Federal University of Rio Grande do Sul
Engineering School
Postgraduate Program in Civil Engineering

A conceptual framework for defining customisation strategies in the house-building sector

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Porto Alegre

2011

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A CONCEPTUAL FRAMEWORK FOR DEFINING CUSTOMISATION STRATEGIES IN THE HOUSE-BUILDING SECTOR

Thesis presented to the Postgraduate Program in Civil Engineering of the Federal University of Rio Grande do Sul as part of the requirements of the Degree of Doctor in Engineering.

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This Doctoral thesis was assessed by the Board of Examiners and considered suitable for obtaining the title of DOCTOR IN ENGINNERING. Its final version was approved by the supervising professor and the Postgraduate Program in Civil Engineering of the Federal University of Rio Grande do Sul.

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CIP - Catalogação na Publicação

Gravina da Rocha, Cecília
A conceptual framework for defining customisation strategies in the house-building sector / Cecília Gravina da Rocha. -- 2011.
222 f.

Orientador: Carlos Torres Formoso.
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Tese (Doutorado) -- Universidade Federal do Rio Grande do Sul, Escola de Engenharia, Programa de Pós-Graduação em Engenharia Civil, Porto Alegre, BR-RS, 2011.

1. mass customisation. 2. decision categories. 3. housing. 4. product development process. 5. construction industry. I. Torres Formoso, Carlos, orient. II. dos Santos, Aguinaldo, coorient. III. Título.

Elaborada pelo Sistema de Geração Automática de Ficha Catalográfica da UFRGS com os dados fornecidos pelo(a) autor(a).

ACKNOWLEDGEMENTS

First, I would like to thank the National Council for Scientific and Technological Development (CNPq) for sponsoring this Doctorate, especially during the period at the University of Salford (U.K.).

I am thankful to my supervisor Carlos Torres Formoso, for his unsurpassed guidance and inspiration during the four doctoral years. I would also like to thank my co-supervisor Aguinaldo dos Santos for the invaluable discussions and for showing me a new way to look at research.

I am grateful to my foreign supervisor Mike Kagioglou for welcoming me at the University of Salford and supporting the development of this research during the overseas period of my Doctorate. I am also grateful to Will Swan and Carl Abbott from the Salford Centre for Research and Innovation (SCRI) at the University of Salford for their eagerness and for facilitating the contact with the British organisations.

It was a pleasure to spend the years of doctoral studies with enthusiastic researchers at the Building Innovation Research Unit (NORIE), the Salford Centre for Research and Innovation (SCRI), and the Design and Sustainability Centre at the Federal University of Paraná. Particularly, I would like to thank Algan Tezel, Aline Krämer, Catherine Barlow, Gheysa Prado, Juliana Brito, Lisiane Lima, Luciana Miron, Nivaldo Gomes, Norman Gilkinson, Patricia Tillmann, Patricia Tzortzopoulos-Fazenda, and Ricardo Codinhoto for the discussions and valuable input on the content of the thesis but also for their friendship. I am thankful to Sergio Kemmer for the endless discussions we had on the implications of the customisation in the production process (now I am also a fan of the line-of-balance technique). I also owe my gratitude to Masa Noguchi for organising and leading the visits to the innovative house-building companies in Japan (and also for uncomplainingly translating all my questions to the companies), which provided important insights to this research. I would also like to thank the supporting staff from the Federal University of Rio Grande do Sul and the University of Salford for their assistance.

Finally, I would like to express my gratitude to the organisations involved in the four case studies and to all the professionals who kindly gave their time for taking part in this research. This thesis would not have been possible without their invaluable participation and information sharing.

And, last but not least, I am particularly thankful to my friends and family for their support and love not only but especially during the doctoral years. Especially, I want to thank Elder for his love, caring, unmatched patience, and for his funny impersonations, which made me laugh even in difficult moments.

ABSTRACT

DA ROCHA, C.G. A conceptual framework for defining customisation strategies in the house-building sector. 2011. Thesis (Doctor in Engineering) – Escola de Engenharia, Programa de Pós-Graduação em Engenharia Civil, UFRGS, Porto Alegre.

There has been an increasing diversity on dwellers profiles and on their requirements in the last few decades, due to major changes in contemporary lifestyles. Such changes are making the traditional provision of standardised houses inadequate, requiring the development of new strategies able to provide customised dwellings. In this context, the application of the mass customisation (MC) approach and related concepts can potentially increase the value of housing through the fulfilling of the specific requirements of dwellers. In spite of that, the literature on the MC approach is limited in providing guidance to organisations in developing customisation strategies, particularly in the house-building sector. In order to address such a problem, a design science approach is adopted in this investigation. Such an approach deals with the construction of solutions (artefact, models, software, among other) for problems with practical relevance and potential for theoretical contribution. The solution devised in this investigation is a conceptual framework to be used by organisations of the house-building sector in defining customisation strategies. The framework entails ten decision categories that define the scope of a customisation strategy and also address some aspects of the clients' interfaces, product design, and operations areas. Other outputs of this research include (i) instantiations (implementations that demonstrate that the solution works), (ii) evaluation of the solution utility, and (iii) evaluation of the theoretical contribution of the solution. The research process undertaken involved keys steps of the design science approach: find a practical problem with potential for a theoretical contribution, obtain an understanding of such a problem, develop a solution, test the solution and evaluate its utility, and assess the theoretical contribution of the solution. Four case studies with organisations (in Brazil and in the U.K.) of the house-building sector were also carried out and were particularly important in the solution devising and solution testing steps. In terms of theoretical contribution of the solution, some of the categories developed (classes of items, module combinations, customisation units, and configuration sequence) are grounded on empirical data and provide new conceptualisations related to the MC approach and which can be used in defining customisation strategies. Other categories (solution space, modules, module interfaces, order penetration point, types of customisation, and visualisation approaches) rely on existing concepts and underpinnings available on the literature on the MC approach. The main contribution of those categories is to adapt such concepts by proposing operational constructs, enabling such knowledge to be more applicable in devising customisation strategies.

Keywords: mass customisation, decision categories, and housing

RESUMO

DA ROCHA, C.G. Proposta de um modelo conceitual para definição de estratégias de customização no contexto habitacional. 2011. Tese (Doutorado em Engenharia) – Escola de Engenharia, Programa de Pós-Graduação em Engenharia Civil, UFRGS, Porto Alegre.

Nas ultimas décadas, houve um aumento na diversidade do perfil dos moradores bem como nos seus requisito específicos em decorrência de mudanças no estilo de vida contemporâneo. Tais mudanças vem tornando a provisão tradicional de habitações padronizadas inadequadas e demandam o desenvolvimento de estratégias de customização capazes de responder aos requisitos específicos dos moradores. Neste contexto, a abordagem da customização em massa (CM) e conceitos relacionados pode potencialmente aumento o valor do produto habitacional através do atendimento dos requisitos específicos do moradores. Apesar disto, a literatura é ainda limitada em termos de estudos que auxiliem organizações a desenvolver estratégias de customização, especialmente no setor habitacional. Visando responder este problema de pesquisa, esta investigação adota a abordagem da *design science*. Esta abordagem tem por objetivo desenvolver soluções (artefatos, modelos, *software,* entre outros) que resolvam problemas práticos e ao mesmo tempo tenham potencial para uma contribuição teórica. A solução desenvolvida nesta pesquisa é um modelo conceitual com categorias de decisão para definição de estratégias de customização no contexto habitacional. O modelo contém dez categorias de decisão, que definem o escopo de uma estratégia de customização e abordam aspectos relacionados a interface com o cliente, design do produto, e operações. Outros resultados da pesquisa, além deste modelo, incluem implementações (operacionalizações que demonstram que a solução funciona), avaliação da utilidade da solução, e avaliação da contribuição teórica da solução. O processo de pesquisa envolveu etapas chave da *design science*: encontrar um problema prático e com potencial para contribuição teórica, obter um entendimento deste problema, desenvolver uma solução, testar a solução, avaliando sua utilidade, e avaliar a contribuição teórica desta solução. Quatro estudos de caso com organizações envolvidas no setor da construção habitacional (no Brasil e no Reino Unido) também foram desenvolvidos. Em termos da contribuição teórica do modelo, algumas categorias (classes de itens, combinações de módulos, unidades de customização, e sequências de configuração) foram desenvolvidas com base em dados empíricos e constituem nova conceitualizações relacionadas a abordagem da CM que podem ser usadas no desenvolvimento de estratégias de customização. Outras categorias (espaço de solução, interface entre módulos, ponto de entrada do pedido, tipos de customização, e abordagens de visualização) baseiam-se em conceitos já disponíveis na literatura. A contribuição destas categorias é adaptar tais conceitos, através da proposição de constructos, visando facilitar a aplicação dos mesmos na definição de estratégias de customização.

Palavras-chave: customização em massa, categorias de decisão, e habitação

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ABBREVIATIONS

2b3p – 2-bedroom 3-person dwelling

2b4p – 2-bedroom 4-person dwelling

3b5p – 3-bedroom 5-person dwelling

3b6p – 3-bedroom 6-person dwelling

4b7p – 4-bedroom 7-person dwelling

4b8p – 4-bedroom 8-person dwelling

4b6p – 4-bedroom 6-person dwelling

5b8p – 5-bedroom 8-person dwelling

C1 – Customisation unit 1

C2 – Customisation unit 2

C3 – Customisation unit 3

C4 – Customisation unit 4

C5 – Customisation unit 5

C6 – Customisation unit 6

CS1 – Case study 1

CS2 – Case study 2

CS3 – Case study 3

CS4 – Case study 4

DIY – Do-it-yourself

GB – Gigabyte

MC – Mass customisation

MRI – Modules Reuse Index

OPP – Order penetration point

PAC – Percentage of activities affected by customisation

PDP – Product development process

QFD – Quality function deployment

SSA – Solution space A

SSB – Solution space B

SSC – Solution space C

SSD – Solution space D

U.K. – United Kingdom

1. INTRODUCTION

This chapter presents the research problem and the questions and objectives that guided this investigation. The first section introduces the mass customisation (MC) approach and highlights two conclusions that emerged throughout the literature review process: (i) several studies adopt only one perspective (marketing, product design, or operations management) in addressing the MC approach, resulting in a fragmented body of knowledge, and (ii) there is a shortage of research focusing on the operationalisation of the MC approach in order to support organisations of the house-building sector in devising customisation strategies. The second section discusses the importance of customisation in the house-building sector and summarizes the contributions of key studies on that topic. The third section summarizes the research problem, which is translated into a set research questions and objectives, presented in the fourth section. In the fifth section, the limitations of this investigation are outlined. The sixth section summarizes the content of this thesis.

1.1 THE MASS CUSTOMISATION APPROACH

The central idea of the MC approach is to provide some degree of customisation while also striving to achieve the standards of efficiency, cost, and quality of mass production (MACCARTHY, BRABAZAN, 2003). The MC approach reflects the advancements in the design and management of production systems and also the sophistication of clients' demand over the years. Prior to the Scientific Administration, craftsmanship was the predominant mode of production, characterized according to Brown and Bessant (2003) by low volumes and high variety. With the advent of the mass production as the dominant paradigm, the reductions in costs, driven by the economies of scale, became the key competitive criteria (PAIVA *et al.*, 2004). The progress in the development of flexible production systems and new information technologies supported the rise of mass customisation systems, delivering higher variety at lower cost (DA SILVEIRA *et al.*, 2001). Such approach is grounded on the assumption that clients differ in their desires, attitudes, and preferences (ENGEL *et al.*, 2000) and that meeting the specificities of each individual will add value to the product. The MC approach also alters the trade-off between cost and differentiation: customisation can be achieved without proportional sacrifices in terms of costs.

Although a customisation strategy can create a competitive advantage, the MC approach is not applicable to all organisations of all markets and sectors. For example, most clients' needs in terms of salt can be met by the two basic kinds of salt available in the market (HART, 1994): for the table and for the road. Similarly, Piller (2007) states that clients just want to get what they want, regardless if this is customised or a standardised product. Those statements highlight the need to focus on what adds value to client and how, rather then simply assuming that an increase in the customisation options will automatically add value to products. In addition to that, the downside or problems that can be introduced by a customisation strategy cannot be overlooked, in spite of the fact that they are not extensively discussed in the literature as its benefits. For example, it could be argued that customisation can potentially reduce the consumption of products since clients would not need to purchase several products to meet their requirements, but have them met by a customised product. Nonetheless, increasing the degree of customisation offered could trigger an increase in the purchase of products, since clients could have several variations of a product instead of a standard one.

Strategies based on the MC approach seek to simultaneously achieve the benefits of the generic strategies of cost and differentiation introduced by Porter (1980). Because of the implicit notion of competition in two dimensions (cost and differentiation), the MC approach is considered to be a paradox or an oxymoron by Selladurai (2004), Hart (1995), Duray *et al.* (2000), Kumar *et al.* (2007), among others. In spite of that, this approach is aligned with the change in the competitive battles, which enables the competition in more than one competitive dimension (PRASAD *et al.* 2001). Yet, strategies grounded on this approach are likely to be more complex than generic strategies of cost or differentiation since they depend on coordinated decisions in different areas in order to provide customisation without proportional increases in costs.

Several studies (BARDAKCI, WHITELOCK, 2005; DA SILVEIRA *et al.* 2001; BARLOW, 1998) advocate the need of a systemic consideration involving all the value chain in order to develop and implement strategies based on the MC approach. This is because customisation has implications over the procurement, product design, and manufacturing areas (SPRING, DALRYMPLE, 2000). Barlow (1998) reinforces the need to integrate the design, production, and marketing activities for providing customised products. Ahlstrom and Westbrook (1999) point out that there should be a dialogue between the operations management and the marketing[1] areas in order to align the market demand with the operations strategy. Salvador *et al.* (2002) argue that the interdependencies among the product, the processes, and the supply chain should be carefully considered when devising a customisation strategy. Based on those authors, it can be argued that a strategy grounded on the MC approach requires coordinated decisions in the areas of marketing, product design, and operations management.

In spite of those arguments highlighting the importance of integrating the different areas, several studies address the MC approach considering the perspective of a single area. Salvador *et al.* (2009), Piller and Kumar (2006), Duray *et al.* (2000), Ernst and Kamrad (2000), and Fisher (1997) are some examples of studies that integrate the perspective of two or more areas. Piller and Kumar (2006) propose a set of mass customisation practices, such as modular design, delayed product differentiation, flexible process, and customer co-design, involving different areas such as product architecture, operations management, and marketing and discuss the strategic priorities affected by them. Alike, Salvador *et al.* (2009) highlights the capabilities of a mass customisation system,

[1] Marketing refers to the activities of findings and satisfying existing, latent, or new client requirements (KOTLER, 2002).

entailing the interface for creating the bespoke products and also considerations from a product design and manufacturing perspectives. Fisher (1997) describes two supply chains considering the nature of the product (functional or innovator) and defines parameters for their effective functioning. He integrates issues related to the product features, the type of demand, and the product life cycle in devising a supply chain. Duray *et al.* (2000) propose four types of mass customisation based on the points of client involvement in the product configuration and the types of product modularity adopted. Ernst and Kamrad (2000) discuss the influence of the modularity and the delayed product differentiation approach in the configuration of the supply chain.

Another critique to existing research on the MC approach is the emphasis on descriptive or theoretical studies that have proposed generic models and taxonomies that cannot be readily used by the industry in devising customisation strategies. Despite the plethora of studies on the MC approach, little is mentioned about the application and the influence of contextual variables such as plant-specific features in devising manufacturing strategies (BROWN, BESSANT, 2003). A number of taxonomies of mass customisation have been proposed, such as Lampel and Mintzberg (1996), Pine (1993), Gilmore and Pine (1997), and Da Silveira *et al.* (2001). Hart (1995) proposes internal and external factors that should be considered by an organisation prior developing a customisation strategy. Although Hart (1995) discusses the implications of the different factors in adopting a customisation strategy, he states that the questions of how an organisation should go about implementing a customisation strategy, when to start, in which areas to focus, and how fast to proceed still remain unanswered. According to MacCarthy *et al.* (2003), the literature is limited in providing understanding of the content of strategies based on the MC approach that are best suited for particular environments. Those statements suggest that the conceptual underpinnings of the MC approach, which enable an organisation to provide customised products with efficiencies near mass production, are outlined. Yet, it seems that they are descriptive or provide prescriptions at a generic level, hindering their adoption by the industry. It seems that devising tools that address the underpinnings of the MC approach but that are also able to integrate context specific features of the organisation under consideration could enable a wider adoption of such an approach by practitioners.

1.2 THE IMPORTANCE OF CUSTOMISATION IN HOUSING

Several trends have contributed for the increasing diversity of household's requirements such as changes in the demographic profile of households, the new roles undertaken by women (HASELL, PEATROSS, 1990; BRANDÃO, HEINECK, 2003), the increase in work at home jobs (FRIDMAN *et al.*, 1997; BRANDÃO, HEINECK, 2003), and the proliferation of equipments and new media, adding new functions to the dwellings (BRANDÃO, HEINECK, 2003; FRIDMAN *et al.*, 1997). Tramontano (2002) highlights five recent trends in terms of household arrangements: (i) an increase in single parent families, (ii) an increase in persons living alone, (iii) an increase in couples in stable relationships but that are not legally married, (iv) an increase in people living together based on common interests or preferences rather than living with relatives, and (v) a decrease in the number of children of the traditional nuclear family.

Apart from those trends, that arose in the last decades, there is a plurality of meanings and dimensions associated to dwellings (SIXSMITH, 1986; EDELSTEIN, 1986; LAWRENCE, 1987; SMITH, 1994). For instance, Smith (1994) identified six essential qualities of a home (continuity, privacy, self-expression and personal identify, social relationships, warmth, and a suitable physical structure) and that were absent in dwellings not regarded as homes. In terms of personal identify, the personalisation of the dwellings is a way in which the individuals express their identity (SMITH, 1994). Likewise, Lawrence (1987) points out several factors, psychological, cultural and demographic, that influence the design, meaning, and usage of dwellings and argues that people experience them differently.

