niinkuin paikalla. (...) Onhan meillä kylppärielementissäkin mahdollisuus esimerkiksi valita jotain laattoja ja jotain sadesuihkua ja tämmöistä niinkuin, asukasvalintaa pystyy tekeen vaikka ois elementoitukin. Joka tapauksessa suurin osa valinnoista täytyy tehdä niinku tämmöisistä toiminnallisuuteen liittyvistä niin hyvin varhaisessa vaiheessa suunnittelua jonka jälkeen on vaikea niitä muuttaa, niin sillä ei oo sinänsä väliä onko se paikalla tehty vai ei. Joka taupauksessa ne tietyt toiminnalliset valinnat on tehty siinä suunnitteluvaiheessa."
Important to be able to offer modifications to higher trim apartments' design during construction Modules can offer higher quality feeling (cutting edge cladding and furnishing)	20(27:30) "Sanotaan näin että kun puhutaan meidän niinkuin laadukkaammista kohteista, niin siellähän niinkuin varaudutaankin muutostöihin enemmän. Se on varmasti yksi syy minkä takia varsinkin tämmöisissä sitten halutaan korostaa vielä sitä yksilöllisyyttä että asiakkailla on mahdollisuus muutostöihin ihan eri lailla, mutta mulla on semmoinen käsitys että näitä kylpyhuone-elementtejä tulee tulevaisuudessa olemaan myös näissä meidän laadukkaammissakin kohteissa. Asiakkaathan on ollut niinkuin-, juuri viime viikolla taisi olla tuossa puhetta työkavereiden kanssa että, puhuttiin kylppärielementeistä, niistä tulee todella vähän reklamaatioita asiakkailta. Asiakkaat on kyllä tyytyväisiä. Ja ne on kyllä hyvin tehokkaita ja kompakteja paketteja ja-. (...) Tää on vain henkilökohtainen mielipide, mutta mitäs sitten kymmenen vuoden päästä kun mä haluan tehdä kylpyhuoneremontin? Mites se onnistuu? Se voi olla vähän haasteellisempi sitten, ja sanotaan että se jopa voisi tehdä, oma ostopäätökseni voisi olla että en ostaisi kohdetta jos siellä on kylppärielementti."

Theme: The Risk Problem: Wood is seen as too risky and expensive to be competitive on fair ground against concrete.

Coding	**Representative quotes**
Low risk projects are attractive for adopting new construction methods (e.g. wood) (continues on next page)	1(1.3.7.1) Ennen uuden rakennustavan kokeilu pitäisi miettiä kokonaisuus etukäteen kunnolla ja sitten todentaa toimivuus mahdollisimman hyvin. Ensimmäinen pilottikohde tehtäisiin esimerkiksi niin että urakoitsija saa uuden tuotteen hiukan edullisemmin suurempien riskien takia. Sitten kokeillaan ja seurataan miten toimii.

To try out new construction methods, first need firm experiences from someone else More interest in developig the customer facing part of the building, not the frame	9(1:09:00) "Kysymys on siitä että ei oltais ensimmäisenä kokeilemassa jotain vaan että pitäisi saada kokemuksia. (...) Enemmän kehitetään ja haetaan sitä asiakasnäkökulmasta mitä se asiakas haluaa ja mitkä on ne jutut asiakkaalle. Ne ei ehkä runkoon ihan suoranaisesti niinkuin liity. Tottakai siinä mielessä että asuntojakaumat muuttuu... " (...) En tiedä mitä vähähiilisyys tuo."
