Modularisation Strategies in the AEC Industry: A Qualitative Comparative Analysis

Many industries have benefited from modularisation in order to automate the sales and production processes. In the Architecture, Engineering and Construction (AEC) industry, the concept of modularisation is associated with dimensional coordination and as such has a different interpretation from that of other industries. This has added to an already extended list of contextual challenges inherent in the AEC industry due to market size, the concept of economies-of-scale, the nature and range of diversity in preferences and requirements to name but a few. Moreover, there is a myth that the AEC industry is bound to stay associated with Build-to-Order or Made-to-Order as its core production strategy. These factors together have caused the AEC industry to stay restricted to product or component level modularisation at the best. This changes the balance in favour of what this paper reviews as a bottom-up approach. On the other hand an alternative strategy – referred to in this research as top-down – remains very much under-exploited. The clients therefore, do not have a neutral means by which they can assess as to what strategy is in their best interest. Likewise if a construction company plans to make a strategic move in their production strategy to more systematically embrace the principles of modularisation to move towards off-site manufacturing more, they do not have a clear decision support tool to help them make the best decision. This study investigates these two main modularisation strategies in the AEC industry to provide some lessons of successful cases on how, where and when they have been applied in different construction companies for different cases. The empirical data collected and collated, and the results from interviews will help clients and companies to analyse their own cases and make operational decisions on how, where and when to best utilise different modularisation techniques while considering the pros and cons of such decisions. This research found that the bottom-up and top-down strategies both have significant advantages and disadvantages compared to not only to each other but also in their own respect.

Keywords: modularisation; architecture, engineering and construction (AEC) industry; top-down modularisation; bottom-up modularisation; industrialised building systems

1. Introduction

Some manufacturing industries have achieved significant advancements in efficiency by offering customised products (Hvam, Mortensen, & Riis, 2008). These industries standardise the product alternatives to facilitate sales and production processes (Felfernig *et al.*, 2014) by incorporating information about product features, product structure, production processes, costs and prices (Forza & Salvador, 2007). A building is seen as a set of major building component systems, such as walls, roofs and foundations, where enterprises within offsite production and on-site assembly of products and components mutually contribute to the AEC project (Lachimpadi, Pereira, Taha, & Mokhtar, 2012). Compared to other industries, the Architecture, Engineering and Construction (AEC) Industry is often criticised for its inefficiency or inability to automate, improve its practices and provide value for its clients (Thuesen & Hvam, 2013).

Some of the substantial challenges facing the AEC industry have been the market size; the diversity of customers' needs, requirements and preferences; and the challenges of achieving the benefits of the economies of scale for personalised end-products (Farr, Piroozfar, & Robinson, 2014; Goulding & Arif, 2013). To overcome the challenges in AEC industries, the principles from mass customisation can be developed and implemented (Hvam et al., 2008). The principles of mass customisation allow for individual products through standardised production process, thus keeping costs down while increasing quality and customer satisfaction

(Kudsk et al., 2013). Therefore, a mass customisation strategy has to not only fulfil a wide variety of customer needs and demands but also harvest the benefits of economies of scale.

The main step towards customisation in the AEC industry is standardisation and modularisation of components, which in this context means transforming traditional craftsmanship production into a modularised system. Modularity is the design principle of having a complex system composed from smaller subsystems that can be managed independently while functioning together as a whole (Langlois, 2002). Modularity in AEC industry could reduce the order lead time and create variety with limited resources (Bekdik, Pörzgen, Bull, & Thuesen, 2018; Kudsk, Hvam, et al., 2013; Sharifah-Akmam, Gajendran, Skitmore, & Brewer, 2018). Modular coordination is a standardisation system based on dimensional coordination system for sizing the building components and placing them within a reference system and off-site fabrication (Lawson, Ogden, & Goodier, 2014; Singh, Sawhney, & Borrmann, 2015). A sustainability assessment of AEC modular projects assists in understanding the wider benefits of modular systems (Lawson et al., 2014; Smith, 2011). Module computation requires some basic data, particularly the sizes, the pipeline characteristics, and the equipment data (Cigolini & Castellano, 2002; Tatum, Vanegas, & Williams, 1987).

When trying to understand a complex system or product, two different strategies are normally used known as top-down and bottom-up (Sun & Zhang, 2004). Several researchers have described the modularisation and design process of AEC industries as an intensive, complex process (Bekdik et al., 2018; Choo, Hammond, Tommelein, Austin, & Ballard, 2004; Haas & Fagerlund, 2002; Mancini, 2014; Sawhney & Maheswari, 2013; Singh et al., 2015). Moreover, due to the complexity in the AEC industry and the huge investments and risks connected with an AEC project, few companies have been able to modularise the entire constructions in one step (Bekdik et al., 2018; Kohler & Hassler, 2002; Kudsk, Grønvold, Olsen, Hvam, & Thuesen, 2013; Vernikos, Goodier, Nelson, & Robery, 2013). An alternative to this one-step implementation is to gradually implement and modularise parts or segments of a construction. Apart from the modularisation techniques and tools, this gradual modularisation process can be approached in two main ways, either by a top-down or bottom-up strategies (Kudsk, Grønvold, et al., 2013). In the former strategy, a large-sized module is analysed, which makes the entire building the product; while in the latter strategy, a smaller sub-part of the construction is modularised, which makes the sub-part the product.

When using a top-down strategy, the entire system is divided into a few main components, which are divided further into smaller elements until a satisfactory understanding of the design and production process is obtained (Kudsk, *et al*., 2013; Sun and Zhang, 2004). For example, when using a top-down strategy for constructing a house, the workflow starts with the large elements (e.g. the whole building), paying little attention to the finer details. By contrast, a bottom-up modularisation strategy examines the smallest elements first and combines them into larger components or modules (Kohler & Hassler, 2002; Kudsk, Hvam, et al., 2013; Sun & Zhang, 2004) to form the final product at a time, namely the building. An example of bottom-up strategy is a detailed description of the lighting mechanism inside a house, which is catalogued and combined with other elements by the design or construction team to form mid-sized components. These mid-sized components are then combined to form the whole concept of the house. Top-down modularisation can be selected for the same lighting system to conceptually determine the large elements of the system and with no concentration on details while considering the high level of interface modularising to other part of the building.