Housing developments ought to meet the new requirements introduced by those trends. Noguchi (2003) observes that clients are no longer satisfied with repetitive products and housing products should be able to meet individual needs. Likewise, Barlow (1999), in assessing the U.K. house building industry, argues that enhancing the attractiveness of new housing products, which will require the development of approaches for meeting clients' current and ever evolving requirements, is a major challenge to be addressed. The idiosyncratic meaning that each dwelling has for each particular household provides an additional argument for developing customisation strategies that enables bespoke needs to be addressed.

In Brazil, the customisation theme has been addressed by Cirico (2001), Oliveira and Moschen (2001), Brandão and Heineck (2003, 2007), Frutos and Borenstein (2003, 2004), Carvalho (2004), and Payeras (2005). Overall, such studies have a descriptive nature and explore strategies or approaches for customising dwelling units (OLIVEIRA, MOSCHEN, 2001; BRANDÃO, HEINECK, 2007; ROSSI, 1998; EBERT, 2006), mapping changes in the dwellings planned or realised by the householders (SZÜCS, 1998; CIRICO, 2001; REIS, 1998; REIS, 2000), calculating the cost associated to the customisation of dwellings (CARVALHO, 2004), and quantifying the construction and demolition waste generated by customisations (PAYERAS, 2005). Overall, such studies focus on the design of the dwellings and suggest some approach to increase their adaptability or flexibility. The customisation topic is also marginally addressed by other studies (CARVALHO, FENSTERSEIFER, 1996; BARROS NETO *et al.*, 2002) centred on the production strategy and on flexibility as a competitive criterion. Such studies explore the different types of flexibility and how these can be pursued in the house-building sector. Yet, they approach the customisation considering only an operations management perspective.

In the international context, there are studies concerning the customisation in the house-building sector in the U.K. (NAIM, BARLOW, 2003; BARLOW, OZAKI, 2003; BARLOW, 1998; BARLOW, 1999), Japan (PATCHELL, 2002; GANN, 1996; BARLOW *et al.*, 2003; NOGUCHI, 2003) and Mexico (NOGUCHI, HERNANDEZ-VELASCO, 2005). Such studies discuss the MC approach, which was devised considering the manufacturing sector, and related principles from the marketing, product design, and operations areas. Noguchi and Hernandez-Velasco (2005) identified the demand for customisation in low incomes residential projects in Mexico. They concluded that the dwellings were modified shortly after occupancy and attributed this to the lack of opportunities for customisation in the sales and design stages.

In the U.K. context, Barlow (1998, 1999) discuss the barriers for the adoption of mass customisation and innovative practices in the housing sector such as the lack of clear strategies, the fear of changes, and the weak competition. Barlow and Ozaki (2003) analyse the receptiveness and demand of client for customisation in a study with an organisation of the residential sector that started to offered options of layout and specifications. That investigation indicated that there was a demand from the clients' side, but that structural changes such as prefabrication and an effective management of the supply chain were required for delivering such customisation. In general, the studies focusing in the British context adopt an industry perspective, identifying hindrances and opportunities to the adoption of the MC approach.

In terms of the Japanese context, Barlow *et al.* (2003) analyse the decoupling point[2] and the supply chains of organisations acting in the residential sector. They conclude that customisation strategies can be supported by different models of supply chain. Gann (1996) explores the similarities and differences of the industrialisation in the car and the housing sectors in Japan. He also highlights the particular features of Japan that enabled the adoption of the MC approach more effectively than Europe and USA. Patchell (2002) also focuses on the Japanese construction industry and examines how the interaction between local and national contractors shapes the construction sector in that country. The studies on the Japanese context have a more practical approach than the others, mostly in terms of what should be considered by an organisation of the house-building sector for developing a customisation strategy. Yet, the particular features of the construction industry and their influence in the adoption of customisation strategies are still a focal point of those studies.

Besides the emphasis on the industry and the supply chain levels, the above-mentioned studies also have a fragmented rather than a holistic approach in addressing the MC approach. For instance, Barlow *et al.* (2003) considers mainly the operations management perspective, describing the supply chains observed. Noguchi and Hernandes-Velasco (2002) address issues within the marketing perspective such as the demand for customisation but do not connect these to the operations management and the product design areas. Hence, there are opportunities for investigating the MC approach adopting a holistic view, integrating the theoretical underpinnings of the different areas involved in undertaking a customisation strategy. The MC approach might seem superficially attractive, but in fact requires the consideration of complex issues such as the definition of attributes on which clients wish to differentiate, how the client will interact with the organisation, and whether the organisation has the capability to offer such differentiation efficiently and profitably (MACCARTHY, BRABAZAN, 2003).

[2] *Decoupling point* is the point in which the client's requirements first enter the value chain. It divides the value chain in two parts: the upstream part, which is forecast driven, and the downstream part, which is demand driven. This concept will be discussed in more detail in section 3.4.

1.3 RESEARCH PROBLEM

This investigation entails a problem with practical importance and theoretical relevance, envisioning contributions to the real world and also to the literature on the MC approach and related concepts. Dwellings should be able to respond to households' specific requirements, increasing the value of such products without a proportional increase in costs and delivery times. Also, if a customisation strategy is not considered at the outset and standard dwellings are provided, adaptations are likely to be carried out by residents as indicated by Miron (2008), Payeras (2005), Noguchi and Hernandes-Velasquez (2005), and Reis and Lays (2002). More often than not, these adaptations will not be conduced in the most effective and efficient way. In order to illustrate the practical relevance of the research problem addressed by this investigation, Figure 1 depicts before and after pictures, showing the alterations informally carried out by residents after the occupancy of dwellings in a low-income settlement studied by Miron (2008). The construction of garages, installation of fences, and other informal modifications jeopardize the quality of the dwellings and the allotment. Hence, the development of tools that support organisations of the house-building sector in devising customisation strategies that are able to meet the householders' requirements can potentially avoid or mitigate such problems.


Figure 1: Example of personalisations informally carried out by householders
(source: Miron, 2008)

From a theoretical perspective, one part of the problem is related to the theoretical background available on the MC approach. In spite of the fact that there is knowledge on the different aspects within the product design, operations, and marketing areas that need to be considered in developing a customisation strategy, there are limited efforts in prescriptive research that enable the application of such a knowledge to solve practical problems. The other part of the problem is related to the idiosyncratic features of the construction industry, hindering the direct application of approaches that have been devised for the manufacturing context.

Construction projects are organised in temporary supply chains that are designed and assembled for the purpose of particular projects (KOSKELA, 2003). This temporary nature has implications in the customisation strategies that can be developed. For instance, it is unlikely that a single customisation strategy will be used for a large volume of products as it happens in the manufacturing sector. More often than not, customisation strategies will vary from one project to another depending on the particular goals and the stakeholders involved. Hofman *et al.* (2009) describe barriers encountered in devising a customisation strategy and, more specifically, a product architecture that could be used across several projects. Those authors argue that most companies operate in a decentralized network of suppliers and clients where there is not a leading organisation that controls the standards of compatibility, precluding the introduction of rules to create standardised product modules.

In the construction industry, each product is a one-off and there is usually little repetition from one project to another (VRIJHOEF, KOSKELA, 2000). Because the suppliers are likely to vary from one project to another, the flexibility and the ability to efficiently cope with the intended customisation is also likely to fluctuate. As in the case described by Hofman *et al.* (2009), some building parts were not modularized since their reuse in future projects was improbable. Some of the characteristics of the construction industry do not fully apply to the house-building sector. For instance, standard dwellings types can be used throughout several projects as suggested by Barlow (1999). In spite of this, each building has to respond to a specific site and an environmental context in terms of the solar orientation, winds, weather patterns, topography, landscape, and views. Hence, a building is placed in a site and needs to relate to its. Because it is not as isolated from its environment as most manufacturing strategies, different strategies may be required for different products.

The scale of the products of the built environment is different from most products of the manufacturing sector, posing a challenge on the scope of the customisation that can be offered. This is especially the case if a modular architecture is adopted and a building is broken down into sizeable modules such as rooms. In most cases, it is unlikely that sizeable modules of a building would be completely independent units[3] prior to the building assembly. In the construction industry many building parts are fabricated on site directly onto the building. If pre-fabricated sub-assemblies are used, they are not completely independent units in most cases. The organisation of a building in sizeable modules is underlined in the ideas of infill and support advocated by the Open Building approach. Some of the challenges faced in this approach relate to infrastructure entanglement and compatibility among building systems made by different manufacturers (KENDALL, 1999). Also, the plurality of meanings and dimensions associated to dwellings introduce a broader scope of requirements, entailing symbolic and semantic needs that should be considered in devising a customisation strategy.

1.4 RESEARCH QUESTIONS AND OBJECTIVES

Based on the research problem summarized in the previous section, three main questions are formulated:

a) How to define a customisation strategy for construction companies that operate in the house-building sector?

[3] Clearly, there are exceptions. An example is a pod system in which the modules (the pods) are complete units, produced prior to the building construction and only assembled onto the building structure on site.

b) How to adapt the conceptual underpinnings of the MC approach into the house-building sector?

c) Which decisions should be made for defining a comprehensive and coherent customisation strategy for house-building companies?

Based on those research questions, four objectives are proposed for this investigation:

a) Devise a conceptual framework for defining customisation strategies in the house-building sector;

b) Refine a set of concepts related to MC, in order to adapt them to the specific context of house building;

c) Propose a sequence of steps for defining a customisation strategy; and

d) Implement the proposed framework in real cases, aiming to assess its utility.

1.5 LIMITATIONS

The categories of decision proposed in the framework define the scope of a customisation strategy and their implications in terms of the interface with client, product design, and operations. Those areas were selected because according to the literature, they are fundamental areas that need to be considered for the successful implementation of a customisation strategy. Nonetheless, it is acknowledged that other areas such as human resources and finances also need to support the customisation strategy.

The categories proposed in thpe framework do not intend address all the decisions that should be considered in the above-mentioned areas in devising a customisation strategy. Also, it is recognized that different perspectives could be adopted for conducing this investigation. The perspective chosen is to address customisation as a strategy that is closely related to the business strategy and to focus on the decisions related to the product development process that shape such strategy. Finally, there were some limitations in terms of the data that could be collected in each of the empirical studies due to their different stages in the product development process. Such limitations will be presented in more detail in the research method chapter.

1.6 CONTENT OF THE THESIS

The remaining part of this document is divided into seven chapters. The second chapter explores the MC approach and how it contributes in increasing the value of housing products. The development process of products is also discussed. The third chapter presents key concepts that support a MC approach considering the perspectives of interface with clients, product design, and operations. In the fourth chapter, the design science approach that was adopted as the research strategy in this investigation is explained. The three stages that were followed in developing this investigation are described and the activities carried out in each of them are detailed.

The fifth and the sixth chapters have a similar structure as depicted in Figure 2: the former presents the development of the first version of the framework and the latter the development of the second version. Each of the chapters contains a description of the empirical studies, the proposed framework, the instantiations[4], and an evaluation of the utility of the framework, considering the perspective of the organisations involved in the empirical studies. The seventh chapter encompasses a summary of the framework and the relationship among the decision categories proposed. It also includes a discussion of the scope of applicability of the framework and its theoretical contribution. The eighth chapter contains an appraisal of the research objectives and the suggestions for future research.

	Chapter 5 – Development of the first version of the framework	**Chapter 6 – Development of the second version of the framework**
Description of the case studies	Case studies 1 and 2	Case studies 3 and 4
The framework	First version of the framework	Second version of the framework
Instantiations	Case studies 1 and 2	Case studies 1, 2, 3, and 4
Assessment of the utility of the solution	Case study 2	Case studies 3 and 4

Figure 2: Structure of the fifth and sixth chapters

[4] An instantiation (or implementation) demonstrates the feasibility of constructs, methods, or models (MARCH, SMITH, 1993).

2. THE MASS CUSTOMISATION APPROACH

2.1 THE NATURE OF THE TERM

The mass customisation (MC) approach was first anticipated by Alvin Toffler in his book *Future Shock* published in 1970 (KUMAR *et al.*, 2007; ULRICH *et al.* 2003; RADDER, LOUW, 1999; PINE, 1993a). According to Toffler (1970), the end of the standardisation could be perceived as several organisations started to produce a range of products instead of a single one. He pointed out that the trends of diversification of the market demand and advancements in technologies had contributed towards the emergence of such an approach. Yet, it was Stan Davis who coined the term in his book *Future Perfect*, first published in 1987 (ULRICH *et al.,* 2003; DA SILVEIRA *et al.,* 2001; RADDER, LOUW, 1999; PINE, 1993a). Since then, several areas such as operations management, supply chain management, product development process, product architecture, and marketing have discussed MC, yet without a consensus on the limits and the scope of the term. Kumar (2004) recognizes a plurality of definitions and suggests two aspects that are common to most definitions: (i) the product delivered is similar to what the client desires, implying that there is some degree of customisation; and (ii) the cost of that product does not suffer a proportional increase as the degree of customisation increases.

It is necessary to make a distinction between the visionary and pragmatic definitions of the MC approach. When the term was first coined, a visionary perspective was adopted which gradually gave place to a more pragmatic perspective (KUMAR *et al.*, 2007). The visionary perspective holds that the MC approach delivers to clients whatever they want, at anytime, any place, and in any form (HART, 1995). The use of flexible processes and organisational structures to deliver a variety of products that are able to fulfil clients' requirements with costs similar to mass produced products is a more pragmatic perspective of the MC approach (HART, 1995). Although variety and customisation are closely related terms, it is important to highlight the difference between them. Customisation is concerned with the provision of product variety in response to clients' individual requirements, while mass customisation means delivering customisation at reduced costs (PINE *et al.*, 1995). Variety is related to the broadening in the range of products offered, not necessarily triggered by clients' requirements.

In spite of the plethora of studies addressing the MC approach, there is not a consensus on the nature of the term. It has been defined as a paradigm (HUANG *et al.*, 2008; BROWN, BESSANT, 2003; JIAO, TSENG, 1999), a strategy (PILLER *et al.*, 2005; BARDAKCI, WHITELOCK, 2005; FRUTOS, BORENSTEIN, 2004; MACCARTHY, BRABOZAN, 2003a; SALVADOR *et al.* 2002; GILMORE; PINE, 1997), a theory (BARDAKCI, WHITELOCK, 2005), a capability (ZIPKIN, 2001), and an ability (DA SILVEIRA *et al.,* 2001). The definition of such term as a paradigm is usually made in contrast to the mass production paradigm. For instance, Jiao *et al.* (2003) state that the MC can be viewed as a new paradigm in which goods and services meet the clients' requirements while keeping the efficiencies of the mass production paradigm. The interpretation of mass customisation as a paradigm is based on the fundamental assumptions embedded in those two production modes.

Underlined in the mass customisation paradigm is the notion that the value of products can be increased by broadening the degree of customisation offered. By contrast, the mass production paradigm focuses on cost reductions that are achieved by the production of a large volume of standard products. The cost reductions arise from the economies of scale, which, according to Hayes and Wheelwright (1984), are generated by spreading the fixed costs, rethinking the production process to reduce the cycle time, using large machine instead of several small ones, and improving the marginal cost per unit, which results from the ability or experience accumulate by an organisation over time[5]. In such paradigm it is implicit that price is a key benefit valued by clients, who accept standard products in return for low costs. Economies of scale are also necessary in the mass customisation paradigm in order to keep costs down. Yet, mass customisation also relies on economies scope that, according to Teece (1980), arises from inputs that are shared across products or processes and utilized jointly without a complete congestion. Economies of scale are gained through the repeated use of standard modules, instead of standard products, whereas economies of scope are achieved by using those modules several times across distinct product variants (PINE, 1993b).

Mass customisation has also been defined as the ability to provide bespoke products through flexible and responsive processes (PILLER, 2007; DA SILVEIRA *et al.*, 2001). Most studies that define mass customisation as a strategy do not usually connects it to the company strategy that it relates to. Frutos and Borenstein (2003) and Bardakci and Whitelock (2005) are exceptions since they define mass customisation as a strategy, but more specifically define it, respectively, as a business strategy and a marketing strategy. Also, numerous studies (PILLER *et al.*, 2005; GILMORE, PINE, 1997; MCCARTHY *et al.*, 2003; LAMPEL, MINTZBERG, 1996) discuss customisation strategies, rather than a customisation strategy, emphasizing that distinct strategies can be devised. In this research, mass customisation is considered to be an approach that can be used in devising customisation strategies, which are closely related to business strategies. Before discussing the perspective of MC adopted in investigation, it is necessary to introduce fundamental concepts related to strategy.

[5] Hayes and Wheelwright (1984) organise these enablers of economies of scale in three time horizons: short term, medium term, and long term.

2.2 THE MC APPROACH AND STRATEGY

2.2.1 Business strategy

The term strategy is derived from the Greek word *strategos* that literally means the art of the general (HAYES, WHEELWRIGHT, 1984). According to General Von Moltke, strategy refers to the practical art of adapting means to achieve desired ends (PAIVA *et al.*, 2004). Contador (1994) proposes the concepts of competitive battlefields and weapons to explain the strategic planning and the competitive strategy. He states that the competitive battlefields define the attributes that clients are interested, whereas the weapon is the means employed by an organisation to compete in a particular field. Different weapons will be selected by the organisation depending on the battlefield under consideration (CONTADOR, 1994). For instance, cost is a weapon for competing in the price battlefield.

The extensive use of the term strategy over the years has made it lost its unique meaning when applied to the practice of management (HAYES, WHEELWRIGHT, 1984). Yet, at least five characteristics are common to the use of the term in management (WHEELWRIGHT, 1984):

a) **Time horizon:** strategy is used to describe activities that involve a long term horizon, in terms of the time required for realising the activities planned and also observing their impact;

b) **Impact:** the impact of a particular competitive strategy is observed only after a considerable horizon of time has elapsed, yet its impact is greater than short-term strategies or operational activities;

c) **Concentration of effort:** the concept of strategy implies the concentration of effort on a limited range of objectives, implying that there is a reduction in the effort towards other objectives;

d) **Pattern of decisions:** only a few major decisions need to be made to define a strategy. Yet, patterns of sub-decisions usually need to be repeated in a variety of subareas to implement a strategy; and

e) **Pervasiveness:** a strategy embraces a wide breadth of processes and day-to-day operations and also requires all levels of an organisation to act in ways that reinforce the strategy.