Adopting WMC in builder vendor projects is considered too risky because of long term performance responsibility Competitive contracting offers lower responsibility, which makes adopting wood more attractive WMC requires partnering or contract arrangements in beginning stage of the project	3(25:00) Kiinnostus puurakentamiseen: "Sanotaan että silleen ehkä pikkusen varauksella suhtaudun niinkuin omissa kohteissa missä meillä on niinkuin grynderin vastuu kymmenen vuotta, niin ollaan aika kriittisiä että lähdettäisiin toteuttamaan puukerrostaloa. Mutta sitä ei toki oo sitten [poissuljettu], että jos meillä on siihen tilaaja joka sen ottaa ja on sitten normaalit urakoitsijan vastuut, niin toki ollaan sitä valmiita tekemään. Sanotaan että siis ehkä yksi on tietenkin se että meillä ei oo siitä kokemusta että lähdettäisiin tekemään niinkun ihan tämmöisiä omia gryndikohteita. Niin yksi on tietenkin sen kokemuksen puute siihen. Toki se on tiedostettu että sitä hyvin tonttejakin saattaisi saada tietyiltä paikoilta hyvin jos on valmis tekemään puukerrostaloja. (...) Semmoinen mielikuva on että kuin sitä ei oo niinkuin vakioitu niitä detaljeita ja kaikkia rakenteita muuten että se on sitten aina niinkuin toimittajakohtainen, että meillä pitäisi olla hyvin siinä alkuvaiheessa kun suunnittelu on käynnissä niin meillä pitäisi olla tiedossa se toimittaja joka toimittaa sen puurungon sinne niinsanotusti, oli se sitten minkälainen ratkaisu tahansa. Onko se semmoinen tilaelementtityyppinen tai CLT tai mikä tahansa se sitten onkin, niin pitäisi olla vähän niinkuin toimittaja valittu minkä detaljeilla mennään. On se semmoinen haaste että pitäisi semmoinen yhteistyökumppani olla jo alkuvaiheessa."
Low risk- high reward projects are attractive for adopting wood in builder vendor projects	3(38:30) Onko jotain mielessä vielä mitä haluaisit sanoa? "No sanotaan nyt sinne puurakentamiseen vielä niin, ehkä meille kun nähtäisiin että kun missä tällä hetkellä olisi sopivaa tonttia, niin tämmöisessä vähän enemmän rivitalotyyppisessä tai yksi-kaksikerroksisessa voisi käyttää, mutta ei oo nyt semmoisia kohteita suunnittelussa. Mutta tuota, se olisi ehkä semmoinen-, ja nähdäänkin että esimerkiksi joku hirsirakenteinen rivitalo oikealla sijainnilla varmasti on niinkuin semmoinen mitä asiakkaat arvostaisi. (...) Se tietenkin että paremman hinnan voi saada, mutta se että sille on kysyntää, että asunnot ei jää myymättä, semmoinen mikä varmasti kiinnostaa niinkuin ostajia."
WMC requires partnering or contract arrangements in beginning stage of the project DBB for WMC is not only costly, but also technically more risky, due to mistake	6(12:05) "Jos joku rakennuttaja haluaa itselleen puukerrostalon niin sen kannattaa pyytää KVR-urakkana, jolloin se urakoitsija valitsee jonkun kumppanin ja sit sen niillä detaljeilla suunnitellaan. Jos se rakennuttaja piirtää ne kuvat valmiiksi että tämmöinen puukerrostalo, ja siellä on kaikki kuvat valmiina, niin siellä on yleensä jonkun toimittajan detaljit olemassa siinä rakennuksessa. Tai sitten ne on jonku rakennesuunnittelijan niinkuin omasta päästä. Ja sitten kun siihen tulee puuelementtitoimittaja niin se sitten muokkaa niitä oman järjestelmänsä

possibilities in repeat work when matching unstandardized specifications	mukaisesti. Ja sitten aina kun jotain muokataan niin hyvin helposti sitten jää jotain asioita huomaamatta, ja tulee virheitä ja tulee puutteita tai tulee huonoja liitoksia tai-, tää on huono tapa. Siinä rupee olemaan niin paljon muuttujia että se sisältää sitten eri tavalla riskejä."