Despite various research studies on modularisation, customisation in the AEC industry (Farr et al., 2014; Hartmann, Meerveld, Vossebeld, & Adriaanse, 2012), some bottlenecks remain, where a lack of support for product modularisation to facilitate automation and digitisation processes in AEC is evident. Moreover, although previous research has been carried out to address modularisation in general (Baldwin & Clark, 2000; Gelman, Kariv, Shapiro, Silverman, & Tadelis, 2005; Mäkipää et al., 2010), few studies have examined how, when and where modularisation techniques in AEC industry should be applied, and no study uses theoretical

concepts to compare the pros and cons of the different modularisation strategies (Piran, Lacerda, Antunes, Viero, & Dresch, 2016). As discussed, aligned with the specific modularisation methods and techniques in use, i.e. car, computer, aviation, shipbuilding, the gradual modularisation process can be divided into two main specific strategies of top-down and bottom-up. However, there is no research to compare these two main strategies, with an aim to offer guidance for AEC companies to determine how best to adopt or implement them providing some theoretical underpinnings, analytically developed based on empirical lesson learned in the real world practices. Accordingly, we select four case companies with top-down and bottom-up modularisation approaches to be compared. We investigate about the background information for all cases and how they implement the approaches. Moreover, we asked about the influences from different modularisation approaches on 11 most important Performance measurements and the gained pros and cons. This study will build upon the state-of-the-art in top-down and bottom-up research in the construction industry and sets out to contribute to our existing knowledge by: (1) adding new dimensions which have not been explored previously to evaluate top-down and bottom-up modularisation strategies; (2) devising a context-specific tool utilising Qualitative Comparative Analysis (QCA) method; and (3) designedly reviewing and adopting the relevant performance indicators in the AEC industry to assess top-down and bottom-up strategies against those indicators. Therefore, this paper aims to fill this gap by comparing top-down and bottom-up as the main modularisation strategies as and where applied to the AEC industry while critically reviewing the pros and cons associated with them. The results of this research can help to inform AEC companies about the benefits and risks of modularisation in a more detailed and pragmatic manner.

2. Research Design and Methodology

This study uses a mixed methodology with an overall inductive approach where it explores the incongruent facts and aims to enhance the practical understanding of the bottom-up and top-down strategies in the AEC industry as theories. Choosing multiple cases multiple units of analysis, we aim to contribute to the existing knowledge in the field by: adding new dimensions which have not been explored before to analyse top-down and bottom-up modularisation strategies in the AEC industry; utilising Qualitative Comparative Analysis (QCA) as an analysis method through a specific research design developed in this study; and systematically reviewing and linking the performance indicators in AEC industry to analyse top-down and bottom-up modularisation strategies using QCA. The study employs a multiple case and multiple unit of analysis approach, which involves analysing various modularisation projects for different products and processes in different companies. The different data sources used include reviews of project, product or process documentations, interviews and participant observations by means of a qualitative comparative analysis (QCA) of performance measures and indicators. The study focuses primarily on the practical implementation of the top-down and bottom-up strategies, and discusses modularisation methods for platform design through different stages of its research methodology design. As such the research design of this study has several components as briefly explained below:

2.1. Case study research

The well-established modularisation strategies in product design and manufacturing – top-down and bottom-up – are investigated in the context of the AEC industry, using a QCA method through an exploratory case study research design (Oakley, 1999). According to Gummesson (2000), when collecting empirical data from large organisations, a qualitative approach provides a good opportunity to obtain the sufficient level of detailed information. Case study research enables comparisons of different theories and observations from empirical data (McCutcheon & Meredith, 1993; Van de Ven, 1989), with considerable advantages over statistical methods (Finifter, 1993). It is however important to take into account that “case studies, like experiments, are generalisable to theoretical propositions and not to populations or universes” (Yin, 2009, p. 38), because cases are not sampling units and should be treated as experiments (Tsang, 2013). Although there is no ideal number of cases, a number between 4 and 10 cases typically works out well (Eisenhardt, 1989). Typically, the primary

sources of data in case study research are through interviews and interactions; other sources of data include personal observations, informal conservations, and attending the meetings and reviews of the archival sources (Karlosson, 2016).

2.2. Qualitative Comparative Analysis (QCA)

The collected data in the multiple cases and multiple unit of analysis case study design of this research will be analysed through a QCA method. As an established method in business, human behaviour, and innovation management studies, QCA is an analysis technique which induces logical conclusions from datasets, hence its relevance to, and appropriateness for this study. It uses logical inference rules to determine what inferences the dataset supports. Both classical 'compare-and-contrast' and rather 'lens' (or 'keyhole') comparison approaches are constructed overtly, or otherwise, on five pillars, namely: frame of reference, grounds for comparison, thesis, organisational scheme and linkages (https://writingcenter.fas.harvard.edu/pages/how-write-comparative-analysis). The primary reason for comparative analysis is the explanatory interest of gaining a better understanding of the causal processes involved in the production of an event, feature or relationship; typically by introducing (or increasing) variation in the explanatory variable or variables (Pickvance, 2005). While Tilly (Tilly, 1984) proposes a rather elaborate classification of comparative analysis (as individualising, universalising, variation-finding and encompassing), Pickvance (2005), argues that the first one is not indeed itself a comparative analysis and there is not enough distinction between the third and fourth to make them two different categories. He therefore, proposes that comparative analysis can be classified under two rather global categories – one seeking to explain similar phenomena by similar features and the other aiming to elucidate different phenomena by different features, which he carries on to argue that both are too restrictive. Subsequently he proposes two other possibilities: explaining similar phenomena by different features and explaining different phenomena by similar features. While abstraction is asserted to be a strategy for creating similarities only, it is not understood to be the only one. Also according to Pickvance (2005) while comparative analysis needs to be distinguished from juxtaposition of descriptions of a series of cases and separated from the sense in which all analysis is comparative, two features which define comparative analysis are understood to be: 1) an interest in the explanatory question of why the observed similarities and differences between cases exist, and 2) reliance on the collection of data on two or more cases, ideally according to a common framework.

This study therefore, uses a mixed QCA classic compare and contrast approach which seeks to build upon all the possible observed similarities and differences (linkages) of two modularisation strategies (ground for comparison) in four selected case studies within the context of the AEC industry using performance measures and indicators (frame of reference) through a point-by-point comparison (organisational scheme) with an argument that this will help clients, designers and companies to make informed decisions in choosing on strategy or the other or a combination of both (thesis).

3. Literature review

3.1. Mass customisation

With the development of lean production, the paradigm of "mass customisation" slowly emerged (Pine, 1993). Mass customisation is defined as the low-cost, high-volume and efficient production of personalised products, which meet all of the customers' individual requirements detailed in their orders (Felfernig et al., 2014; Forza and Salvador, 2007). The fast lane to the mass customisation of complex offerings is modular product packages and their subsequent on-demand configurations; what is also known, for this very reason, as Configure-to-Order (CTO) (Gelman et al., 2005). The best method of customisation is a "Lego brick box" of modular products that can be configured quickly on demand. As the complexity range and product variety increases, Engineer-to-Order (ETO) strategies have become more prevalent to create highly engineered complex product variants engineered to the customer's specific requirements (Wikner & Rudberg, 2005).