Overall, a realised strategy is a combination of deliberate actions, which results from previously defined plans, and emergent decisions, that were not planned but happened as the strategy evolves. Mintzberg (1996) criticizes studies that consider strategies only as deliberates actions, which imply that plans are firstly outlined and later converted into actions, since there are evidences that strategies are partly emergent. He advocates the idea of strategy crafting instead of strategy planning, which is conceived as a straightforward and logical process. Mintzberg (1987) compares the process of crafting a strategy to the work process of a potter. The potter has his mind on the clay but is also aware of his past experience, of what has and has not work, and of his future prospects (MINTZBERG, 1987). All this things are working on his mind as his hands are working on the clay, making a strategy partially planned and partially emergent, embracing plans for the future and models of the past (MINTZBERG, 1987).

Mintzberg (1996) suggests 5Ps to explore the dimensions embedded in the concept of strategy:

a) **Strategy as a plan:** strategy is an intended stream of actions or set of decisions to deal with a situation, implying that it is conceived prior to the actions and that it is intentional;

b) **Strategy as ploy**: as a plan, a strategy can also be a ploy, forcing rivals to assume particular positions;

c) **Strategy as a pattern**: because strategy can be intended, they can also be realised through a consistent and defined set of actions. Deliberate strategies unfold from plans, whereas emergent strategies arise in spite of plans or regardless of them;

d) **Strategy as a position**: is related to the position of an organisation in a competitive environment in relationship to its rivals. In this perspective, a niche market can be viewed as a position that reduces competition; and

e) **Strategy as a perspective**: holds that a strategy is the organisation's worldview, shared by its members. Unlike the previous dimension, it considers that the strategy is internal to the organisation rather than defined by its position in the competitive battlefield in relationship to its rivals.

In terms of strategic planning, three levels can be highlighted (Figure 3). According to Wheelwright (1984), the corporate strategy specifies the its businesses and the acquisition and allocation of corporate resources for each of those business. The second major level is the business strategy that defines the scope or boundaries of each business unit and also the basis on which it will achieve a competitive advantage (WHEELWRIGHT, 1984). A functional strategies specifies how a functional area such as marketing, manufacturing, or research and development, will support the business strategy (WHEELWRIGHT, 1984). As illustrated by the arrows in Figure 3, the strategies should be vertically and horizontally aligned. Functional strategies should support the business strategy in achieving the competitive advantage set out for it and should not be conflicting. The business strategies should also be operationally linked to the corporate strategy (WHEELWRIGHT, 1984).

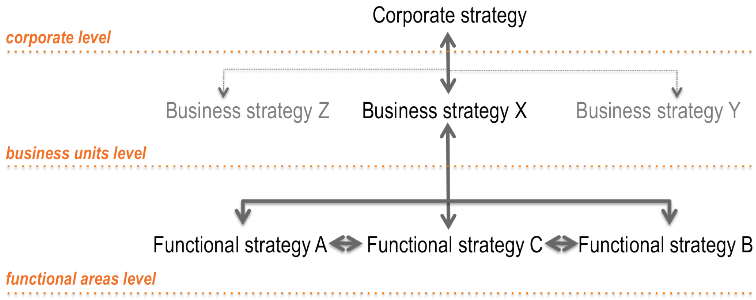

Figure 3: Levels of the strategic planning (WHEELWRIGHT, 1984)

2.2.2 Mass customisation strategies

In this investigation, the MC approach is considered to be a generic conceptualisation, whereas customisation strategies are the tailoring and operationalisation of such an approach to particular environments. More specifically, the MC approach defines the competitive criteria -- the provision of customised products with reduced cost and delivery time -- to be pursued at a business level. Yet, other elements such as the scope of the business, the product, the clients, and the competitors, which are not defined by the MC approach, need to be outlined for establishing a business strategy. In fact, it is necessary to have such elements defined in order to develop a customisation strategy.

The particular context of each organisation plays an important role in defining the customisation strategy to be adopted: the application of the MC approach and related principles should be aligned with an organisation strategic goals and processes. For that reason, customisation strategies are defined as such and not as mass customisation strategies since the provision of customised products efficiently might not be achievable in all situations. Also, this investigation holds that there is not a single customisation strategy, but that several strategies can be developed based on the MC approach.

The MC approach is considered to be applicable at the business units level and should be aligned with the business strategy. It is not conceived as a functional strategy since coordinated efforts across the different functional areas are necessary for its successful implementation. Based on that, Figure 4 illustrates the conceptualisation[6] of customisation strategies based on the MC approach adopted in this investigation. A customisation strategy needs to be supported by coordinated decisions in the areas of marketing, product design, and operations management. It is subject to external forces -- competitive environment and clients -- that can shape or influence such a strategy. The marketing area focuses on the capture and prioritizing of clients' requirements that will be translated in customisable attributes, ensuring that they are not just variety but actually add value to the product. It is also concerned with the interface between clients and the organisation, entailing the offering of the customisation options and their selection by the clients. The product design area focuses on the translation of the customisable attributes into a product architecture. It needs to balance commonalities and

[6] The elements contained in this conceptualisation will be discussed in more detail in the following sections and in chapter 3.

singularities in the design of the product to provide customisation while keeping the cost and delivery time reduced. The operations management area is concerned with the production of the products and ensuring that the production system and the supply chain are able to efficiently cope with the product variants offered.

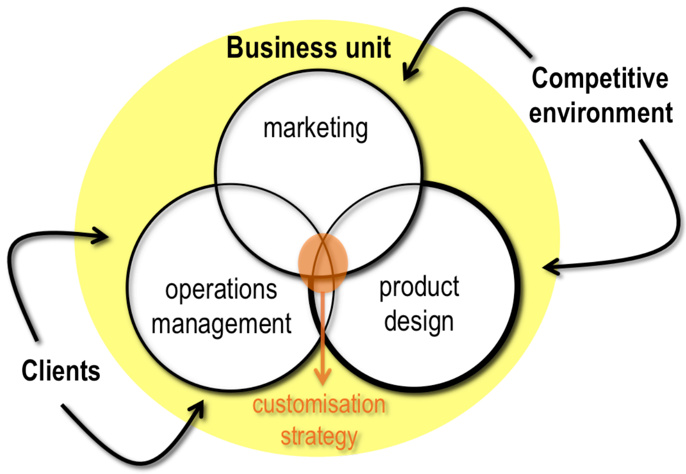

Figure 4: Customisation strategies

2.2.3 The competitive environment for customisation strategies

The competitive environment can enhance or detract the advantage that an organisation can gain from implementing a customisation strategy (HART, 1995; PINE; 1993a). The timing in establishing such a strategy in relationship to rivals also plays a key role since it is more successful implemented if there are no rivals prepare to follow it (HART, 1995; SILVEIRA *et al.*, 2001; KOTHA, 1996). The advantage of the first entrant (or first mover) in developing a customisation strategy emanates from two sources. The first is the offer of customised products that are able to fulfil individual needs, differentiating it from the products provided by competitors. The second is related to the establishment of a one-to-one relationship based on knowledge and trust that enables an organisation to learn more about their clients in each transaction (HART, 1995). An organisation that initiates the customisation has an advantage over its rivals, making clients more loyal to such organisation and less susceptible to change of brands (PINE *et al.,* 1995). In terms of the competitive environment, turbulent markets are suitable environments for customisation strategies (PINE, 1993a; HART, 1996). As the market turbulence, typified by unstable and unpredictable demand, increases, so does the potential for customised products (HART, 1995). Pine (1993a) proposes six structural factors that foster the shift to customisation:

a) **Buyer power:** is related to the control that clients have in defining the products prices and attributes. The greater the power of client in an industry, the less an organisation can control its environment and more turbulent it becomes. Significant buyer power fosters customisation since organisations have to respond more to what their clients wants and needs.

b) **The degree of influence of economic cycles:** the degree to which sales are subject to the cycles of recession, recovery, and expansions also indicates how much control an organisation has over its competitive environment. When organisations lose the ability to control and stabilize their market demand, they can no longer maintain a mass production system.

c) **Competitive intensity**: the number of rivals and how strongly they compete define where an industry stands in the continuum between mass production and mass customisation. Highly competitive environments favour mass customisation. On the other hand, industries in which organisations are happy with their position have little incentive to innovate and increase the range of products.

d) **Price competition versus product differentiation**: is related to the nature of the product. If organisations respond to market turbulence and buyer power by pure price competition, there is little incentive for customisation. This is usually the case for commodities, in which clients do not pay a premium for differentiation. Conversely, in noncomodity industries, the extent to which organisations respond with product differentiation strategies increase the products customisation in that industry.

e) **Level of saturation:** is related to the extent that a product has reached its saturation point in a particular industry, which happens when they have been consumed by almost all potential clients. Saturated markets promote customisation because they enable organisations to introduce products that are able to meet clients' requirements that were not met by previous products.

f) **Vulnerability to substitute products:** the more vulnerable an organisation's products are to substitutes, the more effort the organisation is going to put on understanding and meeting client needs, increasing the degree of products customisation.

g) **Product life cycle length and predictability**: long and predictable life cycles[7] yield stable and predictable demands, reinforcing the mass production paradigm. On the other hand, short and unpredictable life cycles create a turbulent market, which is a favourable environment for customised products.

h) **Rate of product technology change**: is related to the rate of change in product technologies in a particular industry. A high rate of technological changes reduces the life cycle of products, favouring the development of customisation strategies.

[7] A product life cycle is defined as the first shipment of a product until its replacement or withdrawal of the market (PINE, 1993a).

2.3 TAXONOMIES OF CUSTOMISATION

There are several taxonomies in the literature that aim to comprehensively describe the different types of customisation strategies that can be developed under the MC approach. The point in the value chain[8] in which the customisation occurs is a commonly used criterion for describing those types of customisation.

One of the earliest taxonomy was presented by Pine (1993b). He proposes five phases for the implementation of mass customisation: (i) customise services around existing products (add customised services to standard goods); (ii) mass produce customised services or products that clients can easily adapt to individual needs; (iii) move production closer to clients to provide point of delivery customisation; (iv) provide quick response (reduce time throughout the value chain); and (v) modularize components to customize end goods and services. Although Pine (1993b) proposes these five phases as stages in the development of customised products, they can also be viewed as distinct types of customisation.

Lampel and Mintzberg (1996) propose a continuum of five customisation strategies: (i) pure customisation (a product is built to order, and it is assumed that customisation starts at the design process); (ii) tailored customisation (standard processes and materials are used for providing tailored products, that is, customisation happens at the fabrication stage); (iii) customised standardisation (products are made from standardised components, and customised at the assembly process); (iv) segmented standardisation (a set of products is offered in response to the requirements of distinct clusters of clients, but not catered to each client individually); and (v) pure standardisation (a standard product is provided). In the case of segmented standardisation, there is not a customisation of the product itself and, thus, there is not a clear point in the value chain where customisation occurs. It assumes that customisation may be achieved simply by offering a mix of products. Nonetheless, the value chain should be designed for coping with it.

Later, Gilmore and Pine (1997) devised another taxonomy considering four customisation approaches: adaptive, cosmetic, collaborative, and transparent. In the adaptive approach, a standard but customisable product is provided, which is modified by clients at use, after delivery. In the cosmetic approach, a standard product is displayed and advertised differently to different clients. This approach can be defined as a customisation at the sales stage. The other two approaches (transparent and collaborative) do not address the point in the value chain where the customisation occurs, but rather how the product is displayed to clients. In a transparent approach, customised goods and services are provided without explicitly letting the clients know that those products have been customised for them (GILMORE, PINE, 1997). Collaborative customizers conduce a dialogue with individual clients to assist them in articulating their requirements to identify and make precise offers that fulfil such requirements (GILMORE, PINE, 1997).

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[8] According to Porter (1985), the value chain is a collection of activities that an organisation performs to design, produce, market, deliver, and support its products.

Da Silveira *et al.* (2001) suggest a broader taxonomy, entailing eight generic levels of mass customisation, based on the analysis of taxonomies proposed by previous authors (Figure 5): (i) design: collaborative design, production, and delivery of a product based client specific requirements; (ii) fabrication of a product according to client preferences following pre-defined designs; (iii) assembly: combination of modular components into different mixes according to clients' orders; (iv) additional client work into a standard product; (v) additional services into a standard product; (vi) packaging and distribution of products in different ways; (vii) use: delivery a product that can be altered during usage; and (viii) standardisation: no customisation is offered.

	Gilmore and Pine (1997)	**Lampel and Mintzberg (1996)**	**Stage of MC (1993)**	**Spira (1996)**
Levels of MC	**MC approaches**	**MC strategies**	**Stages of MC**	**Types of customisation**
8. Design	Collaborative; transparent	Pure customisation		
7. Fabrication		Tailored customisation		
6. Assembly		Standard customisation	Modularity	Assembling component into unique product variants
5. Additional custom work			Point of delivery customisation	Performing additional custom work
4. Additional services			Customised services; provide quick response	Providing additional services
3. Package and distribution	Cosmetic	Segmented standardisation		Customising packaging
2. Usage	Adaptive		Embedded customisation	
1. Standardisation		Pure standardisation		

Figure 5: Generic levels of MC (DA SILVEIRA *et al.*, 2001)

In terms of the boundaries of the MC approach, some authors do not consider the adaptation of products by clients or do-it-yourself products as types of customisation. According to Zipkin (2001), customisation is one means to offer variety, whereas products that can be configured during use refer to a distinct approach. Alike, Piller (2004) points out that customisation strategies usually entail a co-design process that involves a close collaboration between the organisation and the client in order to capture the client requirements and traduce them into a product. For Duray *et al.* (2000), a product cannot be considered as customised unless there is some degree of client involvement in the design process. Based on such viewpoints, the embedded customisation (PINE, 1993b), the customisation at the use level (DA SILVEIRA *et al.,* 2001), the adaptive customisation (GILMORE, PINE, 1997), and the segmented standardisation (LAMPEL, MINTZBERG, 1996) could not be considered as types of customisation. In this investigation, it is considered that approaches that do not require clients' active engagement are types of customisation and can configure customisation strategies. Approaches that do not require clients' active engagement can be as valid as other types of customisation in fulfilling specific requirements and increasing products value. In fact, in some cases providing customised products without the client participation can be more effective than having a co-design process[9].

[9] This concept and its implications in a customisation strategy will be further explored in section 3.1.1.

Duray *et al.* (2000) propose a taxonomy that differs from the previous ones because it combines the point of the client involvement and the type of modularity employed. They define four types of mass customisation (Figure 6):

a) Fabricators: involve the client early in the process when bespoke designs can be realised. They resemble a pure customisation strategy, but employ modularity to gain commonality of components. For instance, modular components can be altered in fabrication to meet a particular order or components may be designed for a specific application.

b) Involvers: involve clients in the product design and fabrication stages but incorporate modularity during the assembly and delivery stages. No new modules are tailored-made for clients and customisation is achieved by combining standard modules that meet the client needs.

c) Modularizers: involve the client in the assembly and delivery stages but use modularity in the design and fabrication stages. Modularity provides for components commonality, but is not use for customisation. An example is to use a platform that is shared across a range of products and add components from a pre-defined set of options to create product variants.

d) Assemblers: involves the client at the assembly and delivery stages and also uses modularity in those stages. They provide mass customisation by using modular components to present a wide range of choice to clients. The product is perceived as customised because the range of options is relatively large compared to mass produced goods.

		Types of modularity			
		Design	Fabrication	Assembly	Use
Point of client involvement	Design	**1** **Fabricators**		**2** **Involvers**	
	Fabrication				
	Assembly	**3** **Modularizers**		**4** **Assemblers**	
	Use				

Figure 6: Types of mass customisation (DURAY *et al.*, 2000)

A major limitation of the taxonomies of mass customisation available on the literature is that they are devised considering the manufacturing sector, and thus cannot be readily applicable to the house-building sector. Another problem is that they provide descriptions of the approaches but offer little guidance to organisations in the development of customisation strategies in terms of what approach or approaches should be pursued. The taxonomy proposed by Duray *et al.* (2000) contributes in discussing the implications of the different types of modularity and the operations performance (SALVADOR *et al.* 2002). That taxonomy was empirically tested by Duray *et al.* (2000) by analysing and classifying organisations according to it. In spite of that, it is still generic and not able to respond to context specific situations. For instance, Duray *et al.* (2000) do not discuss if two or more types of customisation can be use at the same time by an organisation. In fact, the organisations analysed are classified as one type or the other, implying that the mass customisation types proposed are excluding. Yet, an organisation could have a platform that is shared across a range of products (a modularizer), while also offering a wide range of modular components to be selected by clients and added to the product at the assembly stage (an assembler).

2.4 CUSTOMISATION AND VALUE GENERATION

Customisation strategies are grounded on the assumption that clients have particular requirements and that fulfilling those requirements and increasing the products value create a competitive advantage. In fact, the client demand for customisation or sensitivity to customised products is a key factor that needs to be evaluated prior pursuing a customisation strategy (DA SILVEIRA *et al.* 2001; HART 1995; PILLER, 2004). Customisation strategies are more likely to succeed if clients value customisation or can be persuaded to do it (KOTHA, 1995). Such strategies will be appreciated by clients that do not focus only on reduced costs, but seek for products that are able to fulfil their requirements, even if a premium is involved. Markets in which requirements are unique, meaningful, and vary across clients are suitable environments for developing customisation strategies (HART, 1995; PINE, 1993a; PILLER, 2004). The adaptation of products carried out by clients, the proliferation of product varieties, and the difficulties of clients in selecting products (HART, 1995; KOTHA, 1995; BROEKHUIZEN, ALSEM, 2002) are other indicators of the potential for customisation. Considering the role of clients in the successful implementation of customisation strategies, it is necessary to discuss the concepts of client satisfaction and value and how they relate to the MC approach.

2.4.1 Value and satisfaction

Driven by more demanding clients and global competitions, organisations are searching for new ways to achieve and maintain a competitive advantage (WOODRUFF, 1997). Prior efforts focused on internal process of the organisation such as quality management and re-engineering, yet client focus and the offer of product with superior value was also another source of competitive advantage (WOODRUFF, 1997). Value is an important element of the relational marketing and the ability to provide superior value is a competitive advantage of great success (RAVALD, GRONROOS, 1996). In fact, delivering superior value to clients is an important concern of business management (ULAGA, CHACOUR, 2001).