Low risk projects are attractive for adopting new construction methods (e.g. wood)	13(1:04:00) "Tiedän että niinkuin mukava olisi niinkuin tilaelementtiratkaisu, niin sitä esivalmistusta sitä kautta niinkuin nostaa. Se on taas niinkuin oma kuvionsa. Ja sen opettelu että minkäkokoisessa hankkeessa se on sitten järkevää ottaa työn alle ja ruveta tutkimaan ja tekemään. Sen täytyisi olla ehkä tommoinen ihan perus-. (...) Toinen varmaan mitä osa kauppaa, että Ruotsista tuodaan elementit niin siellä täytyy aika hyvissä ajoin olla tilaukset. En mä tiedä, oliko joskus että pitää olla tyyliin täysin suunnitellut systeemit olla jo tyyliin vuotta aikaisemmin että he saavat sen sinne tuotantoonsa."
Competitive contracting offers lower responsibility, which makes adopting wood more attractive WMC is more costly, which is not suitable for builder vendor projects (where apartment selling price is market driven)	4(45:30) "Jonkin verran on pohdittu että sitte lähdetäänkö ihan niinkuin me KVR-urakoitsijaksi puu- tai tällaiselle puolelle. Ei ole vielä kun ei ole meidän ydinalaa. (...) Meidän näkökulmasta suurin asia varmaan on se kustannus jos kumminkin ollaan perustajaurakoitsija. Ei niitä varmaan hirveen monta gryndipuukerrostaloa ole niinkuin Suomeenkaan tehty. Kyllä ne kaikki taitaa olla jotain ARA- tai vuokratuotantoa mitä Suomessakin on tehty. Se yhtälö vaan että se rakentamisen kustannukset versus ulosmyyntihinta eivät kohtaa tällä hetkellä. Että ne ihmiset ei oo valmiita maksamaa siitä sitä x-määrää lisää että ne saisivat puukerrostalon kuin että asuisivat betonikerrostaloissa."
TMC is more risky than RC construction Weather protection lowers the risk, but should be accounted for in project planning to not become a burden	23(44:45) "Jos joitakin tontteja saadaan sillä varjolla että sen pitää olla puurakentamista, niin silloin voi olla että mietitään, tai joitakin yksittäisiä hankkeita voi olla käynnistymässä meille, mutta-. Kyllähän se iso massa on kuitenkin lähtökohtaisesti aina niin, -se on tätä perusvarmaa betonirakentamista. Rakentamisen aikaiset riskit on kuitenkin varmaan-, ja takuuaikaiset riskit on niin paljon suurempia verrattuna betonirakentamiseen. Betoni kun se saa kastuakin siinä rakentamisen aikana, että se ei ole moksiskaan. Kunhan se saadaan vaan sitten kuivatettua. (...) On niissäkin [sääsuojissa] omat haasteensa ja omat kustannuksensa tulee sitä kautta. Kyllähän se työmaalogistiikkaan ja kaikkeen vaikuttaa niin paljon että-. Tavallaan jos aletaan sääsuojaan rakentamaan niin se pitäisi huomioida jo heti lähtömetreillä suunnittelussa ja tavallaan rakenteissa ja kaikessa että se pystytään se logistiikka sinne hoitamaan sinne sitte mahdollisimman kivuttomasti sinne sääsuojan alle. Pitäisi olla lähtökohtana jo että tullaan sääsuojan alla tekemään niin sitä voisi suunnittelussa tavallaan niinkuin huomioida sitä paremmin ja ottaa sieltä tavallaan kaikki ylimääräiset niinkuin kustannukset sitä kautta pois."
WMC requires partnering or contract arrangements in beginning stage of the project	12(56:20) "Pitäisi lähtökohtaisesti tehdä ratkaisu siinä ennen kuin asiaa lähdetään syvällisemmin suunnittelemaan niin siinä vaiheessa tehdä se rakenneratkaisuvaihtoehtotarkastelu sitten ja tehdä sitten päätös siitä että tämä hanke mennään puurakenteisena ja sitä kautta hakea siihen yhteistyökumppanit ja osaaminen, ja näin."