However, compared to other industries, the building industry has been slow in adopting this new paradigm (Benros & Duarte, 2009; Davison, Gibb, Austin, Goodier, & Warner, 2006). This, according to (Piroozfar & Larsen, 2010), is due to the idiosyncrasies of the AEC industry which are fundamentally different from other industries', in eleven distinct but not mutually exclusive areas. Each of those areas are suggested to bear an impact, though to different extents, on how modularisation, industrialisation and subsequently customisation can be strategised and implemented in the AEC industry. Those differences owe their existence to different understandings of the concepts and definitions of module, modularity and modularisation between AEC (where modularisation has traditionally been perceived as dimensional coordination) and manufacturing industries. Azhar et al. (2013) on the other hand, found twelve decision-making factors which influence the decisions with regards to modular building systems over conventional construction, with consensus being the most critical one.

3.2. Modularisation

A modular platform is normally used to create variants through configuration of existing modules (Jiao, Simpson, & Siddique, 2007; Meyer & Lehnerd, 1997). Product modularity is considered a key enabler of mass customisation that allows for the production of modules and components in volumes. Modularisation aims to support the management of product variety and process variability by decomposing complex products and processes into smaller and simple parts (Piran et al., 2016). According to Tihonen et al. (1996) the complexity of production is directly related to the degree of modularity of the product.

Modularisation minimises redundant efforts and non-value-adding or wasteful activities (Gelman et al., 2005). Wikner and Rudberg (2005) categorised the most commonly mentioned strategies of modularisation throughout literature as ETO, Make-to-Order (MTO), Assemble-to-Order (ATO) and Make-to-Stock (MTS). Additionally, in the context of AEC, Concept-to-Order (CoTO) is also used to describe a situation in which a customer is strongly involved at the early conceptual design stages of a building (Winch, 2003). The most important area for modularisation involves the interfaces between the components rather than the components themselves (Shafiee, 2017; Shafiee, Piroozfar, & Hvam, 2018).

3.3. Modularisation strategy

There are two different strategies for applying modularisation, namely, top-down and bottom-up strategies The top-down strategy is typically more conceptual hence used for big projects with a higher level of complexity (Chia & Holt, 2006; Whittington, 1996), whereas the bottom-up strategy is normally more detailed at product level and therefore deemed more suitable relatively smaller projects with lower levels of complexity (Kudsk, Hvam, et al., 2013). However, choosing a modularisation approach is a strategic decision based on many factors (Kudsk, Grønvold, et al., 2013) which may vary in construction industry from manufacturing. The top-down strategy uses general macroeconomics (input-output) and statistical data derived from industry production processes, while the bottom-up strategy breaks down the building stock into buildings, elements and materials which are linked to a detailed (upstream) process analysis (Kohler & Hassler, 2002). The two strategies are not mutually exclusive and can be used concurrently from opposite ends of a project in such way that the top-down strategy obtains an overview of the building to find areas of potential modularisation.

According to Forza and Salvador (2007), during the modularisation process, it is necessary to determine (a) the relationships between the components, (b) the constraints and incompatibilities of the different solutions, and (c) whether to use a 'bottom-up' solution adding components one at a time or a 'top-down' solution starting from an abstract description. This description is then put into context and upgraded in successive phases (Forza & Salvador, 2007). Thuesen & Hvam (2013) conduct an in-depth case study through observations and semi-structured interviews to illustrate the application of bottom-up modularisation in the AEC industry. Kudsk et

al. (2013) illustrate the case study examples to illustrate the success of bottom-up modularisation. They also investigated the potential areas and real case studies in AEC about the application of top-down modularisation.

3.4. Performance measurement in the AEC industry

A performance measurement system (PMS) involves regular collection and analysis of data about project input, output, efficiency and effectiveness (Sabone & Addo-Tenkorang, 2016) through a set of metrics used to quantify the impact of different activities on those factors (Kohler & Hassler, 2002; Neely, Gregory, & Platts, 1995). Takim et al. (2003) go beyond this to assert that performance measurement is used as a systematic way to judging project performance by evaluating the inputs, outputs and the final project outcomes. Beatham et al. (2004) suggest that there are three specific types of PMS widely used in the construction industry: KPIs, KPOs (key performance outcomes) and perception measures. Pillai et al. (2002) propose an integrated performance index model and the Construction Industry Task Force (1998) developed a key performance indicator (KPI) model. Although some studies have asserted that project management performance factors include time, cost, quality, safety and client satisfaction (Demirkesen & Ozorhon, 2017), the project performance measures and indicators are widely agreed to include much more than that. Table 1 summarises the most commonly mentioned key performance measures and indicators in the literature which were considered relevant to modularisation.

Table 1. Performance measures and indicators in the AEC Industry

	Performance Measures and Indicators	Study (Author, Year)
1	Cost/ cost implications/Return on Investment (ROI)	(Canadian Construction Innovation Council, 2007; Cheung, Suen, & Cheung, 2004; Chew, Conejos, & Azril, 2019; Construction Industry Institute, 2011; Kohler & Hassler, 2002; Luu, Kim, & Huynh, 2008; Neely et al., 1995; Pillai et al., 2002; Rankin, Fayek, Meade, Haas, & Manseau, 2008; Sharifah-Akmam et al., 2018; Skibniewski & Ghosh, 2009; Wong, 2004; Xu, Chan, & Qian, 2012)
2	Economies of scale/Repetition	(Beach, Webster, & Campbell, 2005; Jagarajan et al., 2017; Kibert, 2007; Kohler & Hassler, 2002; Xu et al., 2012)
3	System or product compatibility and interoperability	(Beach et al., 2005; Eray, Sanchez, & Haas, 2019; Toor & Ogunlana, 2010; Zhang, Teizer, Lee, Eastman, & Venugopal, 2013)
4	Interface design and tolerances	(Beach et al., 2005; Eray et al., 2019; Zhang et al., 2013)
5	Multi-party and collaborative working process	(Ahuja, Yang, & Shankar, 2009; Beach et al., 2005; Cheung et al., 2004; Constructing Excellence, 2005; Roberts & Latorre, 2009; Toor & Ogunlana, 2010; Zhang et al., 2013)
6	Contextual conditions (including site, geographical location, climate/weather, etc.)	(Xu et al., 2012; Zhang et al., 2013)
7	Maintenance/repair/refurbishment	(Chew et al., 2019; Kohler & Hassler, 2002; Ortiz, Castells, & Sonnemann, 2009)
8	Sustainability (including environmental impact, embodied and operational energy, GHG emissions, etc.)	(Chew et al., 2019; Constructing Excellence, 2005; Faludi, Lepech, & Loisos, 2012; Ortiz et al., 2009; Roberts & Latorre, 2009; Sharifah-Akmam et al., 2018; Xu et al., 2012)
9	Innovation and new technologies (including BIM, OSM, building simulation and structural analysis packages, robotics, etc.)	(Ahuja et al., 2009; Canadian Construction Innovation Council, 2007; Farr et al., 2014; Rankin et al., 2008; Succar, Sher, & Williams, 2012; Xu et al., 2012)
10	Sizes and dimensions	(Godoy-shimizu et al., 2018; Ortiz et al., 2009)
11	Lifecycle/lifespan (of product, component or and building)	(Godoy-shimizu et al., 2018; Ortiz et al., 2009; Warburg, Braune, Eyerer, Herrmann, & Gallon, 2005)

The discussion of findings section highlights these factors during the interview and in discussion section to investigate how these performance measurement factors might affect or be affected by the modularisation strategy applied in the case studies.