In spite of the importance of the concept of value, there is not a consensus concerning its definition and scope. The concept of value can vary depending on the context in which is being used, and is sometimes confused with cost and price (MIRON, 2002). Woodruff (1997) discusses several definitions of value and identifies some commonalities in those definitions:

a) Client value is something that is inherent to the use of some particular product, differing from other types of values such as personal or organisational values, which are usually enduring beliefs about right and wrong.

b) Value is something perceived by the clients, rather than determined by third parties.

c) The perception of value entails a trade-off between what the client receives such as quality, benefits, utilities and what the client has to give in return for acquiring and using the product.

Monroe (1990) defines value as the ratio between the clients' perceived benefits and perceived sacrifices (Formula 1) further expanding the third commonality identified by Woodruff (1997). Perceived benefits are related to the performance of a product and its attributes and to the extent that they contribute towards more abstract goals and objectives aimed by the client (WOODRUFF, 1997). Saliba and Fischer (2000) suggest that the benefits yield from the ability of products to perform certain functions, resolve particular problems, and provide particular pleasures that can include symbolic aspects such as status, image, respect, and comfort. Conversely, sacrifices embrace the negative aspects related to the purchase and use of a product such as the transaction cost, the transaction time, and the costs of repairs and maintenance (SALIBA, FISCHER, 2000). Inconveniences such as discomfort, long waiting periods, sub-standard performances, lack of fulfilling options, and difficulties in purchasing or ordering products described by Hart (1995) can also be included as sacrifices.

$$\text{Perceived value} = \frac{\text{Perceived benefits}}{\text{Perceived sacrifices}}$$

Formula 1: Perceived value (MONROE, 1990)

Besides the perceived benefits and sacrifices pointed out in the literature on value, other benefits and sacrifices can be drawn by reviewing studies that focus on the MC approach. According to Piller (2004), there are three dimensions of customisation, which can also be understood as major benefits of customised products:

a) **Style:** relates to modifications on the outer appearance of products aiming at sensual senses. For instance, it can entail options of colour, shape, style, and flavour. The aspiration for a particular outer appearance is driven by the desire to cope and adapt with trends set by fashion, peers, and role models. It is also a means to express the client desire for uniqueness, which can be conveyed by products that are ahead of the average trend.

b) **Fit and comfort:** customisation based on the fit of a product with the dimensions of the recipient can be the starting point for customisation. An example is the tailoring of a product according to body measurement or the dimensions of other physical objects.

c) **Functionality:** addresses the selection of additional attributes for products such as speed, precision, power, outputs devices, and upgradability. Functionality is often overlooked as a form of customisation and, out of the three, is the less utilized in the industry.

Customisation might be able to generate two or more of those benefits instead of a single one. For instance, having a large house can be viewed as a customisation in terms of fit since it is able to foster a large family. Yet, such customisation can also portray status that is a symbolic benefit.

Although an argument for customisation strategies is the provision of products with superior value due to the benefits associated to them, sacrifices can also incur. The sacrifices in purchasing and using customised products can be classified as direct such as cost and delivery time or indirect such as cognitive or psychological costs (PILLER, 2004). Direct sacrifices include the premium usually associated to customised products, the increase in the delivery time compared to mass-produced products, and even the time allocation for performing the co-design. According to Piller (2004) and Piller *et al.* (2005), there are three types of cognitive and physiological costs, which can also be conceptualise as perceived sacrifices:

a) **Burden of choice:** happens when an excessively large number of options is offered, overwhelming clients and increasing the complexity in configuring a product variant. Hence, increasing the options available for a product does not automatically yields superior levels of satisfaction;

b) **Matching needs with product specification:** clients might also have difficulties in configuring a product variant due to the lack of knowledge and skills to transfer their requirements into an explicit product specification. Even a common product like a pair of sport shoes can have a complex configuration process if the client has do explicit decide between different widths, sizes, cushioning, colour, and patterns for the outsole; and

c) **Information gap concerning the organisation behaviour:** for many clients customising a product is a novel experience. For that reason, they can become unsure and not know what to expect from the organisation providing the product. In addition to that, the client is usually ordering a product that was never seen and that is not available on the market. Also, the client needs to wait more time for receiving the product than buying a standard and off-the-shelf product. Besides that, because the product is customised and there is no clear point for defining an optimal performance, it is difficult to judge whether a case of warranties applies compared to purchasing a standard product.

Toffler (1970) had also foreseen the burden of choice problem. He stated that the increase in a product options would require clients to make decisions in several levels and also to be provided with information to substantiate those decisions. Hence, the task of purchasing a product would embrace a long incubation period to become familiar with brands, models, and options, even in selecting a product within a particular range of price (TOFFLER, 1970). Toffler (1970) also stated, almost four decades ago, that the car industry would soon reach a point in which it would be technologically feasible to produce more variety than clients would want or need. Such statement holds true as indicated by Scavarda *et al.* (2009): vehicle manufacturers are adapting their product variants when operating in emerging and developed markets. More than ever, organisations should offer options that are meaningful to clients and that add value to products, since providing unimportant or unsuitable options can be negatively perceived by clients.

Seeking to assess the potential for developing a customisation strategy, Hart (1995) proposes the client sacrifice[10] concept, defined as the gap between the product desired by the client and the products available on the market. Hart (1996) argues that he coined such the term to de-emphasise the client satisfaction whose measure does not identify the gap between the benefits a client receives and the one they would love to receive for little or no additional cost. It is possible to clients to be highly satisfied only because a particular organisation is the best option available; the concept of client sacrifice forces organisation to recalibrate the value, highlighting un-met and un-recognized clients requirements (HART, 1996). According to Pine and Gilmore (2000), designing for the average is the root cause of client sacrifice: every mass produce product comprises a bundle of take-it-or-leave-it attributes that are offered to all clients. The more features bundled the greater the likelihood of introducing attributes that disqualify the offer either because the client does not want the attribute or would not like to incur the additional price for it (PINE, GILMORE, 2000).

Considering the definition of value proposed by Monroe (1990), Hart (1995, 1996) and Pine and Gilmore (2000) proposed an operationalisation of the client sacrifice concept (Formula 2). It is defined as the gap between the perceived value of the customised product under consideration against the perceived value of a basic product. As the gap increases so does the potential of customised products and customisation strategies to succeed. As depicted in Formula 2, different basic products can be used for comparison. A standard product can be used in case the organisation is a first entrant and there no customised products are offered in the market targeted by that organisation. If customised products are already provided, the products available on the market can be used as the basis for comparison. If an organisation has a leading product in the market in terms of customisation or is far ahead of competitors, the clients' ideal product can be used for assessing the gap[11].

	Product under consideration Customised product		**Basic product** Standard product Products available on the market Client's ideal product
gap =	**Perceived value**	**--**	**Perceived value**
	↓		↓
	Perceived benefits Perceived sacrifices		Perceived benefits Perceived sacrifices

Formula 2: Operationalisation of the value provided by customised products

The operationalisation proposed for the client sacrifice concept advances in assessing the client sensitivity to customisation by introducing the concept of value that was implicitly addressed by previous research on MC. By adopting such operationalisation three points that should be considered by organisations in devising customisation strategies become clear:

[10] Later, Hart (1996) reconceptualises the concept of client sacrifice as the gap between the ideal goods and services benefits and what the client can purchase.

[11] In that case, the value of the ideal product is likely to be higher than the product under consideration, but the gap still expresses the difference between them.

a) A customised product can add value not only by offering more benefits than the product used as the basis for comparison but also by diminishing the perceived sacrifices. For example, an organisation may gain a competitive advantage by offering the same range of options than its competitors but delivering the products quicker and at a lower cost. Also, an organisation may gain a competitive advantage by allowing clients to dismiss attributes of a product, reducing the client sacrifice by removing unwanted features of a product. Hence, increasing the number of attributes that clients can select in a product, which is the scheme most intuitively associated to the MC approach, is not the only means to provide customisation.

b) The literature implicitly suggests that the MC approach is superior to the mass production approach. In spite of the benefits that are generated, the sacrifices that incur in configuring and purchasing customised products such as burden of choice and matching needs with specification should not be overlooked. By recognizing the perceived sacrifices that apply in a particular customisation offer, an organisation can focus on developing alternatives that minimize or avoid them.

c) As observed by Woodruff (1997), in reviewing definitions of the value concept, the value provided by customised products is not absolute and should be assessed in relationship to other products. This holds true for the MC approach and client sensitivity to customisation can be assessed by comparing the perceived value of the customised product under consideration against a standard product, products available on the market, or the client's ideal product.

2.5 CUSTOMISATION AND THE PRODUCT DEVELOPMENT PROCESS

The MC approach can be deployed for devising customisation strategies that are closely related to the business strategy. The competitive environment, the rivals, the clients, and the competitive criteria of a particular business unit provide the context for a customisation strategy to be developed. Yet, the set of processes that comprises the strategic planning of products until its delivery to clients, defined as the product development process (PDP), reveals how this strategy is translated in terms of technical decisions and actions. In this investigation, it is considered that analysing the business strategy and the product development process are complementary approaches to understanding customisation strategies and the decisions involved in shaping such strategies.

2.5.1 Limits and scope of the product development process

The term product development process is used by several authors, such as Rozenfeld *et al.* (2006), Ulrich and Eppinger (2000), Cooper (2008), and Clark and Fujimoto (1993), yet without a consensus on the scope and the boundaries of the term. One of the broadest understandings of the term is proposed by Rozenfeld *et al.* (2006) who state that the PDP initiates with the formulation of the new product strategies, based on the business and corporate strategies, and is concluded with the withdrawal of the product from the market. Other definitions of the

PDP usually have a narrower scope. Wheelwright and Clark (1993) and Ulrich and Eppinger (2001) consider that the PDP begin with the deployment of the strategic planning, similarly to Rozenfeld *et al.* (2006). Yet, they limit this process to the production ramp up. Clark and Fujimoto (1995) propose an even narrower scope and suggest that the PDP comprises four stages: (i) concept generation (assessment of the market demand and technical possibilities); (ii) product planning (translation of the concept in a product, which fulfils the objectives set for the product and conflicting requirements); (iii) product engineering (translation of the product in a detailed set of design specifications and development of prototypes); and (iv) process engineering (design of a process and a production system able to deliver the product according to the detailed design).

For Cooper (2008), the PDP comprises the identification of an idea until its launch in the market as a product through a series of stage and gates (Figure 7). An important contribution of the stage gate conceptualisation is to introduce a systematic discipline for assessing the phases of PDP and moving from one phase to the next one, establishing a strategic decision process (ROZENFELD *et al.* 2006). According to Cooper (2008), the stage gate system is a conceptual road map with five generic stages that seeks to guide the development process of products, showing what needs to be done and how it needs to be done (Figure 7). He states that the stage gate system has two core components: (i) a series of stages in which the activities of the product development process are realised; and (ii) gates for assessing projects and deciding if they should go ahead or be killed. The gates have three elements (COOPER, 2008): (i) deliverables, include documents to be generated for the assessment; (ii) criteria used for assessing the deliverables; and (iii) outputs: decisions such as go, kill, hold, or recycle, a plan of actions for the next stage, and a list of deliverable for the next gate.

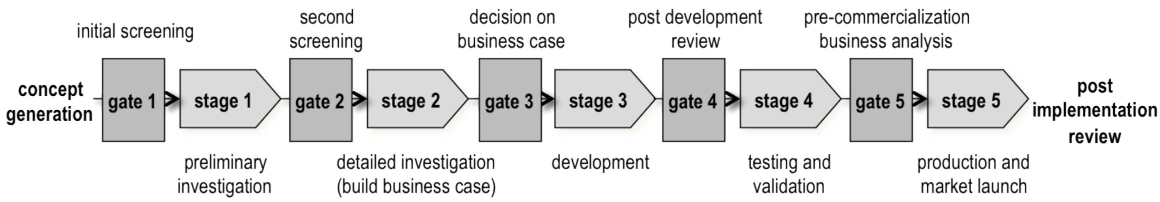

Figure 7: Generic model of the stage gate system (COOPER, 2008)

According to Ulrich and Eppinger (2001), the product development process is a sequence of steps or activities, most of which are intellectual rather than physical, that an organisation employs to conceive, design, and commercialize a product. They propose a generic model with six stages (Figure 8): planning, concept development, system-level design, detail design, testing and refining, and production ramp-up. Such model provides detailed information on the activities that are carried out during the concept[12] development stage that has implications on the types of customisation that will be offered in the product. At that stage, concepts alternatives for the product are generated based on the clients' needs and target specifications, from which the team will select a set of concepts to move forward (ULRICH, EPPINGER, 2001).

[12] A concept is a description of the form, functions, and attributes of a product, accompanied by specifications, an analysis of similar products available on the market, and an economical justification of the project (ULRICH, EPPINGER, 2001).

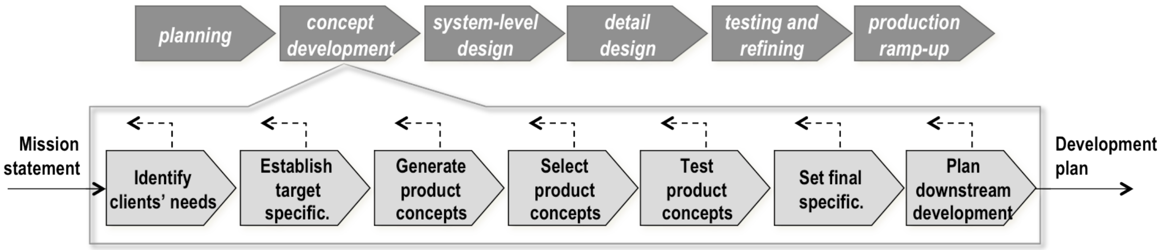

Figure 8: PDP model and activities of the concept development stage (ULRICH, EPPINGER, 2001)

2.5.2 The product development process in the construction industry

The PDP models previously discussed have been conceived considering the manufacturing context. In spite of that, they can also be used for guiding and analysing the product development process of building projects but require some adaptations. Tzortzopoulos (1999) developed a PDP model for the house building industry, in particular for small size construction companies, that entails seven phases: (i) planning and development of the project concept, involving the identification of plots and the development of feasibility analysis; (ii) preliminary design of the project; (iii) design of the project; (vi) development of the project design to be submitted to planning authorities; (v) detailed design; (vi) supervision of the construction process, and (vii) supervision of the occupancy. By analysing such model and the particular features of the construction industry it is possible to highlight some points that differentiates the development process of building projects from manufactured products.

Building projects have a one-off nature since for each project, a particular supply chain is set up and is not likely to be repeated in other projects (KOSKELA, 2003). Also each project has a plot and the building developed needs to address the particular environmental features of such plot. Because of those reasons, in the construction industry most product development processes results in only one product: a project that suits a particular plot. This is different from the manufacturing sector in which the development process of most mass-produced goods such as cars, televisions, and computers entail the production of a high volume of such products[13]. Also, the outputs of a product development process are the design and the set of specifications for a product and also the design of the production system and the supply chain configuration that are able to deliver such product (ROZENFELD *et al.,* 2001). Because the stakeholders involved in building projects and the products are likely to vary from one project to another, the extent that these outputs apply in construction is more limited.

[13] Clearly, should a contractor adopt an off site manufacturing approach and establish a factory that is able to produce a particular range of products, the process will start to resemble the development process of manufactured products.

3. CONCEPTS RELATED TO THE MASS CUSTOMISATION APPROACH

This section presents key concepts closely related to the MC approach: choice menus, solution space, co-design process, product architecture, modular architecture, flexibility, and postponement. Those concepts are related to clients' interfaces, product design, and operations, which is aligned with limitations defined for this investigation. Choice menu are interfaces developed by organisations that enable clients to configure customised products. A closely related concept, embedded in every choice menu, is the solution space, which defines the scope of a customisation strategy and the attributes of a product that are customisable. The co-design process can be used by an organisation to engage with clients to better understand their needs and translate them into an adequate product. It can produces benefits that are related to the process of creating the product, rather than the customised product itself. In terms of design, the solution space should be translated in a product architecture that enables the product variants to be efficiently produced. A modular architecture is usually a suitable product architecture when developing customisation strategies since the modules can be produced as independent entities and later combined for creating the product variants according to clients orders. From a production viewpoint, flexibility and postponement (or delayed product differentiation) are concepts that enable production systems to cope with the product variants created under a customisation strategy. They contribute in meeting the goals of cost and delivery times similar to mass-produced products underlined in the MC approach.

3.1 CHOICE MENU[14]

Choice menu (LIECHTHY, 2001; FOGLIATTO *et al.*, 2008), choice boards (SLYWOTZKY, 2001; BHARATI, CHAUDHUR; 2006), product configurators (HELO, 2006; FORZA, SALVADOR, 2002), and toolkits (ZHANG *et al.*, 2009; FRANKE *et al.*, 2009; VON HIPPEL, 2001; SCHREIER, 2006; SALVADOR *et al.*, 2009) are some terms used in the literature for addressing the interfaces used for communicating customisation options and supporting the configuration of products by clients. In some cases, the different terms imply different types of interface. For instance, when the term configurator or configuration system is adopted it is usually addressing a software tool (PILLER, 2004). These interfaces can range from simple devises such as a menu to select from, but usually have mechanisms to enable clients to better select what they need (OLIVA, 1999). Choiceboards allow

[14] In this investigation, the terms choice menu, choice boards, product configurators, and toolkits will be used interchangeably.

clients to design individualized products by choosing from a set of attributes, components, prices, and delivery options (SLYWORTZKY, 2001). Yet, such products should fall within a limited set of specifications, which is often defined as a solution space.

According to Piller (2008), clients are integrated in the value creation process by utilizing the solution space, namely, by defining, configuring, or modifying their individual solution within the given set of choice options. Analysing the client idiosyncratic requirements and identifying the product attributes along which clients' needs diverge help to define the solution space (SALVADOR *et al.* 2009). A solution space outlines what an organisation will and will not offer in terms of customisation (SALVADOR *et al.* 2009). Besides identifying the products attributes on which clients wish to differentiate, an organisation should ensure that it has the required capabilities to provide such customisation efficiently and profitably (MACCARTHY, BRABAZON, 2003). The solution space term is also used for defining the set of abilities required for producing a particular product variant. For instance, Von Hippel (2001) states that the economical production of customised products is only achievable when such products fall within the capabilities and degree of freedom built into the organisation's production system. An important trend common to those definitions is that the product variants offered are circumscribed by clearly defined boundaries.

Choiceboards have already been used in several industries. In spite of that, Slywortzky (2001) identifies three major barriers to their broader adoption:

a) The high degree of clients' involvement: many organisations have not conceived their processes to cope with the degree of clients' involvement required in a choice menu, requiring a re-structuring of their entire manufacturing, sales, and delivery systems;

b) The lack of a highly responsive supply chains that can deliver products according to clients' orders: choice boards create a shift in the clients' role: they become product makers instead of product takers. Hence, the clients' selection send signals to the supplier's manufacturer system that set in motion the wheels of procurements, assembly, and delivery conversely to a forecast driven system.

c) Lack of a critical mass of clients able to use choice boards. Because most choice boards are available in digital environments, clients should have some degree of digital literacy for using the boards.

Despite those barriers, the number of organisations operating with toolkits is growing along and there is a number of software vendors offering standard toolkits for product configuration as recognized by Slywortzky (2001) and corroborated by Piller (2004). In fact, there is a broad spectrum of toolkits for configuring product variants. Toolkits are heterogeneous in terms of what client can do and how they can do it (SCHREIER, 2006). On the one end the continuum, there are simple toolkits in which users[15] are just allowed to choose from different options from a catalogue within particular attributes such as colour, size, and shape (MACCARTHY, BRABAZON, 2003; FRANKE, PILLER, 2004). On the other end of the continuum, there are toolkits that assign the user with a much more active role, enabling them to create and design products, which allow for radical innovations (FRANKE, PILLER, 2004). Franke and Piller (2004) mention that open source software exemplify those more extremes toolkits since users are (almost) free to program whatever they wish.

Von Hippel (2001) discusses toolkits in the context of product innovation. He asserts that organisations are abandoning the frustrating effort to understand clients' requirements accurately and in detail and outsourcing key innovation tasks to clients after equipping them with toolkits. Such shift is necessary because of the striving difficulties in learning and serving unique market of one as the pace of change of markets and client requirements grows faster (VON HIPPEL, 2001). Von Hippel (2001) seems to argue that the problems of understanding client requirements and translating them into a solution space, which is at the core of a customisation strategy, would be solved by toolkits. Yet, regardless if the configuration process is carried out by clients using a toolkit or by an organisation, as in a transparent customisation, the organisation still need to tailor the toolkit and the solution space embedded in it in a way that enable clients to configure suitable product variants. Hence, the effort in understanding and translating clients' requirements still exist. In fact, the scope of a customisation strategy, in terms of what can and cannot be customised, is embedded in a choice menu. Based on that, it is argued that all customisation strategies have a choice menu, namely, a definition of the product attributes that can and cannot be customised, although they might not be translated and presented to clients via an interface device such as on-line toolkit or a catalogue.

Von Hippel (2001) also proposes five elements of a toolkit that are useful in understanding the toolkit concept:

a) Toolkits should support problem solving. In particular they should enable users to carry out complete cycles of trial and error and to learn by doing. If such features are not offered, the client must order a product and have it built to learn about design errors, which can be a wearisome and costly way to learn.

b) Toolkits should offer a solution space that encompasses the product variants that client want to create, having an appropriate scope. In small solution spaces, clients will select attributes from a list, whereas large solution spaces allow clients to create novel designs actively. Clearly, the degree of freedom built into the toolkit should be aligned with an organisation's abilities and production, sales, and delivering processes.

[15] In the literature on toolkits the term "users" often substitutes the term "client". It indicates the active role undertook by clients and their engagement in the product development process, contrasting with a more traditional view of clients as consumers.

c) Toolkits should be user friendly, enabling clients to operate them with their ordinary design language and skills. This means that minimal training should be necessary for clients to be able to use the toolkits competently.

d) Toolkits should contain libraries of commonly used modules that the client can use in his designing his product variant, enabling him to focus on the truly bespoke elements of that product. Modules can also be used as a starting point from which the client can add or subtract until reaching a product variant that fits his requirements.

e) The solution space embedded in the toolkits should ensure that the designs created by clients are producible, without any revisions or amendments by the organisation. The language of the toolkits should be convertible to the language of the production system. If adaptations are required in order to manufacture the product variants, the purpose of the toolkits is lost.

Besides supporting the devising of a product variant that is able to fulfils clients' particular requirements, toolkits also provide the organisations with data about client's preferences and behaviours, enabling them to secure clients' loyalty (SLYWORTZKY, 2001). With every transaction an organisation becomes more knowledgeable about their clients and is able to foresee and better fulfil their requirements by tailoring the choice menu (SLYWORTZKY, 2001). The knowledge acquired by the organisation can also be used to create a barrier against clients' switch of suppliers (PILLER, KUMAR, 2006). Yet, it can be argued that such asset is related to the customisation strategy, rather than the choice menu itself. In fact, such topic is particularly discussed when addressing the first entrant (or first mover) advantage. Nonetheless, the choice menu provides a means to gather, compile, and analyse the clients' requirements in a format that is meaningful and readily usable by the organisation.

3.1.1 The co-design process

The active engagement of client in designing a product or configuring a product variant by using an interface such as an on-line toolkit or a printed catalogue is defined as a co-design process. Although, customised products can be provided without such process, it can add value and increase clients' satisfaction (KUMAR, 2004). According to Piller and Kumar (2006), the co-design process instils the client with a sense of ownership, besides the recognition that the product was tailored according to his requirements. To participate in such process may be considered a creative problem solving process and can become a motivator to purchase a customised product (PILLER, 2004). Based on Schreier (2006), five benefits emanates from customised products, particularly from those that entail the client participation in the product configuration process:

a) Practical benefits: includes the better fit between idiosyncratic requirements and the product characteristics. Those benefits are closely related to the fit and functional dimensions of customisation proposed by Piller *et al.* (2005);

b) The perceived uniqueness of the self-designed product: is closely related to the style dimension -- a customised product becomes a means to communicate the client's identity -- proposed by Piller *et al.* (2005);

c) The process benefits: the joy that ensues from the design act itself and that has a positive impact on the value of the outcome of the design process, namely, the self-designed product; and

d) The 'pride of authorship' effect: taking pride in having done it oneself. It emanates from the cycles of trial and error and learning by doing that the client is likely to undertake. It makes clients value more customised products than standard products designed by a design agent.

Converting the co-design process of a product in the core element of a product, rather than the product itself, can also be used for acquiring a competitive advantage. In fact, such notion is underlined in the prosumption (XIE *et al.* 2008) and experience (PINE, GILMORE, 2000) concepts. Prosumption consists in an integration of physical activities, mental effort, and socio-physiological experience, undertaken by the client that results in the production of a product that he will eventually consume and that become his consumption experience (XIE *et al.* 2008). Experiences are memorable events that engage clients in inherently personal ways like going to a park or visiting a museum (PINE, GILMORE, 2000), which require the clients' active participation. Nonetheless, if a customised product can be provided via a co-design process, entailing a close engagement between clients and the organisation, it can also be provided with a minimal collaboration between those two parts. An example is do-it-yourself products in which customisation is carried out by the client with minimal input from the organisation.

In the context of customisation strategies, in which the main goal is to provide customised products and the co-design process can be employed to provide additional value, the risks that ensue in involving clients in configuring products cannot be overlooked. For instance, to elicit and capture clients' requirements is not a simple task since they may have difficulties in clearly expressing what they want or need (ZIPKIN, 2001). Also, the client will define the product in terms of its attributes, which might not contribute towards the more abstract goals and objectives in terms of value aimed by the client. Clients may specify attributes that they considered valuable, but that in fact might not be aligned with the desired outcomes. In addition to that, problems such as burden of choice or mass confusion, matching needs with products specification, and information gap concerning the organisation's behaviour (PILLER, 2004; PILLER *et al.*, 2005) apply particularly to customisation strategies that engage the client in the configuration process. This is because in such cases, the notion that the products provided is customised is explicit whereas in transparent strategies it might not be apparent to the client. Hence, the extent that these problems are likely to occur in a particular context and also that benefits that emanates from the co-design process should be assessed prior defining the degree of client involvement.

3.2 PRODUCT ARCHITECTURE

Product architecture is a conceptual representation of the physical components used for making a product, together with any interactions between them that affect the functioning of that product (WANG, KIMBLE, 2010). Ulrich (1995) proposes three elements for defining a product architecture:

a) The arrangement of functional elements;

b) The mapping from functional elements to physical components; and

c) The specification of the interfaces among interacting physical components.

Different decisions concerning these three elements shape the product architecture within the continuum of architectures that a product design can assume. One end of the continuum is the modular architecture. Such architecture is typified by a one-to-one correspondence between functional elements and physical parts and decoupled interfaces (ULRICH, 1995). The other end is an integral architecture. Such architecture is typified by a complex mapping (not one-to-one) from functional elements into physical components and coupled interfaces (ULRICH, 1995). This means, that two or more physical components perform more than one function or conversely two or more functions are performed by a single component. Although, most products cannot be classified strictly as modular[16] or integral the notion of continuum indicates that a product design can assume different architectures. Furthermore, it also suggests that any product design has an architecture (MARTIN, ISHII, 2002), regardless if it was deliberately devised or not.

Overall, modular architecture should be aimed if a customisation strategy is to be pursued. Integral architectures are not suitable for customisation strategies because they would require a product design to be developed from scratch for each order, jeopardizing the criteria of cost and delivery time similar to mass produced products. Conversely, a modular architecture fosters the provision of customised products with minimal increases in cost and delivery time. A modular architecture enables different products to be created while minimizing differences across their constituents (SALVADOR, 2007). In fact, devising modules that can be configured into several product variants provide three main benefits (PINE, 1993b): (i) economies of scale, that are gained through the production of high volumes of standardised components rather than standardised products; (ii) economies of scope, that are gained by using the modules over and over again in several product variants; and (iii) customisation is provided by using a limited number of modules to provide several product variants.

3.2.1 Modular architecture

In spite of the plethora of studies on modular architecture, there is not a single definition of term. Gershenson *et al.* (2004) identify two elements of consensus in reviewing several definitions. The first is that a modular product

[16] Representing a product modularity, defining how modular is a product, and how much modularity is enough or appropriate for a particular context are topics that require further research as indicated by Gershenson *et al.* (2004).

is made up of modules, and the more the components of a product fit into these modules the more modular the product is. The second is the independence and connection between modules, which ideally should enable modules to be interchangeable. These elements are indeed tackled in different definitions of modular architecture depicted in Figure 9.

Two points should be considered in devising a modular architecture or assessing the degree of modularity of a particular product design. The first point is that modularity is the property of a set of products, namely a product system, rather than the property of a single product (SALVADOR, 2007). Salvador (2007) asserts that, at the very minimum, a module should be a portion of at least one product variant within a product system. He states that by combining a subset of modules, any product variant can be obtained, and conversely each product variant can be partitioned in terms of modules. The second point is that a product architecture has several hierarchical levels and the unit of analysis to look at when analysing or devising a product modularity needs to be clearly defined (SALVADOR *et al.*, 2002; FIXSON, 2005; SALVADOR, 2007). Fixson (2005) uses the example of a hair dryer to illustrate this idea: if the main and highest level function which is to dry hair is selected, then all components of the product would be considered as a module, because no specific component can actually be assigned to this function independently. Conversely, if the function level is too low, for instance, hold part C in position Y, then eventually one and only component delivers this function (FIXSON, 2005). Clearly, in most cases the level of interest in terms of the functions and physical parts would be somewhere between these extremes. This is because modules will be a set of physical parts of a products, that are smaller than the product itself and bigger than its minimal parts such as screws and nails.

	Definitions of modular architecture (or modules)
Baldwin and Clark (1997)	In a modular architecture, the modules that constitute a system and their functions should be defined, as well as the interfaces that describe how modules interact. A modular design is composed of units that are design independently, but that work as an integrated system.
Ulrich (1995)	A modular architecture has a one-to-one mapping between functional elements and physical parts and de-coupled interfaces between components.
Muffatto (1999)	A module is a set of components that are coherent as a sub-assembly, or chunk, that usually has a standardised interface.
Sanchez and Mahoney (1996)	Modular products have decomposable systems with a high degree of independence (loose coupling).
Pahl *et al.* (2007)	The modularity of a product can be classified according to the functional and physical independence of its components. A component is functionally independent when it fulfils exactly one function and there is a unambiguous relationship between function and component, whereas a components is physically independent when it represents a coherent unit before the product is assembled

Figure 9: Definitions of modular architecture

Modular architectures are typified by loosely[17] coupled interfaces among interacting modules. When a product system is loosely coupled it means that to some extent it can be broken down into smaller units or modules (SALVADOR, 2007). This implies that a product variant can be built by first producing the modules and then putting them together into a particular configuration. By definition, interacting components are connected by interfaces that may involve geometric connection or non-contact interactions (ULRICH, 1995). In spite of the fact

[17] The term decoupled is also used in the literature.

that the geometric or physical interactions are more intuitively associated to modules interfaces, other types of interactions can ensue. Based on Pimmler and Eppinger (1994), at least four types of interactions among components can be highlighted:

a) Spatial: identifies the need for adjacency or orientation between two or more components;
b) Energy: identifies the need for energy transfer between two or more components;
c) Information: identifies the need for information or signal exchange between two or more components; and
d) Material: identifies the need for material exchange between two or more components.

According to Pimmler and Eppinger (1994), the definition of number and types of interactions is dependent upon the context of the given design problem and in some case some types of interactions apply more than others. Overall, examples of the four types of interactions can be found in products of the built environment. Considering spatial interactions, the components of a building need to be in a particular location considering a tri-dimensional reference system in relationships to other components. For instance, a sink should be in a specific position in terms of height, breadth, and depth in relationship to a bathroom walls and floor to allow it to be ergonomically used by people. An example of energy interaction is the load transfers across slabs, beams, pillars, and foundations of a building. In terms of information interactions, automated systems for operating a building lightening based on presence sensors have information exchange among their components. Finally, air conditioning, and water and sewage systems have material exchange across the components that form such systems.

Platform is a closely related concept to modular architecture. Robertson and Ulrich (1998) define a platform as a group of assets, such as components, knowledge and people, processes, and relationships, which are shared across different product variants. This definition is narrowed in this investigation, encompassing only the components that form a product. A platform approach is complementary to modularity in providing customised products efficiently. Platforms enable several models to be produced from a core design, whereas modularity enables standard parts to be combined in different ways, increasing the number of product variants (ALFORD, 2000). A platform[18] can be described as a basic common module that is used in several variants of a product family (BLECKER, ABDELKAF, 2006). The notion that modularity is the property of a system rather than a single product introduced by Salvador (2007) assists in defining the platform concept. A platform can be defined as a particular kind of module that encompass a larger chunk of physical parts than the other modules and that is used in every product variant that can be generated in a particular system.

[18] An example of platform, discussed by Alizon *et al.* (2009), is the common underbody developed by Ford and used to create different car models.

3.2.2 Typologies of modular architecture

Typologies of modular architectures exemplify how the concept of modularity can be translated in different product designs. One of the earliest and broadest taxonomy was proposed by Pine (1993a) based on Palm and Tung (1991)[19] and comprises six types of modular architecture (Figure 10):

a) Component sharing modularity: the same component is used across multiples product variants to provide economies of scope. It is adequate if an organisation need to reduce the proliferation and costs of product variants while keeping some degree of customisation. Yet, this kind of modularity never results in truly customised products.

b) Component swapping modularity: is the complement of component sharing. Separate components are paired with the same basic product, creating as many product variants as there are components to swap. For greater effectiveness, the separate component should have three characteristics: it should provide high value to client, once separated it should be easily and seamlessly reintegrated, and should have great degree of variety to meet the differing clients' requirements.

c) Cut-to-fit modularity: one or more of the component is continually variable within pre-defined or practical boundaries. For example, National Bicycles Industrial in Japan provides customised made bicycles by combining components, some of which are tailored to fit the client body measurements. This type of modularity is useful for products whose client value lays on components that can be continually varied to match individual requirements.

d) Bus modularity: uses a standard structure that can attach a range of different kinds of components. The term comes from computers, which have a backplane that forms the pathways of information transfer between memory, processing unit, and other components that are plugged into it. A key distinction of this architecture is that the standardised structure allows variations in the type, number, and location of the other modules.

e) Mix modularity: can use any of the above types of modular architecture, with the distinction that the components are so mixed up that they become something different. Restaurant menus that create different dishes from a pre-defined set of ingredients and coffee vending machines are examples of mix modularity. The key factor in determining if such modularity is suitable for a particular product is the recipe and if it can vary within defined limits for different market segments or individuals.

f) Sectional modularity: entails one or more set of components that have one or more standardised interfaces, enabling the components to be mixed and matched in different

[19] ULRICH, K; TUNG, K. Fundamentals of product modularity. In: Winter Annual Meeting Symposium on Issues in Design/Manufacturing Integration, ASME, 1991, Atlanta. **Proceedings...** Atlanta, 1991. p.73-79.

configurations. Piping systems and pre-fabricated kitchen units in which an unlimited number of configurations can be created from a set of components are example of such type of modularity.

Later, Ulrich (1995) proposes three subtypes of modular architecture (Figure 10), which focuses on the interfaces among interacting modules, in more detail than Pine (1993a):

a) Slot: the interfaces of each of the components forming a slot architecture is different. Hence, they cannot be interchanged;

c) Bus: there is a common module to which the other modules are connected through the same type of interface. It differs from the bus modularity proposed by Pine (1993a) in the sense that the interfaces are standardised; and

b) Sectional: all components have the same interface and hence can be interchanged and there is no single component to which the others are attached. This subtype is similar to the sectional modularity proposed by Pine (1993a).