4. Data collection

4.1. The case selection rationale

Four case companies were selected for this study using the following selection criteria:

1) Produces complex and highly-engineered building elements or components for the AEC industry,
2) Clearly demonstrates the use of bottom-up or top-down modularisation strategies for at least one of their construction categories,
3) Potential access exists to management and senior experts at the companies,
4) Located in Northern Europe (so that they share a common culture for consistency and comparability of the findings), and
5) Top managers in the case companies will sponsor and support all the projects.

It is also worth noting that the choice between bottom up and/or top down approaches does not need to be – and in case of this study has not been – *fait accompli,* determined by what the company do deliver (i.e. the complete building solution or building sub-components). To the contrary, and due to agility, flexibility and availability of the production technologies in the AEC industry, the decision can be made as and when felt needed. In our study for instance, cases 1, 3 and 4 deliver both building sub-components and whole building solutions and in all 4 case companies chosen for this study, both modularisation strategies are applied regardless of what their end-product would be. We however, chose the particular case projects based on the inclusion/exclusion criteria as explained above. Selecting more case studies from other regions in Europe or worldwide, would have added views and perceptions constituted with other construction markets with different, contextual, cultural and organisational factors. However, this was considered to be distracting the focus of this study from what its promise has been intended to deliver. Hence, it was decided to keep the focus on four case companies in the north European context following the mentioned factors which allowed us to gain an in-depth understanding of the modularisation process in each cases as well as access to their archival documents and records; which will help build up a methodologically sound underpinning study to help develop later stages in other AEC industry markets across Europe and internationally. Table 2 summarises the background information of each case company.

Table 2**.** Background information of the Case Study Companies and selected projects

	Bottom-up		**Top-down**	
Company	**Company A (Medium-sized)**	**Company B (Small-sized)**	**Company C (Medium-sized)**	**Company D (Medium-sized)**
Projects case number	***Case 1***	***Case 2***	***Case 3***	***Case 4***
Brief background	Swedish; active across Scandinavia, the Baltic countries, northern Germany, Russia and Poland; products delivered as integrated modules to the site; use of expert knowledge in different areas pertaining to product and process.	Danish SME; focuses both on the physical product and the entire process of the design, fabrication, installation, customer service and support throughout the product's lifecycle.	German; mostly active in Germany; specialised platform for housing; cover the needs of 90% of market; complies with German architectural traditions yet flexible enough to produce different house	Swedish; main contractor; Multi-family housing; leading in prefabricated concrete innovative comprehensive solutions based on a project's specific needs, requirements and preferences.

			combinations and variations.	
Product that are modularised	Shafts incorporated in building services mainly used in Russia and Sweden (modularisation and configuration project)	Complete modules for balconies	Project: Affordable housing for the middle class (across Germany)	Full family house (modularisation and configuration project)
Changes in processes that accompanied modularisation	The sales, engineering and installation processes	The sales, engineering and installation processes	The sales, engineering and installation processes	The sales, engineering and installation processes
Building type	Residential buildings	Existing residential buildings	Residential, mainly single-family houses, small multi-story buildings	Residential buildings, family houses
Modularisation method	Bottom-up	Bottom-up	Top-down (fully modularised)	Top-down (fully modularised)
Individual or across the platform modularisation	Across the platform (customised shafts)	Across the platform (customised and modularised product and installation)	Across the platform (even installation is standardised)	Across the platform (customised building)
Sponsors/ responsible	Head of engineering	Owner of the company, CTO	Senior management/Head of business unit	Head of business unit

4.2. Interviews

Building upon the findings of the literature review, exploratory interview questions were designed, commensurate with the research objectives (Hollway & Jefferson, 2000; Yin, 2009). The questions were administered through a combination of emailed correspondence and face-to-face interviews. Because of an exploratory nature, where more effort was devoted to ensuring the depth of the data inquiry, considering that the knowledge claims in this study differ from a pure statistical study (Yin, 2009). One person from each company was invited to participate in the interview with two researchers. The selection was made based on the interviewees' familiarity with modularisation, their role in the company and their involvement in the relevant processes and projects. Hence, in total we conduct 4 interviews concentrating on one or more than one project each, which lasted for around one hour. While the senior management team in each company was aware and supportive of the process, they did not participate in the interview if they did not possess the required in-depth knowledge of the project in question. Therefore, the interview participants have different positions and responsibilities within the organisational structure of their respective companies. Table 3 presents the background information of the interviewees. To increase the validity and provide the triangulation on data collection aspect, two researchers conducted all the interviews, documented individual notes and recordings. We ensured the reliable data collection as it was triangulated between what was documented from both case studies and interviews. The credibility of data analysis was also guaranteed as the interpretation of the data is analysed independently by three researchers, compared with each other based on which them the final interpretations were agreed upon.

Table 3. Background Information of the Interviewees

	Bottom-up		**Top-down**	
	Company A	**Company B**	**Company C**	**Company D**
Age range	40-50	30-40	40-50	30-40
Years of relevant experience at the case company	25 years	3 years	25 years	6 years

Current role	Manager of concept platforms (innovation)	Researcher, Configuration engineer (configuration systems manager)	Manager of concept platforms (innovation)	Project Leader

A first version of the questionnaire was developed based on the findings of the literature review, using a brainstorming session within the research team to specify the main constructs of the interviews. The questionnaire was designed to identify how best to implement two main modularisation strategies in the AEC industry. A pilot study was carried out to test and modify the questions to ensure that the research instrument met the intents of the research design. The outline of the interview questions was provided to the interviewees prior to the interviews so they could prepare in advance.

5. Cross Cases Qualitative Comparative Analysis

The results are discussed in three separate sections. The first section presents the steps the case companies followed to apply the modularisation process. The second section discusses the interviewees' perceptions on how some factors might affect or have been affected by the modularisation strategy applied at the case company. The third section discusses the advantages gained and the challenges faced as a result of applying the modularisation.

5.1. The steps involved in the modularisation process

Table 4 summarises the steps the companies undertook to achieve the intended level of modularisation in each case study. The results are extracted from the answers to the question: "Can you elaborate on the stages and processes of the work, highlighting what steps were taken before, during and after applying the strategy?"

Table 4. Steps for Applying the Modularisation Strategy in Each Case Company

Steps	Case No	Strategy	Comments
Project scoping	**1**	**BU**	The modules were developed in a project involving external consultants. The market requirements for the modular products and the main functions were identified.
	2	**BU**	In the early phases, the customer segments and products were adjusted to be more focused – e.g. other product types and customer groups were deselected; the focus was on balconies for existing apartment buildings.
	3	**TD**	Everything was started from scratch. Pre-process is quite important. All the processes are on-site.
	4	**TD**	First we gather all the relevant information by talking to the professionals in a long-term project.
Product modularisation	**1**	**BU**	The modules were designed in greater detail, prototyped and tested in a factory.
	2	**BU**	The next step involved analysing the modules of balconies and product structure visualisation. The mounting principles were reduced from 15 to 3 (now 10). The future modules were defined in two categories: standard and flexible modules, where the integration to the buildings had to be somewhat flexible.
	3	**TD**	It is not only the physical products that are modularised but also all the processes related to the customers and all connected activities.
	4	**TD**	Then we developed frameworks to fulfil the interfaces' compatibility with the next product. We started to modularise different processes and products in a parallel manner to modularise the user interfaces and to acquire and/or develop the right level or amount of required/necessary knowledge. Simultaneously, we started to implement all the information inside the configuration system and test the small deliverables as system versions by experts.
Organisational concerns	**1**	**BU**	The modules were developed and tested over a 12-month period. In the project period, the requirements, functions, structures and interfaces were discussed in a series of workshops involving sales, engineering, fabrication, and installation teams.

2	**BU**	The processes for sales, engineering, project management and installation of the balconies were developed based on the modular product structure. Sales was supported with a configurator; the engineering and project management was supported with a project management tool; and installation was supported with IT-based instructions for the installers.
3	**TD**	The sole focus of the whole company was modularisation.
4	**TD**	We were fully supported by the managers to implement the changes in the organisation through iterative testing of the configurator.

Based on the backgrounds of cases 1 and 2, the modularisation process is comparatively similar as both projects focus on the details of one product (shafts in case 1 and balconies in case 2) and the relevant processes, requirements, functions, structures and interfaces were discussed based on the modular design. In both cases, projects started with a clear scope and discussion of the stakeholders and product details; while considering the relevant processes. Moreover, cases 3 and 4 discussed the conceptual scoping of the project in top-down process in high level of project abstraction and how the team had to consider and connect all the products at once and determine the level of detail by discussing with the professionals on all levels of the product and production process and hierarchy. In all selected cases except case 2, the companies manufacture both building sub-components and entire building solutions. They also use both bottom up and top down approaches in a range of their different offerings regardless of whether they are building sub-components or complete building solutions. For the selected project cases, bottom up or top down as a modularisation strategy is absolutely the choice of the company based on the management decisions and visions.

5.2. The impact of modularisation strategy on performance indicators in the AEC industry

The interviewees were asked to share their perceptions of how the factors listed in Table 5 might affect or be affected by the modularisation strategy applied at their company. All the factors that complied with the key performance indicators were extracted from the previous studies listed in Table 1. Table 5 represents the results from the answers provided on the questionnaire (where 1 = strongly disagree; 2 = disagree; 3 = neither agree, nor disagree; 4 = agree, and 5 = strongly agree). All the results discussed below are based on the specifications of the AEC industry discussed earlier in the literature. The results indicate that top-down approaches are more favoured when it comes to achieving higher scores for AEC industry performance indicators. This was unexpected, and the general expectations in the sector does not suggest this either. Despite the meaningful difference between the scores, the test itself does not bear any statistical significance. This stage was merely used as a testbed for the more detailed probing during the interviews. This will be discussed in this section and later on in the discussion section.

Table 5. Perceptions of Factors Influencing or Affected by the Modularisation Strategy

		Bottom-up		**Top-down**	
	Factor	**Case 1**	**Case 2**	**Case 3**	**Case 4**
1	Cost/ cost implications/Return on Investment (ROI)	4	4	5	5
2	Economies of scale/Repetition	5	4	5	5
3	System or product compatibility and interoperability	4	4	5	5
4	Interface design and tolerances	4	5	5	5
5	Multi-party and collaborative working process	2	5	5	5
6	Contextual conditions (including site, geographical location, climate/weather, etc.)	5	5	5	5

7	Maintenance/repair/refurbishment	5	4	5	5
8	Sustainability (including environmental impact, embodied and operational energy, GHG emissions, etc.)	5	No effect (3) *	5	5
9	Innovation and new technologies (including BIM, OSM, building simulation and structural analysis packages, robotics, etc.)	No effect (3)*	5	5	5
10	Sizes and dimensions	3	4	No effect (3) *	5
11	Lifecycle/lifespan (of product, component or and building)	4	1	5	No effect (3) *
	Total Score (Out of 55)	44	44	53	53
	Percentage	80%	80%	96%	96%

**In some cases, the interviewees stated that some factors had no effect; these are marked as "no effect" in the table and are assigned a value of three in the scores. This is because no effects indeed is equivalent to when the interviewees neither agreed, nor disagreed to the statement.*

5.3. Cross-sectional comparative analysis between modularisation strategies

Interestingly overall scores for both bottom-up cases were 44 out of 55 or 80%, whereas overall scores for top-down cases were both at 53 out of 55 or 96%. This shows a meaningful difference in favour of top-down approaches. As mentioned, it was expected that bottom-up strategies would be more favourable with respect to the AEC performance indicators, but this was proven otherwise. This could be due to several reasons. Firstly the Northern European construction industry's history of embracing non-site-based modern methods of construction seems to have played a role in developing such perceptions. Secondly and at a more individual case-based level, it seems that both companies have an established record of application of top-down strategies where long-term benefits seems to have started paying off. This has offset the front-end investment in a longer ROI periods. In an intra-category comparison between the two top-down cases, there seems to be some discrepancies despite the equal final scores. Given that interviewees were experts in the field and directly involved and fully aware of all project aspects in their respected companies, those discrepancies become very important in drawing a clearer picture of how, why and where they may have been rooted. This was probed more during the later stages of interviews and cross-checked with the company and project documents to enable us find the reasons for such differences. While sizes and dimensions were scored 3 (no effect) for case 3 and 5 for case 4, it was the other way round for lifecycle or lifespan of the product and the building. This can be attributed to two different reasons. Firstly, the case company 3 is a German company mostly active in affordable housing for the middle class in Germany, where expectedly the sizes and dimensions would not be a very influential variable due to limited variation on them needed to meet the market requirements. The lifecycle/lifespan of the product and the building on the other hand seems to be more influential which is always the case with social and affordable housing to reduce the maintenance and running costs. The case company 4 on the other hand is a Swedish main contractor, specialised in multi-family housing and leading in prefabricated concrete innovative comprehensive solutions. Due to their specialisation and their system (being based on prefabricated concrete), the expected influential indicators are more on size and dimension than lifecycle/lifespan issues. All other areas did not show meaningful differences in terms of perception of importance of the performance indicators.