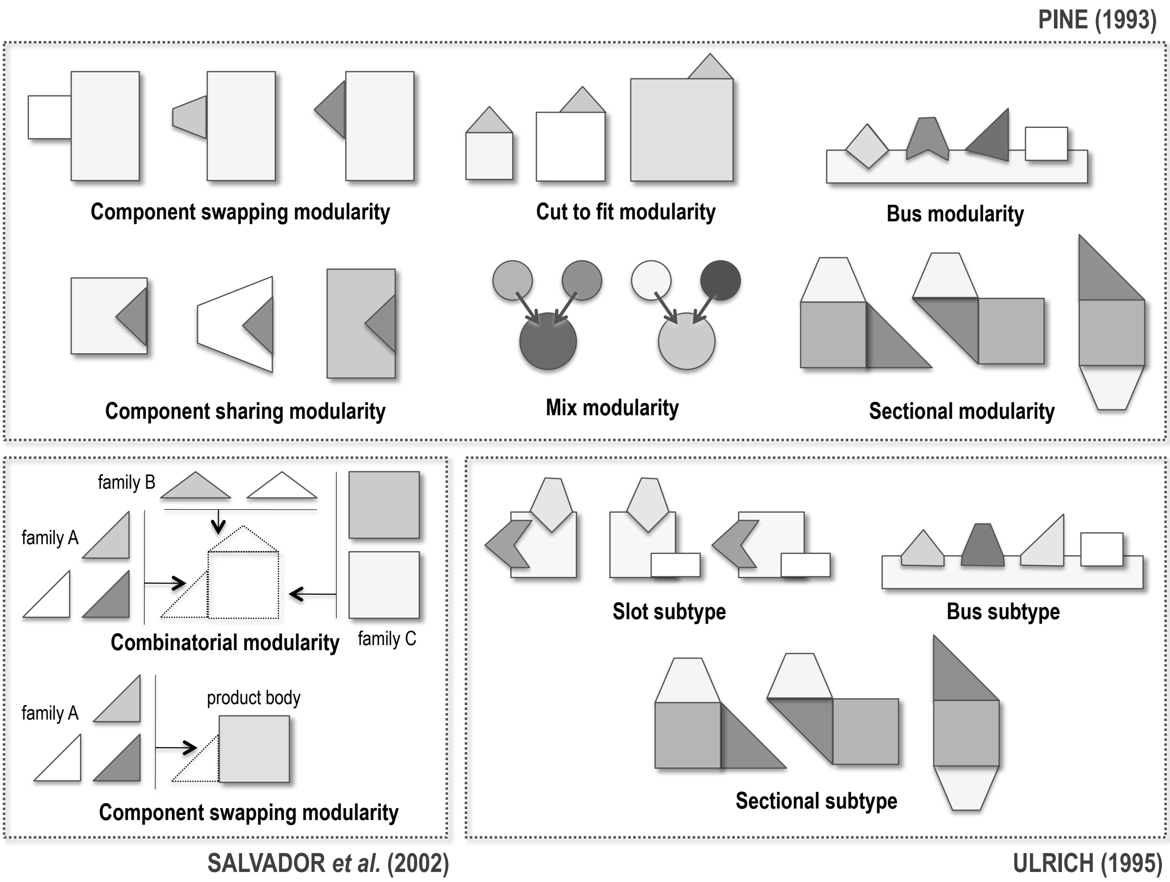

Figure 10: Typologies of modular architecture (PINE, 1993a; SALVADOR *et al.,* 2002; ULRICH, 1995)

Salvador *et al.* (2002) expand and detail the component swapping modularity proposed by Pine (1993a), by examining the number of variants available per component forming the architecture (Figure 10):

a) Combinatorial modularity: the product is built from a set of families of components. The interfaces between the families is standardised and is dependent on the specific family, but independent from the component within that family. The product variants created under this product architecture differ on most attributes.

b) Component swapping modularity: product variants are obtained by swapping components from one family of component but maintaining a basic product body. The product variants created under this product architecture differ on a limited number of attributes.

An important idea introduced by the two types of modular architecture proposed by Salvador (2007) is that the components forming an architecture can be single or be part of families of components. Such notion is implicit in the other typologies of modular architecture previously presented, but it is not directly addressed. In the bus modularity (ULRICH, 1995; PINE, 1993a), the component swapping modularity (SALVADOR, 2007), and the component sharing modularity (PINE, 1993a), it is implicit that there is a single component for the core components shared across the products variants, whereas for each of the other components, they may be one or more options available. Consider the computer example. The memory component can be available in 4 GB or in 2 GB, 4 GB, or 8 GB. Based on Salvador *et al.* (2002), that set of options can be defined as a family of components. Yet, for other components such as the motherboard, only one option can be available across several computer models. Several other types of architecture can be conceptualized by varying the number of components families and the number of components available in each of these (one or two or more):

a) An architecture with one family and only one component in it, resulting in one product variant. According to Salvador (2007) this is not an adequate unit for applying modularity since it should be the property of more than one product.

b) An architecture with two or more families some of which have only one component and other which have two or more components. If there is only two families and one of them has only one component and the other more than two, such architecture is the component swapping modularity proposed by Salvador *et al.* (2002).

c) An architecture with two or more families and all of them entail two or more components. This architecture is the combinatorial modularity proposed by Salvador *et al.* (2002).

d) An architecture with two or more families, each of them with only one component.

3.3 FLEXIBILITY IN OPERATIONS MANAGEMENT

Operations management plays an important role in the implementation of a customisation strategy since strategic decisions on this functional area can assist in providing customised products at reduced costs. The alteration in the traditional trade-off between flexibility and cost is at the heart of the MC approach. In such approach, it is underlined that flexibility is not contradictory to costs efficiencies (DEMEYER *et al.* 1989). The change in that trade-off was actually anticipated by Toffler (1970) who states that the pre automation or primitive technologies produce standardisation whereas advanced technologies such as CAD and CAM[20] enable greater product variety to be produced. According to Kumar *et al.* (2007), the MC approach created a shift in the strategic planning that did not happen since the seminal paper by Skinner (1969)[21] who criticizes the assumption that manufacturing could compete only in the strategic dimension of cost.

The shift in the cost and flexibility trade-off underlined in the MC approach makes such approach closely related to the operations management area. In some cases, it is even considered as an exclusively capability of operations in spite of the evidences that such an approach needs to be considered by other functional areas to be successfully implemented as a strategy. For instance, Paiva *et al.* (2004) associate the MC approach to the manufacturing competitive criteria of mix flexibility and consider that it brings such criteria to its ultimate consequence. In spite of that, mix flexibility is not the only type of flexibility that can be adopted in pursuing a customisation strategy. In fact, customisation strategies can be developed without the support of flexible production systems such as in the case of the adaptive customisation proposed by Gilmore and Pine (1994). Nonetheless, it is necessary to explore the concept of flexibility and its constitutive elements in order understand how it relates to customisation strategies.

Flexibility can be defined as the ability to change an operation in some way (SLACK *et al.*, 1999) or the capability of a system to assume a range of states (PAIVA *et al.,* 2004). Seeking to further define the nature of the change and the range of states that systems can assume, Slack (1983) proposes five types of flexibility:

a) **New product flexibility:** the ability to make something novel;

b) **Mix flexibility:** the ability to make a different mix of products;

c) **Quality flexibility:** the ability to change the quality level;

d) **Volume flexibility:** the ability to change the volume of the output; and

e) **Delivery flexibility:** the ability to change delivery times.

Regardless of the type, flexibility has three dimensions (SLACK, 1983): (i) the range of states a system adopted, (ii) the cost of moving from one state to the other, and (iii) the time which is necessary for moving from one state to the other.

Upton (1994) defines flexibility as the ability to react or change with minor penalties of cost, effort, and performance. He also states that flexibility can be seen both as a set of capabilities, that is what an organisation

[20] CAD (Computer aided design) and CAM (Computer aided manufacturing)

[21] SKINNER, W. (1969) "Manufacturing -- the Missing Link in Corporate Strategy." **Harvard Business Review**. v.47, n.3, p.136-145.

is able to perform, or a source of competitive advantage in a particular context, that is what the client sees. According to Upton (1994), flexibility is characterized by three aspects:

a) **Dimension:** is related to the scope of the change or the adaptation required. It may be related to changes in a product, parts of it, or in a process. In terms of dimension, a change can be discrete or continuous.

b) **Time horizon:** is related to time frame (second, hour, day, month, or year) necessary for the change or adaptation to take place. Such dimension differentiates the operational flexibility that is required daily or hourly from the strategic flexibility that happens in the long term.

c) **Elements:** is related to the most important element of flexibility for a particular context. They can entail:

  a) Range: concerns the ability to accommodate a large range on the dimension of change. It can be represented as the number of states within the range or some metric of the distance between extremes of the range. The range increases as the number of state increases.

  b) Mobility: is the ability of a system to provide mobility within a particular dimension of change. It is measured by the difficulty of change, which can be operationalised as time or the cost of the change. Flexible systems have small penalties for moving from a state of the range to another.

  c) Uniformity: is concerned of the uniformity of performance of a system against some performance measure. A flexible system has a performance measure that is invariant and independent of the position assumed within the range of states. Uniformity is representative of indifference to where, within the range, the system is operating.

3.4 THE ORDER PENETRATION POINT[22]

The order penetration point[23] (OPP) is the point in which the client order first enters the supply chain, differentiating the activities that are demand driven from the one that are forecast driven (YANG, BURNS, 2003). The OPP is also the point at which strategic stock is often held, for coping with fluctuating clients' orders and product variety that occurs from this point on (NAYLOR *et al.* 1999). It sets up distinct goals to be accomplished by the activities performed upstream and downstream of that point. Prior to the OPP, the demand is leverage and

[22] The position of the order penetration point addresses the flexibility required for pursuing a customisation from a supply chain perspective. In such context, the term agility is often used. Conversely, in the context of the production system, the term flexibility is more often used and is related to the internal processes of an organisation. Nonetheless, both terms are concerned with how an organisation is able to respond either through its internal process or the supply chain configuration to the product variety introduced by customisation strategies.

[23] This point has also been termed in the literature as the decoupling point (DC) or the customer order decoupling point (CODP).

there is a limited variety of products (NAYLOR *et al.* 1999). Lean principles such as the elimination of all types of waste should be applied prior to the OPP since the demand is smooth (MASON-JONES *et al.* 2000). After the OPP, the demand becomes unstable and there is a proliferation of products (NAYLOR *et al.* 1999). Agile principles such as providing quick response to volatile markets should be adopted after the OPP since demand is variable and the product variety increases (MASON-JONES *et al.*, 2000).

The positioning of the OPP is a crucial decision in configuring a supply chain and depends on a balance among the product type, the market, the organisation processes, and the stock characteristics (YANG, BURNS, 2003). Because of its strategic implications, it should also be aligned with the business strategy and the competitive criteria pursued by an organisation. In spite of that, Olhager (2003) states that the discussion in the literature on the strategic importance of the positioning of the OPP is still sparse. He highlights key reasons for moving the OPP upstream and downstream, which are summarized in Figure 11. For instance, if delivery speed can be made into an order winner in a market where it used to be a qualifier, an organisation can benefit by shifting the OPP forwards in order to reduce the delivery time (OLHAGER, 2003). In terms of customisation strategies, Olhager (2003) adds the risk of stock obsolescence due to volatile demands as another parameter to be considered in addition to the customisation degree, cost, and delivery time, in determining the position of the OPP.

Move upstream (backwards)	Move downstream (forward)
Higher customisation degree	Lower customisation degree
Higher cost and delivery period	Reduced cost and delivery period
Reduced inventory	Higher levels of inventory
Lower risks of inventory obsolescence	Higher risks of inventory obsolescence
Lower buffers levels	Higher level of buffers
More parts produced based on demand	More parts produced based on forecast
Lower risks of stock out and over-stocks	Higher risk of stock out and over-stocks

Figure 11: Benefits and drawbacks in moving the OPP based on Olhager (2003)

The OPP can assume different positions throughout a value chain, creating different supply chain configurations. Based on Naylor *et al.* (1999), five classes of supply chain can be distinguished (Figure 12 and Figure 13):

a) **Buy-to-order**: is a suitable supply chain if all products provided are unique, do not contain the same raw materials, and if the demand is variable. Clients should be prepared to accept a long delivery time. Because the products are designed and produced based on demand, there is no risk of product obsolescence (BARLOW *et al.* 2003), overstock, or stock-out. On the other hand, such a supply chain is not able to take advantage of new markets as rapidly as the other classes of supply chain.

b) **Make-to-order:** has the ability to produce different products as long as they are made from the same raw materials. Such a supply chain is able to cope with distinct locations, volumes, and product mix, in terms of the number of different combinations and amount of the basic model that can be customised. The delivery time is reduced compared to the previous supply chains. This supply chain is only exposed to the risk of holding raw materials and components as stock.

c) **Assemble-to-order:** is able to respond to a variety of product mix within a range of products and also a variety of locations. The delivery time is reduced. On the other hand, there is a slight increase in the risk of overstock and stock-out of components.

d) **Make-to-stock** and **ship-to-stock**: provide standard products from a defined range. Products are ordered and stocked based on forecast and purchased by clients with minimal lead-time (BARLOW *et al.* 2003). The demand forecast should be precise in order to avoid stock-out or overstocks. Make-to-stock supply chains can cope with demand in varied locations but require a leverage demand of standard products. Ship-to-stock supply chains provided standard products in pre-defined locations.

According to Naylor *et al.* (1999), assemble-to-order supply chains allow customisation to be postponed until as late as possible. This is because such a supply chain configuration enables the component modularisation, which according to Pine (1993b) is the best method for achieving full mass customisation since it minimizes costs while maximizing individual customisation. The cost savings emanate from the economies of scope and scale at the component level, since they are used across several products and produced in large volumes (PINE, 1993b). In make-to-order and buy-to-order supply chains it is not possible to have modularised components since the client order enters the supply chain prior to the product assembly and can entail the customisation of the product design. Also, the reduced delivery time, which is at the heart of the MC approach, cannot be fully exploited in such supply chains. Similarly to the association of the MC approach to mix flexibility, it seems that such an approach is also associated to assemble-to-order supply chains. Yet, this is a narrow perspective of the MC approach, that does not considers how it can be used for devising customisation strategies that are able to respond to context specific situations. It is recognized that modularizing components and producing customised products by assembling those components in different configurations is an effective strategy, particularly if reduced cost and delivery time are required. Nonetheless, this does not apply for every situation and customisation strategies can entail a myriad of types of customisation, not all of which require mix flexibility or an assemble-to-order supply chain.

The nature of the products demand influences the configuration of a supply chain and also the aspects that need to be considered for improving its performance. Fisher (1997) points out problems in the configuration of supply chains are related to the type of product, functional or innovator[24], and the type of supply chain, physically efficient or market responsive. Functional products satisfy basic requirements, which do not change often and have a long life cycle, producing a stable and predictable demand (FISHER, 1997). Ship-to-stock and make-to-

[24] Most products such as ice cream, computers, car, apparel and cookies all can be offered as a basic functional product or in an innovative form. The type of product will be defined by the product variety, the average stock-out rate, product life cycle, and the lead time required for made-to-order products (FISHER, 1997).

stock supply chains are suitable for those products since they can be produced based on forecast and purchased by clients with no delivery time. On the other hand, innovative products have a reduced life cycle and a volatile and unpredictable demand, which results in higher risks of stock-out and stock-over than functional products (Fisher, 1997). Fisher (1997) argues that they also have reduced life cycles because imitators erode the competitive advantage that innovative products enjoy, forcing organisations to introduce new products. He also states that the reduced life cycle in addition to the great variety typical of those products further increase the demand unpredictability. Nonetheless, competition is not the only driver for reduced life cycle. The pace of introduction of new technologies, turning existing products obsolete, also contributes in reducing the life cycle of products (PILLER, 1993a).

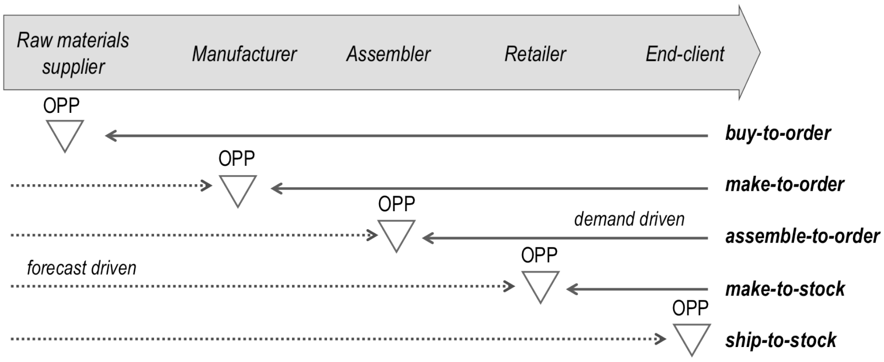

Figure 12: The order penetration point and the classes of supply chain strategies based on Hoekstra and Romme[25] apud Naylor *et al.* (1999)

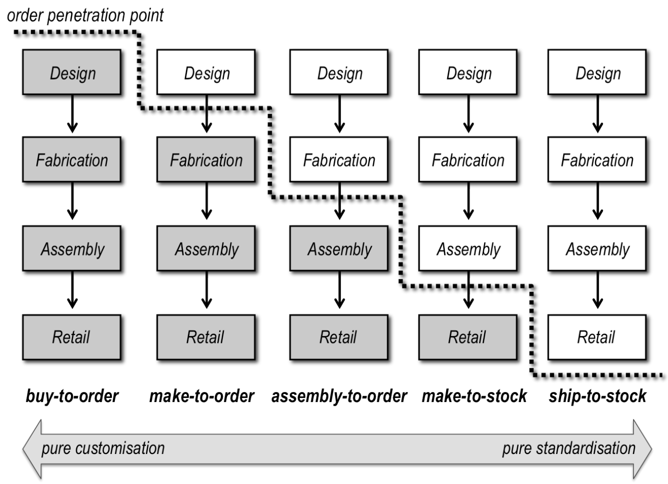

Figure 13: Another representation of the order penetration point based on Barlow *et al.* (2003), Lampel and Mintzberg (1996), and Yang and Burns (2003)

In order to understand how a supply chain can cope with functional and innovative products, it is necessary to elicit the two functions carried out by a supply chain (FISHER, 1997). The first is the physical function, which is related to the conversion of goods from the raw materials to products that are delivered to final clients (BALLOU

[25] S. Hoekstra, J. Romme, Integral Logistics Structures: Developing Customer Oriented Goods Flow, McGraw-Hill, Londres, 1992.

et al., 2000). The second is the market mediation whose objective is to ensure that the product variety reaching the markets matches what clients want to purchase. Such a function is less evident than the physical functional but equally important (FISHER, 1997). Physical costs embrace the costs of production, transportation and inventory, whereas market mediation costs incur when there is a mismatch between supply and demand, resulting in overstock or stock-out. The market mediation for functional products is relatively simple because it is possible to have a perfect match between supply and demand, since it is predictable and stable. For those products, organisations can concentrate in exceeding in the physical function, aiming at cost reductions and increase in efficiencies. Conversely, for innovative products the focus should be on the market mediation function since the damage of over and under stock are greater than the loss related to the physical function (FISHER, 1997).