5.4. Intra-category comparative analysis of modularisation strategies

The intra-category comparison of two bottom-up cases seems to show more discrepancies and would probably be more challenging to discuss. One of the biggest discrepancies seems to be in multi-partite working processes with a score of 2 for case company 1 and a score of 5 for case company 2. It is indeed interesting to see that the case company 1 whose clients are from a wider geographical spread (probably with some language barriers)

are reporting this as less of an issue. This may be due to two reasons. One and the more important one is that probably the product of the case company 1 is a part of building services hence although still quite crucial in terms of its technical specification and performance, it is less sensitive in terms of aesthetics, and therefore less problematic in multi-partite working processes where lower number of stakeholders may be involved in the direct decision processes affecting the choice of those product. The other less likely but still possible reasons can be related to the level of product development and/or the openness/flexibility of the product system which might be higher in the case company 2 product. This is understandably linked to, and not mutually exclusive from the first reason. Lifecycle/lifespan of product and building is significantly different between the two bottom-up cases (4 for case company 1 and 1 for case company 2). This is due to the nature of the product in each case company. This means case company 1 who produce a building services component are more exposed to issues pertaining to the lifecycle/lifespan of their product whereas this performance indicator is less of an issue with respect to case company 2 products, which are prefabricated balconies. This can also be associated with the level of wear and tear and the lifespan associated with different building components. The other two areas of relative significant discrepancies include sustainability (with 5 for case company 1 and 3 (no effect) for case company 2) and new technologies (with 3 (no effect) for case company 1 and 5 for case company 2). With respect to sustainability it is quite expected that a building services component or product is more sensitive in terms of its contribution to or influence on sustainability than a merely decorative component. It is however, very interesting to see that new technologies are perceived to be more influential in delivering the balconies than they are perceived to be in service ducts. This can be due to two different reasons. Firstly it might be because the case company 1 already excelled in their product and changing in the technology may not impact their quality of service or product. This by no means is to imply that case company 2 is not so, but to suggest that because of the visually and aesthetically sensitive attributes of the product of case company 2, there may still be incremental, cosmetic or demand-oriented changes which are required; what can be heavily depending on and facilitated by adoption of new technologies. No significant differences were observed in other performance indicators.

The results show that top-down modularisation in the AEC industry has higher total positive effects on all the measured factors compared to the bottom-up strategy. However, the investments, complexity, size and speed of the modularised projects defined for the bottom-up strategies is much lower, simpler, smaller and faster than the top-down modularisation projects. Normally, top-down projects involve all aspects of the product and corresponding connected services which also leads to a high ROI because of the great gained benefits. Business model in case company 1 is to have a mixed approach of bottom- and top-down modularisation to use bottom-up for all the products while in parallel to have a conceptual top-down modularisation for the whole building and then which enable the company to reach a detailed modularised building in long term. Aiming for this business model in case company 1, they focus on several bottom-up modularisation for different product and then use them all in one big top-down modularisation strategy and connect them together to be able to modularise a full house; raising a very interesting case of combining both strategies to try to maximise the benefits of both as the portfolio of company resumes to successfully boom and thrive.

5.5. Pros and cons of bottom-up and top-down strategies

During the interview process, an elaborated explanation of the pros and cons was sought for the different case companies. The interviewees in case companies 3 and 4, where a top-down strategy is used, mentioned that the vast modularisation across the company limited their market share and customer diversity. We however, believe that there has possibly been a more optimistic reading of the incident. Choosing to resort to a top-down strategy has made the respective companies more specialised in their offerings. This may have resulted in what seems to be limiting the market share or diversity in the customer demographics but in return means that those companies may have to face much less competition in the market. Furthermore, it means that those

companies should probably seek to contribute – through some market and product R&D, publicity, campaigning, raising awareness, education, and training activities – to the inevitable change in the construction market climate. This may also mean that the company would only earn considerable benefits from a specific building types with modularised components, thus allegedly and expectedly making the company vulnerable to loss of their share in the market when their specific modularised products are no longer suited to their customers' specific requirements or to the market requirements. To ensure that this is not going to affect the company in long run and due to normal market turbulent which may be more frequent or severe in the construction industry as opposed to other industries, R&D and market research would find a substantial and major role in such companies to make sure that their system is always updated and in full capacity to meet the market demand if not being ahead of it. This probably need to follow what is an established practice for instance in car manufacturing where a product platform (with its modularised components) is designed and has a certain service life of 4-6 years during which only minor improvements and alterations are introduced, whereas the platform will be redesigned and replaced after its service life is reached with some modules and components being carried over to the next platform generation while the other being totally redesigned or replaced. What this means is that AEC industry would need to adopt more and more the principles of 'agile production' to be able to resort to the benefits top-down strategies may have to offer to be able to survive the market changes. Suffice to say that as top-down modularisation strategy is comprehensive, the modularisation process involves the full range of products and requires a whole platform design, testing and production, which is time-consuming and costly. Additionally, a lower system agility, at least at the beginning, might impose serious restrictions on alterations to the platform, products and/or processes compared to the bottom-up strategy. Therefore, several first years to begin with are absolutely crucial to be able to acclimatise to the subsequent new regimes in the client demographics and market demand constructs while balancing the sheets and at the same time developing the product and platform inventory to the level that the new system grows more resilient and can sustain long-term changes in the market environment and client profiles.

By contrast, case companies 1 and 2 reported challenges related to the lack of integration with other modules in the building, a dependency on the IT systems and modularity as well as the lack of interface design modularisation. All of such reported issues were expected and already being faced where modularisation is attempted to be adopted partially by established construction companies who do not want to embark on to modern methods of construction fully and completely. These concerns mean a loss in profit when the orders are outside of the solution space because there is no professional expert at that stage who can estimate the costs and carry out the necessary calculations. However, this loss is more within the profit margin such construction companies are comfortable to sustain with, and rarely are they expected to have detrimental impact on the company. Another important point worth mentioning is that strictly speaking such strategies are not novel and have been in practice in different parts of the world for the past 50 years. Table 6 and 7 summarise the participants' comments on the pros and cons for the four case companies.