3.5 THE POSTPONEMENT APPROACH[26]

The concept of postponement has a long history of practical applications as well as academic research and empirical description (PAGH, COOPER, 1998). Such concept was initially discussed by Alderson (1950)[27] who noted that products tend to become differentiated as they approach the sales stage (ERNST, KAMRAD, 2000). The concept was visionary at the time, since long delivery time in production and distribution made it difficult to rely on postponement (YANG *et al.* 2004). In a postponement approach, the processing of unique requirements of each product variant is delayed as much as possible, enabling economies of scale to be explored without compromising the variety of products (ERNST, KAMRAD, 2000). The rationale of postponement is to delay the activities that differentiate a product until information about the clients' orders can be clearly identified (YANG, BURNS, 2003). In fact, products can be differentiated by postponing different value chain activities. Based on that, at least five types of postponement can be highlighted (ZINN, BOWERSOX, 1988):

a) **Labelling postponement:** is based on the assumption that products are marketed under different brand names. Products are shipped in unlabelled packages to the warehouse and labelling takes places once the client order is received.

b) **Packaging postponement:** it is based on the assumption that a product is marketed in different packages sizes. Products are bulk shipped to the warehouse and packaged once clients' orders are received.

c) **Assembly postponement:** is based on the assumption that a base product with a number of common parts is sold in a number of different configurations according to clients' orders.

d) **Manufacturing postponement:** parts are shipped to the warehouse where manufacturing is completed to client order. Manufacturing postponement differs from assembly postponement in

[26] Postponement is also termed in the literature as delayed product differentiation.
[27] Alderson, W. (1950), "Marketing efficiency and the principle of postponement", Cost and Profit Outlook, Vol. 3, p. 15-18.

the degree of warehouse assembly: the former is a job shop whereas the latter is closer to an assembly line.

e) **Time postponement:** the key attribute that is customisable is the time of shipment, which is based on actual orders, instead of forecast.

According to Lee and Feitzinger (1997), postponing the differentiating of a product until the latest possible point in the value chain is the key to effective mass customising. Such a comprehensive approach enables organisations to operate with maximum efficiency and to quickly meet clients' orders with minimum amount of stock (LEE, FEITZINGER, 1997). It also fosters a new way of thinking about product design, process design, and supply chain management, encouraging organisations to define which components will be standardised and which will be customised, what activities will be performed based on forecast and which will be performed based on demand, and where inventories are justified (YANG, BURNS, 2003). Hence, organisations need to rethink and integrate the design of their products, the production and delivery processes, and also the supply chain network (LEE, FEITZINGER, 1997). In fact, the economies of postponement emanates from at least two factors that are closely related to the product design (PILLER, KUMAR, 2006):

a) Component standardisation: prior to the point of differentiation, products parts should be common to as many products variants as possible. An example is to have a standardised core that is shared across the product variants. The cost savings result form the risk pooling effect[28] and the reduction in inventory costs; and

b) Modularisation of the product design: mass customisation requires modular product design for providing products variants. A module has several variants, each of them performing the assigned function at a different performing level, allowing the performance to suit specific requirements[29]. The assembly of the modules with the standardised core is essentially a simple process and is usually identical across product variants.

In terms of the supply chain configuration, a postponement approach requires the partitioning of the supply chain in two stages: standardised parts of the product are made at the upstream stage, while the differentiated parts are made in the downstream stage, based on the client's requirements expressed in an order (PILLER, KUMAR, 2006). Also, postponement is based on the principle of designing products using common platforms, components, or modules, and assembling those only when the final destination or client requirements are known (CHRISTOPHER, 2000). The success of the postponement is a directly related to the extent that the products offered by an organisation are closely related and differ from each other only in a limited number of attributes (PILLER, KUMAR, 2006). In a postponement approach, products are retained in a neutral and non-committed status as long as possible (YANG *et al.* 2004), which produces the following benefits (CHRISTOPHER, 2000):

[28] Demand variability is reduced if it is aggregated rather than individual, since a high demand from one client will be offset by the low demand of another client.
[29] This is similar to the family of components concept discussed by Salvador *et al.* (2002).

a) **Reduced volume of inventory:** inventory can be kept at a generic level, resulting in fewer stock-keeping variants and less stock in general;

b) **Flexible inventory:** because the inventory is generic, its flexibility is greater, which means that the same components or platforms can be embedded in a variety of product variants; and

c) **Greater demand forecast:** forecast is easier at the generic level than at the level of individual products.

The postponement approach seeks to increase the efficiency and effectiveness of supply chains by moving the product differentiation point closed to end clients (NAYLOR *et al.* 1999), being closely related to the order penetration point. Although, those concepts may seem similar there are differences between them. The OPP is the point in which a client order first enters the value chain. Such an entrance defines the nature of the activities carried out upstream and downstream from that point. Conversely, the postponement approach suggests that the product parts that are not subject to customisation should be produced early in a production process, leaving only the customised parts to be produced after the client order is received. Hence, all products have an order penetration point[30], although not all of them have been devised considering the postponement approach. As noted by Yang and Burns (2003), postponement is a reasonable starting point for making a decision on where to locate the OPP. In considering such an approach, organisations should ask themselves if the activities carried out after the OPP are closely related to clients' orders and if the activities carried out prior to the OPP are not at all associated to client orders (YANG, BURNS, 2003). If not, there are opportunities for moving the OPP closer to clients and delaying the product differentiation, which might requires changes in the scope and sequencing of the value chain activities and/or the design of the products.

[30] In customisation strategies, the client's requirements usually enter the value stage in more than one point, although the OPP refers to the first point of entrance.

4. THE RESEARCH METHOD

This investigation adopts a design science or constructive research approach. Such an approach is presented in the literature in comparison to natural sciences (MARCH, SMITH, 1995), formal sciences and explanatory sciences (VAN AKEN, 2004), and positivist and interpretative perspectives (VAISHNAVI, KUECHLER, 2007). According to March and Smith (1995), natural sciences such as traditional research in physics and biology aims to understand reality, by proposing scientific claims and testing their validity, whereas design science attempts to create artificial objects to attain particular goals. Van Aken (2003) states that the mission of explanatory sciences such as the natural sciences is to describe, explain, and eventually predict observable phenomena in the field in question; whereas formal sciences such as mathematics focuses on developing a system of propositions whose main test is their logical consistency. Conversely to the natural and the explanatory sciences, design sciences such as architecture, medicine, and engineering aim at developing valid and reliable knowledge to be used in devising solutions to problems (VAN AKEN, 2003). In fact, design sciences have particular ontological[31] and epistemological[32] assumptions, which differentiate them from the positivist and interpretative perspectives (VAISHNAVI, KUECHLER, 2007). For instance, design sciences value the creative manipulation and control of a particular phenomenon, through the creation and application of a solution, whereas the positivist perspective is concerned with the pursuit of truth (VAISHNAVI, KUECHLER, 2007). Based on that, it can be argued that design science is more than a research approach: it involves a whole new way to look and think about research (MANSON, 2006). Hence, the procedures in conducing design science research and the criteria for assessing its quality differ from the ones adopted for formal sciences and explanatory sciences.

4.1 THE DESIGN SCIENCE APPROACH

The design science approach is concerned with the devising and evaluation of man-made artefacts aiming to resolve real-world problems. March and Smith (1995), Van Aken (2004), Denyer *et al.*, (2008), Voordijk (2009), and Holmstrom *et al.* (2009) advocate that such approach assist in resolving the application and relevance problems that happens in disciplines concerned with problem-solving such as management, medicine,

[31] Ontology describes the nature of reality, what is real and what is not, and also what is fundamental and what is derivative (VAISHNAVI, KUECHLER, 2007).
[32] Epistemology is concerned with the nature of knowledge and how can we be sure of what we know (VAISHNAVI, KUECHLER, 2007).

information technology. As argued by Van Aken (2004), in these disciplines it is not sufficient to describe and understand a problem: it is also necessary to actually develop and test solutions.

Kasanen *et al.* (1993) explain that this mode of research is widely used in technical sciences, mathematics, computer science, and clinical medicine. Because different areas adopt such approach the solution can assume different forms such as a conceptual model, a protocol, a physical artefact, or even a software. Mathematical algorithms, artificial languages, and new pharmaceuticals are examples of constructions (KASANEN *et al.*, 1993). March and Smith (1995) propose four outputs for constructive research in the information technology area:

a) Constructs: form the vocabulary of a specific domain and constitute the conceptualisation for describing a problem and specifying its possible solutions;

b) Model: a group of premises that express relationships among constructs;

c) Method: a set of steps for executing a task; and

d) Implementations or instantiations: operationalisation of construct, models, and methods.

Vaishnavi and Kuechler (2007) propose a fifth output, denominated better theories, based on the idea that the artefact construction tests the body of knowledge, having a similar role to experiments in natural sciences. Technological rules can also be considered a sixth type of output. According to Van Aken (2004), technological rules are chunks of general knowledge involving a broad prescription for addressing a class of problems in an intended context of application. It is implicit in March and Smith (1995) that constructive research initiatives should provide all the four outputs. Clearly, this does not apply to all research areas. It seems that the forth output should indeed be addressed in initiatives using this approach since the practical functioning of solutions should be assess into some extent. However, the other three outputs can be said to represent different types of solutions, even though there are overlaps and precedence relationships between these. For instance, for creating a model it is necessary first to define constructs. Likewise, technological rules or better theories might not be an output of all investigations adopting a design science approach. Nonetheless, the outputs proposed by March and Smith (1995) draw attention to the importance of defining the scope in terms of the outputs and the purpose of the solution developed when adopting this approach.

In terms of the research process, several authors such as March and Smith (1995), Kasanen (1993), and Lukka (2003), Vaishnavi and Kuechler (2007), and Holmstrom *et al.* (2009) propose different stages of the constructive or a design research approach (Figure 1). March and Smith (1995) state only that the constructive research process has two fundamental activities: creating things that serve human purposes and evaluating their performance in use. Differently, Kasanen (1993), Vaishnavi and Kuechler (2007), and Lukka (2003) propose a detailed sequence of steps. As depicted in Figure 14, there are some similarities and also some differences among the sequences of steps proposed. The development of a solution and its evaluation are two steps common to all four sequences (Figure 14).

Another common trend, addressed in most sequences of steps, is that the research process is not linear but involves loops. Vaishnavi and Kuechler (2007) define those loops as circumscriptions: the gain of an understanding that is only achieved by the specific act of construction. Circumscriptions can happen at the development and evaluation steps and lead to revision of the problems awareness, creating a new cycle of design construction (VAISHNAVI, KUECHLER, 2007). Another loop can also occur at the conclusion stage, feeding back into the problem awareness stage and creating a new research cycle. According to Hevner *et al.* (2004), the construction process is inherently iterative and incremental: the evaluation stage provides essential feedback for the construction phase in terms of the quality of the development process and the solution itself. Prior and after the construction, the researcher creates hypothesis on how the solution will behave and deviations from the expected behaviour will lead to questioning, search for explanations, and ultimately to a modification of the solution (MANSON, 2006). For March and Smith (1995), the application and test of a solution precede its complete devising because only through the solution study and use it is possible to formalize the models, constructs, and methods on which it is based.

<table>
<tr><th>March and Smith (1995)</th><th>Kasanen (1993)</th><th>Vaishnavi and Kuechler (2007)</th><th>Lukka (2003)</th></tr>
<tr><td></td><td>Find a problem with practical relevance and that also has research potential</td><td>Awareness of the problem</td><td>Find a practically relevant problem with potential for theoretical contribution</td></tr>
<tr><td></td><td></td><td></td><td>Assess the likelihood for long-standing research collaboration with the target organisations</td></tr>
<tr><td></td><td>Obtain an understanding of the topic</td><td></td><td>Obtain an understanding of the problem from a practical and theoretical perspective</td></tr>
<tr><td rowspan="2">Create things that serve human purposes</td><td rowspan="2">Innovate, namely construct a solution</td><td>Suggestion of a tentative design</td><td rowspan="2">Innovate a solution idea and develop a solution that solves the problem at hand;</td></tr>
<tr><td rowspan="2">Further development of the tentative design and implementation</td></tr>
<tr><td rowspan="2">Evaluate the performance of things in use</td><td rowspan="2">Demonstrate that the solution works</td><td rowspan="2">Implement the solution and test how it works</td></tr>
<tr><td>Evaluation of the design against previously defined criteria</td></tr>
<tr><td></td><td>Present its connection to theory and the research contribution</td><td rowspan="2">Conclusion</td><td>Identify and analyse its theoretical contribution.</td></tr>
<tr><td></td><td>Assess the scope of application of the solution</td><td></td></tr>
</table>

Figure 14: The sequence of steps of the design science or constructive research approach

The construction and evaluation steps are at the heart of the design science approach. Nonetheless, a challenge lies in defining when whether a solution is completed and the interactive activities of constructing and evaluating a solution should be terminated. Hevner *et al.* (2004) shed some light on this. They state that a solution is complete and effective when it satisfies the requirements and constraints of the problem it was meant to solve. Hevner *et al.* (2004) point out that utility, quality, and efficacy are parameters for evaluating a solution. Bonatto (2010) and Schramm (2009) have employed utility and ease of use for assessing the proposed solutions.

However, these are generic criteria. Bespoke criteria should be defined based on the purpose of the solution to be developed and the constraints of the problem at hand.

Holmstrom *et al.* (2009) suggest a sequence of steps that differs from the ones summarized in Figure 14 since it is based on the different forms that the means-ends analysis assumes. Such a sequence encompasses four phases: Phase 1 – Solution incubation; 2 – Solution refinement; 3 – Explanation I, substantive theory; and Phase 4 – Explanation II, formal theory. According to those authors, the means-ends analysis represents the present state, desired state, and difference between those two states, whereas the design science provides the details of how this can happen. The first phase entails the framing of the problem, involving either the search of means for a given end or the framing of an end that a given means can provide. As discussed by Holmstrom *et al.* (2009), a problem is not discovered but constructed. Because of that, it hinges on the researcher's background and worldview. In the second phase, the rudimentary solution design is subject to empirical tests in a trial-and-error iterative process. In this phase the mean-ends analysis includes the identification of: (i) design patterns, documentation that the solution design or means-end propositions behaved as expected, and (ii) technological frames, certification that the solution is able to cope with the idiosyncrasies of the different contexts in which it is applied (HOLMSTROM *et al.* 2009). The third phase involves the examination and evaluation of the solution from a theoretical viewpoint, after it has been refined in the previous phase and is able to meet the goals set for it. In this phase, the means-end analysis converges into a mid-range theory of practice or substantive theory, by empirically examining the solution in multiples contexts (HOLMSTROM *et al.* 2009). In the fourth phase, formal theories are developed from the substantive theories. Unlike these theories, formal theories do not need to be situated within an empirical context: their meaning is embedded in the logic of the theory itself (HOLMSTROM *et al.* 2009). Mid-range theories or substantive theories resembles the technological rules proposed by Van Aken (2004) in the sense that they involve a theoretical knowledge circumscribed by an empirical context or related to a particular class of problems, and because of that are less abstract than formal theory. Conversely to the sequence of steps summarized in Figure 14, the four phases proposed by Holmstrom *et al.* (2009) explore in more detail the theoretical contribution of the solution and how it relates to the existing knowledge.

4.2 THE RESEARCH STRATEGY

4.2.1 Overview of the research process

Figure 15 depicts the outline of the research process carried out of this investigation. It is divided into three sequential stages. Each stage contains the main steps of a constructive research process, based on Lukka (2003) and Kasanen (1993): (a) find a practically relevant problem which also has potential for theoretical contribution, (b) understand the problem and establish its connection to prior theory, (c) develop and implement a solution to the problem, (d) test the solution and assess its practical functioning, and (e) assess the theoretical contribution of the solution. Four empirical studies were also developed throughout those stages.

Stage A was developed between March 2008 and August 2010. As illustrated in Figure 16, it involved the first phase (solution incubation) and a part of the second phase (solution testing) described by Holmstrom *et al.* (2009). At that time, the problem was not yet defined as decision categories. The two initial steps in this stage (find a problem and obtain an understanding) can also be viewed as the problem construction or framing. Stage A involved part of the second phase described by Holmstrom *et al.* (2009) because the solution was subject to empirical testing. The version A of the framework portrays the solution at an embryonic stage, when the findings of the examination were shown to the company involved in case study 2 (Figure 17). A main outcome of stage A was defining that the problem to be tackled is the decisions that need to be considered by an organisation for defining a customisation strategy. Once this was defined, the challenge in the second and third cycles of the solution development in stages B and C of was to develop those categories of decision.