Table 6. Pros and Cons of Bottom-up

Cases	Pros	Cons
Case 1	• A better understanding with modularisation from different product's perspective and the real benefits from the modularisation. • A better understanding of other technologies such as configuration. • Alignment with the whole organisation and support from management and better understanding of collaboration for a common benefit	• No connections between different modules and processes e.g. shafts and installation process are not aligned. So, we cannot get the full benefits from our shafts modularisation and there are still a lot of manual works to be done.

Case 2	• A very good focus on our business model and targeted market. We have product and processes standardised which increases internal productivity. • The huge increases in profitability during the last 10-15 years. The company is ahead of the competitors and we are very fast in both processes and products. • Very good communication both with the vendors and customers. That became the focus area after modularisation and simplification of the products. So now we are the first in terms of customer relationship. • A continuous attendance and support from management team in this process leads to constantly developing the modules in terms of products and processes.	• Dependency on our modularisation IT tools such as configuration systems which made the team unaware of the specificities of the products, pricing structure and processes. We are struggling to make the data from the IT system visible to the organisation.
Intra-category analysis of pros and cons of bottom-up strategies	1. The financial benefits 2. The utilisation of technology 3. Alignment with top managers 4. Clear communication with all stakeholders including venders, customers, etc.	1. The lack of connectivity (interface design modularisation) to other relevant products/processes. 2. Lack of constant knowledge of product details due to the support of modularisation.

Table 7. Pros and Cons of Top-down Modularisation

Cases	Pros	Cons
Case 3	• offering cheap and quite efficient services both in the sales and installation processes • Having a high quality of service • Being very fast in the (on-site, off-site) process	• The project outside the platforms (we are losing money on the projects which are not fitting into our modularised platforms such as in western Germany)
Case 4	• A very high profit as soon after modularisation. • The project will be simplified. • Customers are more satisfied and they can customise their houses. • The output has a better quality. The projects are faster. • There is no waste as before. We don't sell by-chance products anymore.	• Very time-consuming (five years) project and it is very difficult to find qualified people for these kind of projects. It is hard to make people collaborate and contribute. Complexity of the project is high and the workload is high.
Intra-category analysis of pros and cons of top-down strategies	1. Fast implementation 2. Low cost sales and implementation 3. Hugh quality service 4. Satisfied customers (fast, cheap, competent) 5. Decrease in waste	1. Modularisation process in Top-down is time consuming and expensive. These projects are complex and a big change for organisations 2. The Top-down approach dictate the limited product families to be sold and limit the market as well.

6. Discussion

In this section, we will summarise the cross comparative analysis presented in section 5. Both bottom-up and top-down modularisation strategies reported to be positively influential in construction industry. However, organisations and clients alike might need to be aware of the lesson learned and experiences accumulated when they want to change their production strategy or choose a system for their projects. The most important lessons learned from bottom-up approach are reported as the amount of concentration on only one product and missing the connection with all the other products and also sections. This conforms to what has previously been suggested by Beach et al., (2005) and Zhang et al., (2013). The most important lessons learnt from the top-down strategy is also the awareness of the organisation about their ROI targets as the project can be both lengthy and expensive before getting beneficial. Concerns have been raised by other researchers in this area before (Kohler & Hassler, 2002; Neely et al., 1995; Sharifah-Akmam et al., 2018; Xu et al., 2012).

Table 8 presents the summary of the cross comparative qualitative analysis.

Table 8. Summary of cross-comparative qualitative analysis

Strategies	Summary of discussion of lessons learned

Bottom-up	• The legal, installation, sub-contractor issues should be taken into consideration to achieve a satisfactory level of modularisation. To elaborate more, the physical module is not the only part and the whole process (legal and installation) has to be aligned. • In case of lack of connectivity and interface modularisation, the organisation should not expect to reach the full benefits of modularisation. • It has to be an organisational move and alignment to get the best out of this. Which requires the support from managers in the organisation. • The organisations have to be aware of the dependencies on modularised products and their IT support tools in the future.
Top-down	• Top-down projects in construction industries could last long and become expensive before being beneficial. However, the interview results report a significant ROI for top-down modularisation after implementation. • There might be limitations for selling products out of the defined modularised products. • Top-down approach might be conceptual but comprehensive in terms of connecting different process and products in a higher level of system abstraction.

What we found in this study as a secondary and indirect repercussion was that shifting the paradigm from conventional to modularised construction has a transitional period which, like any other 'teething period', is of paramount importance to the success of the business. This may have not been referred to before directly especially in the construction industry. Moreover, for customers who may want to make a crucial decision about the choice of the company with a modularisation strategy or may want to make the decision about the strategy themselves there are factors argued explicitly in our industry expert interviews which will have some direct or indirect short-, mid- and long-term impact on the project throughout its entire lifecycle. Some of such factors, although spotted as performance measure and indicators were not believed to have any significant or meaningful impact on the choice of modularisation strategy (either for a client or for a construction company). What turned out to be the case was that although some of such issues were pointed at in the expert interviews in the case company probably as trivial issues from a construction professionals' point of view, they may be of higher importance in clients' opinion. These issues were related to health and safety; maintenance and upkeep, repair and refurbishment; quality; and most importantly clients' satisfaction, which indeed triggered a closer interrogation of the collected data to come up with the other factors. No previous research in relevant areas has looked into the question at hand from this point of view or flagged concerns about what was found in this study. In all of the case studies, the company chose the modularisation strategy regardless of the type or size of the end-product. Indeed three of the case companies produce a full range of end products (materials, sub-components, components, modular units and complete building solutions) in the AEC industry.

7. Conclusion

This research aim to define and compare bottom-up and top-down modularisation strategies in AEC industry (Figure 1). This study examined four AEC case companies all active in Northern Europe with substantial experience in modularisation. A qualitative comparative analysis (QCA) methodology was developed to interrogate the selected case companies about their approach to application of modularisation using multiple units of analysis and multiple data enquiry techniques. Following a critical review of the literature firstly themes and areas were identified, and then a data collection and analysis strategy was decided upon and developed. The in-depth analysis of the case companies started with a secondary data analysis of factsheets and technical data pertaining to each case supplemented by the participating companies. Experts with direct involvement in those project cases were interviewed to gain sufficient depth in data querying pertaining to each case. The study achieved findings which contribute to the existing knowledge and fill the gaps related to strategies for developing and applying modularisation by the construction companies and also help the construction clients to make a better and more informed decision when it comes to making a decision about the choice of the construction system or method. This study deploys multiple cases, multiple units of analysis and add new dimensions for exploring top-down and bottom-up modularisation strategies in the context of the AEC industry. This will be conducted using QCA method to systematically review and link up the use of top-down and bottom-up to performance indicators in the AEC industry which will operationalise the research instrument of this study. The study developed some practical guidelines for companies who are considering embarking on

modularisation, provided some insight for clients as to what they need to consider and set some milestones for future studies to develop a framework in this particular area of this research or within a broader scope of modularisation, platform design, automation, (pre)fabrication, standardisation, off-site manufacturing and (mass) customisation in the AEC industry.

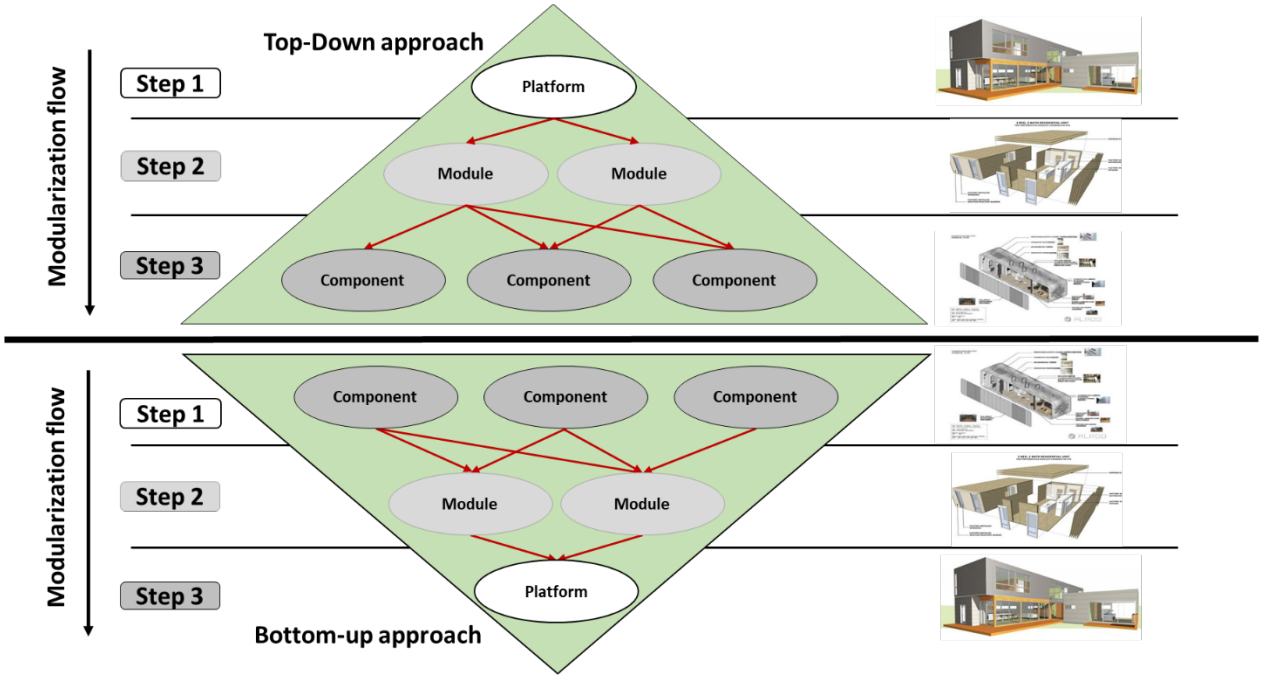

Figure 1. Top-down vs bottom-up strategies (after (Kudsk, Grønvold, et al., 2013) and further developed based on the three main areas of contribution of this study)

Both strategies – bottom-up and top-down – have had significant positive and negative impacts, to differing extents, on the creativity and innovation in the design process, particularly on "open innovation", as a concept widely believed to be the next stage of development in the mass customisation paradigm. As expected, the cost implications of the two strategies – as they are in this study, and as they could be in the future due to further developments of the modularised system with advancements in IT (such as CAD and BIM) and manufacturing technologies (such as rapid prototyping, additive manufacturing, large scale 3D printing) – are quite diverse and subject to radical and almost unpredictable changes and shifts. Although bottom-up and top-down strategies are suited to best serve what is known – in prefabrication and industrialised AEC systems – as close systems and open systems respectively, modularisation cannot be suggested as a conclusive proposition. This is because an unprecedented pace of development in the cost and affordability of, and the availability and access to, technology (in information, manufacturing and AEC/building disciplines); as well as recent advancements in interoperability, the internet of things and the internet of places, have created an atmosphere in which no traditional boundaries may hold up or are easy to realise. From a lifecycle vantage point, a top-down strategy may be more justifiable than a bottom-up strategy, or vice versa, depending on the chosen Life Cycle Assessment methodology and scope (i.e. cradle-to-gate, cradle-to-grave or cradle-to-cradle), on the lifecycle inventory and on where the emphasis is intended to be placed (i.e. on embodied energy/carbon, operational energy/carbon or whole lifecycle energy/carbon).

The limitation of the study could be the geographical location which is (limited to) Scandinavian countries where construction industry is more associated and familiar with industrialised systems. This however, is not really a limitation but may put the study up with some sort of advantage – as in those AEC contexts in Scandinavia, modularisation and platform design may have, by default, a higher/better chance of getting

accepted and applied. The other limitation could be the number of cases reviewed although this does not negatively impact the validity and reliability of the research due to its carefully adopted and devised methodology. The other limitation of the study, which could be assumed more as a future study than a limitation, is the investigation into the effects of the differences between AEC industries (specially compared to internal sectors in AEC industry) on modularisation approaches. Besides, the future research can discuss the differences between AEC and other industries and their influence on modularisation approaches. The other limitation of the paper is the selection of the top-down and bottom-up approaches by the company and to select the whole complex building for the top-down and smaller size project for bottom-up approach.

There are potential areas for future research. This study examined some aspects of the modularised systems as an exploratory research, including economies of scale, cost implications, tolerances and maintenance/repair, in-depth but rather independently. In this study, limited number of representative case companies rated the mentioned factors and explain the benefits and challenges elaborately. All the findings and discussions from the real cases in this paper are inspiring for new in-depth studies and the research is reporting the exact gained knowledge from the case companies. Therefore, future work could develop a framework based on the findings of this study to conduct a comprehensive study which uses a systemic strategy to investigate the correlation and interdependency of those factors. Moreover, in-depth investigations could be conducted to examine issues surrounding the manufacturing and production of both modularisation strategies, such as repetition, precision, accuracy of the moulds, formworks and jigs, installation equipment and manufacturing facilities. Further investigation into areas pertaining to time, including lead-time, time required for raw-material acquisition, manufacturing, assembly time, disassembly, and recycling, quality, clients' satisfaction, and post-occupancy evaluation could also shed light on the practicalities and hindrances of the wider application of modularisation strategies. A critical qualitative comparative analysis of the application of these modularisation strategies in different countries could also add significant depth, breadth and value to the existing body of knowledge in this field. Also probably a longitudinal study can prove to be of some significant benefits to measure and document long term benefits of modularisation especially sofar as maintenance, upkeep, refurbishment and repairs are concerned for the two approaches/strategies investigated in this paper.

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