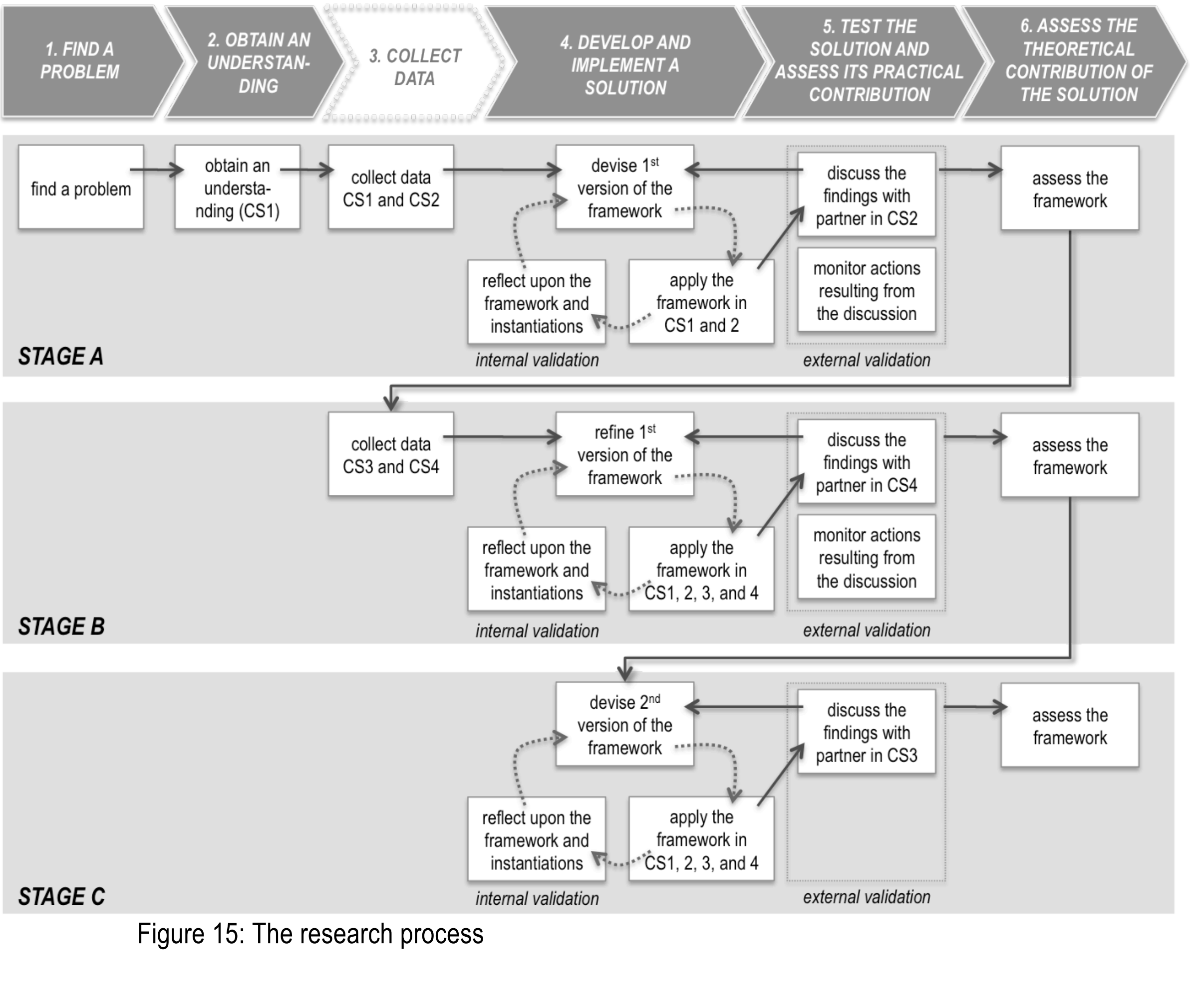

Figure 15: The research process

Stage B was developed between a September 2010 and January 2011 and stage C between February and November 2011. These stages correspond to the second phase proposed by Holmstrom *et al.* (2009), involving the testing and refining of the solution through its application in multiple contexts (Figure 16). The third phase proposed by Holmstrom *et al.* (2009) is concerned with the derivation of mid-range theories and the assessment of the theoretical contribution of the solution, which was carried out at the end of stages B and C (Figure 16). The version B of the framework shows a revised version of the solution, used for examining the four empirical studies in stage B (Figure 17). Version C shows the completed solution, at the end of stage C (Figure 17). As displayed in Figure 17, some of the decision categories proposed proved to work in stage B and were not altered in the subsequent stage, whereas other were reviewed and expanded.

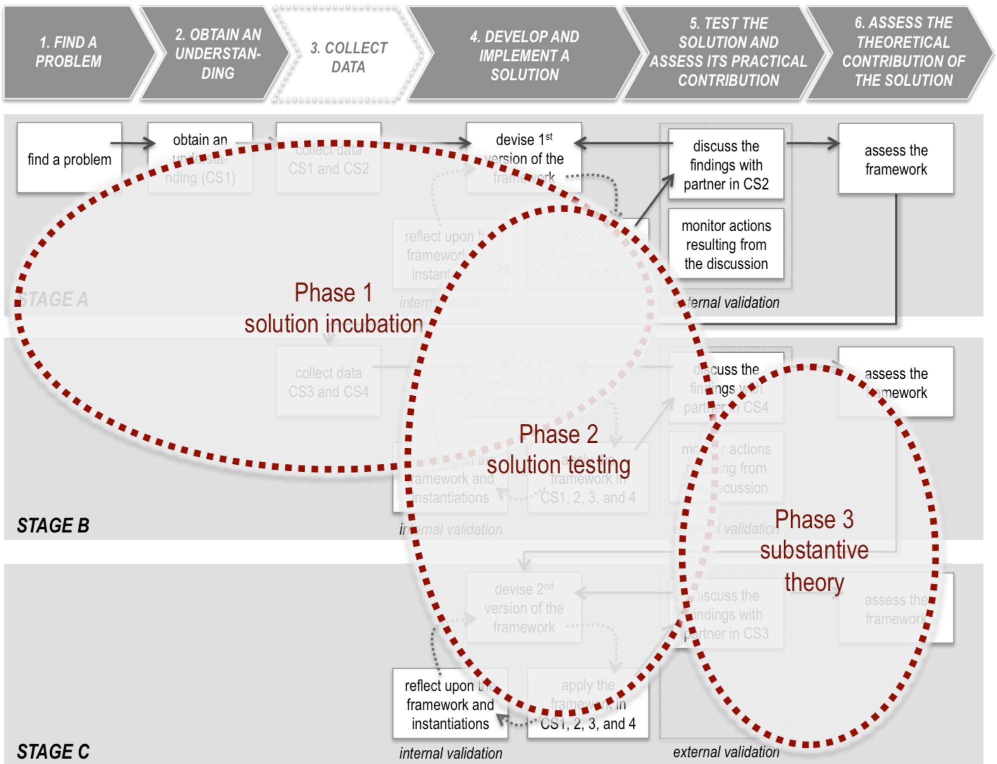

Figure 16: The phases proposed by Holmstrom *et al.* (2009) in the research process

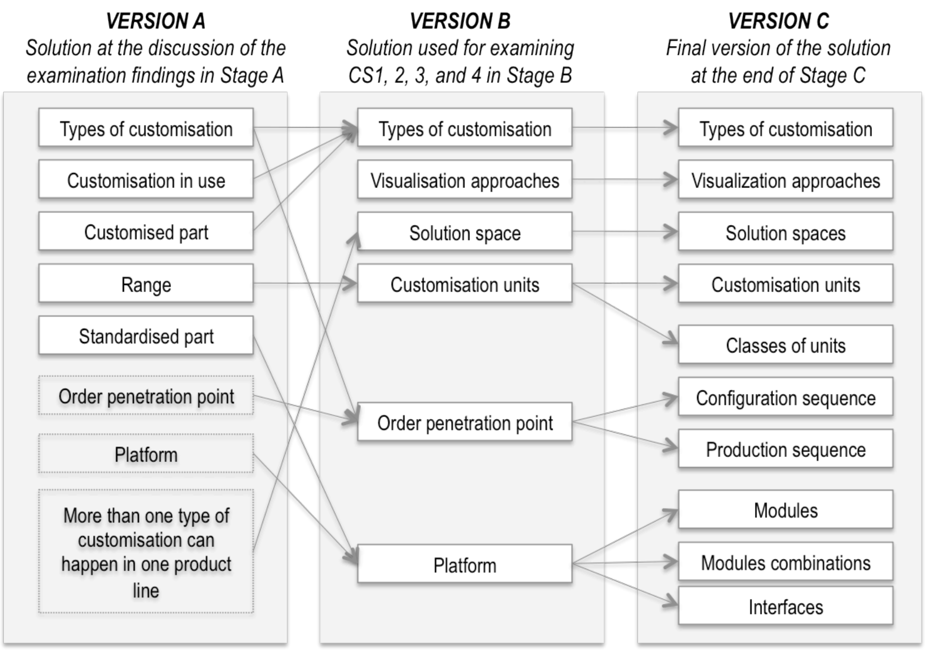

Figure 17: Some versions of the decision categories

4.2.2 Inputs and outputs of the investigation

Figure 18 depicts the inputs and outputs of this investigation based on Lukka (2003), Van Aken (2004), March and Smith (1995), Owen (1997), and Vaishnavi and Kuechler (2007). The solution devised in this research is a framework with decision categories for defining customisation strategies. The three first outputs proposed by March and Smith (1995) are embedded in the solution. Most constructs are contained in the decision categories the definition of the relationship among them establishes a model. The sequence that should be followed in defining the categories for devising a customisation configures a method. The examination of the empirical studies using the framework generated the instantiations, which provide the basis for two other outputs (Figure 18). The instantiations were used for presenting the findings to the organisations involved in the case studies, in order to assess the utility of the solution, which is a third output of this investigation.

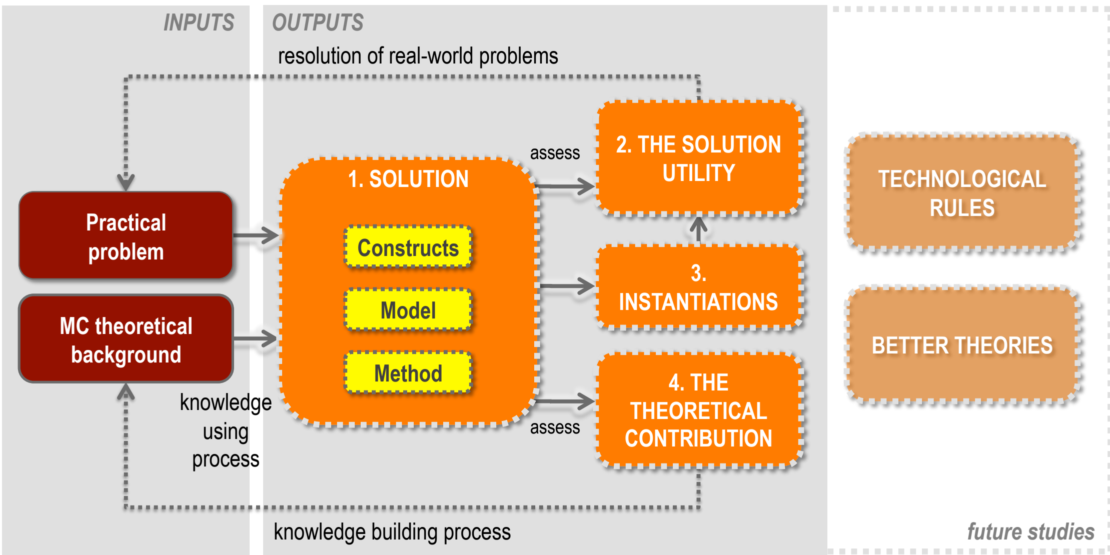

Figure 18: The inputs and outputs

A fourth output is the theoretical contribution of the solution. The relationship between these outputs and the existing body of knowledge (or prior theory) is expressed in the general model for generating and accumulating knowledge proposed by Owen (1997) and also adapted in Figure 18. The solution devising configures the knowledge using process (VAISHNAVI, KUECHLER, 2007). In this process, the MC theoretical background is used for developing the solution (Figure 18). Conversely, the assessment of the theoretical contribution configures the knowledge building process in which new knowledge is built or tested by examining the solution from a theoretical viewpoint (Figure 18). The dashed arrows in Figure 18 show how the outputs feed back into the inputs: the solution utility (or practical functioning) contributes in resolving practical problems, whereas the theoretical contribution of the solution enhances the existing body of knowledge. Technological rules and better theories are outputs that can be accomplished by future research. The four instantiations presented in this investigation in addition to future studies can provided the basis for deriving the technological rules by observing the overall patterns of decisions that emerged in the empirical studies.

4.2.3 The steps of a design science approach

4.2.3.1 Steps 1 and 2: frame the problem and obtain a deep understanding of it

The research process started with the definition of a problem with practical relevance and potential for theoretical contribution. From a theoretical viewpoint, there is a lack of investigations focusing on customisation strategies in the house-building sector that provides guidance for organisations in this sector in developing such strategies. From a practical viewpoint, there is evidence that customisations in housing products happen irrespective of customisation strategies. This means that in many cases customisations are carried out informally, inefficiently, and ineffectively.

After the identification of the research problem, a literature review was carried out in order to gain a deep understanding of the problem and of the theoretical background that could provide basis for addressing it (Figure 20). The literature review focused on topics such as product development process and mass customisation, considering the perspectives of marketing, supply chain management, production management, product design, and product architecture. Throughout the literature review process, the close relationship between the business strategy and the customisation strategy became evident as a key factor for its successful implementation. Based on this, the initial research problem focused on investigating how mass customisation could be pursued in the early stages of the product development process, which has a strong link with the business strategy. An exploratory case study was carried out with Company 1 that was starting the development of a new product. Initially, the researcher only participated in the meetings held by the design team and did not use formal procedures for data collection. As the study tava d, there were limitations in investigating the mass customisation approach in this context once the company was still defining its business model and discussing the portfolio of products to be developed. Based on this, it was decided that the second empirical study would be carried out with an organisation in later stages in the product development process.

Case study 1 and the literature review provided the basis for creating the hierarchical structure that was used for describing the empirical studies (Figure 19). The first level encompasses the strategic level. Identification of the clients, competitive criteria, business opportunity, and rivals were the concepts used to describe such level. The second level is related to the decision categories that support customisation strategies. The third level encompasses the product development process, practices, and product. In this investigation, the product development process is broadly defined, involving a product strategic planning, its design, production, and delivery to clients. It also encompasses several activities, involving the areas of marketing, product design, and operations. A main idea behind this hierarchical structure is that the decisions concerning a customisation strategy could be inferred by looking at the different levels of the structure and later systematized into categories of decision (Figure 19). Hence, it assumed that the data related to the second level would not be directly gathered in the empirical studies, but that the set of decision categories is the solution, to be devised based on the data related to levels 1 and 3 and the concepts related to MC approach available in the literature. While devising the structure, it was also foreseen that, depending on the empirical studies, it would not be possible to gather data in all levels. Hence, the structure was important for clarifying what would and would not collected in each of the studies. Finally, this structure was useful for collecting and analysing the data, ensuring consistency in terms of the descriptions generated for the four empirical studies.

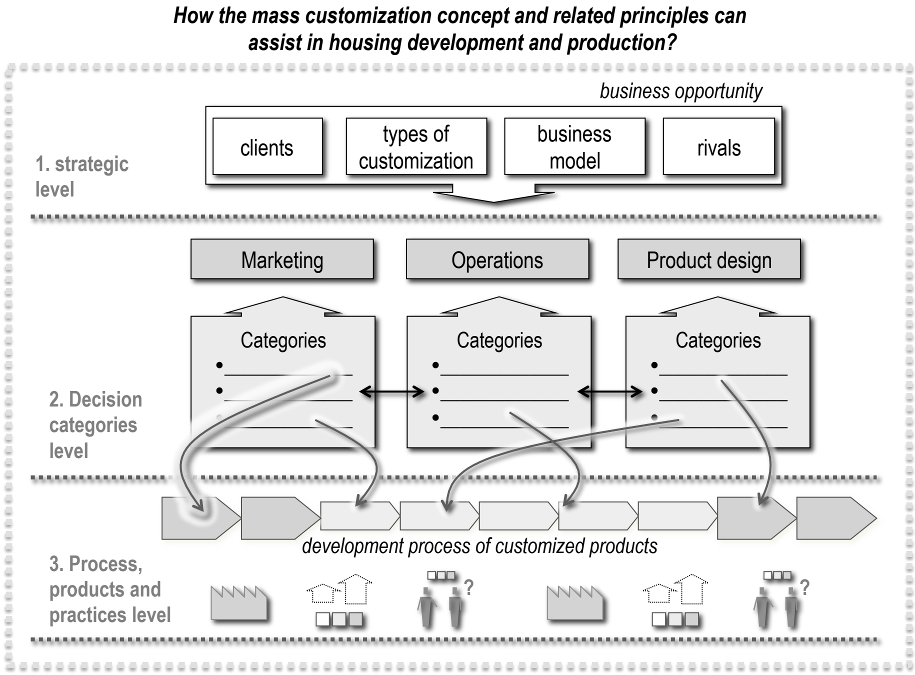

Figure 19: The hierarchical structure

4.2.3.2 Steps 3 and 4: collect data and develop the solution

The third step involved the data collection using the hierarchical structure in order to create a description of the empirical studies[33]. The fourth step is broken down into three activities, as depicted in Figure 20: devise the decision categories that form the framework, apply the framework in the case studies, and reflect upon the framework and the instantiations. Once an initial version of the framework was created, it was used to examine an empirical study. The output of this examination is an instantiation: the analysis of the empirical study according to the categories proposed in the framework. The researcher then reflected upon the framework and the instantiations, leading to a new development cycle. The solution development had several loops until producing the versions of the framework and the instantiations presented in this document (Figure 20).

As shown in Figure 20, this reflection involved a qualitative assessment of the instantiations against the studies descriptions, which were produced using the hierarchical structure. The basis for such assessment is the instantiation and not the solution itself, implying that the solution is indirectly evaluated based on its application in different contexts. Three criteria were used for this qualitative assessment (Figure 20): fitness, precision, and abstraction. Fitness is related to the framework ability to accurately reflect the understanding provided by the

[33] Further details of the data collected in the studies are provided in sections 4.3.3, 4.3.4, and 4.3.5.

study description. Precision is related to the scope and definition of the decision categories in order to avoid redundancies and overlaps among them. Abstraction is related to the conservation of the categories and their definition in a generic level, without introducing specificities of the empirical studies, enabling it to be used in different contexts.

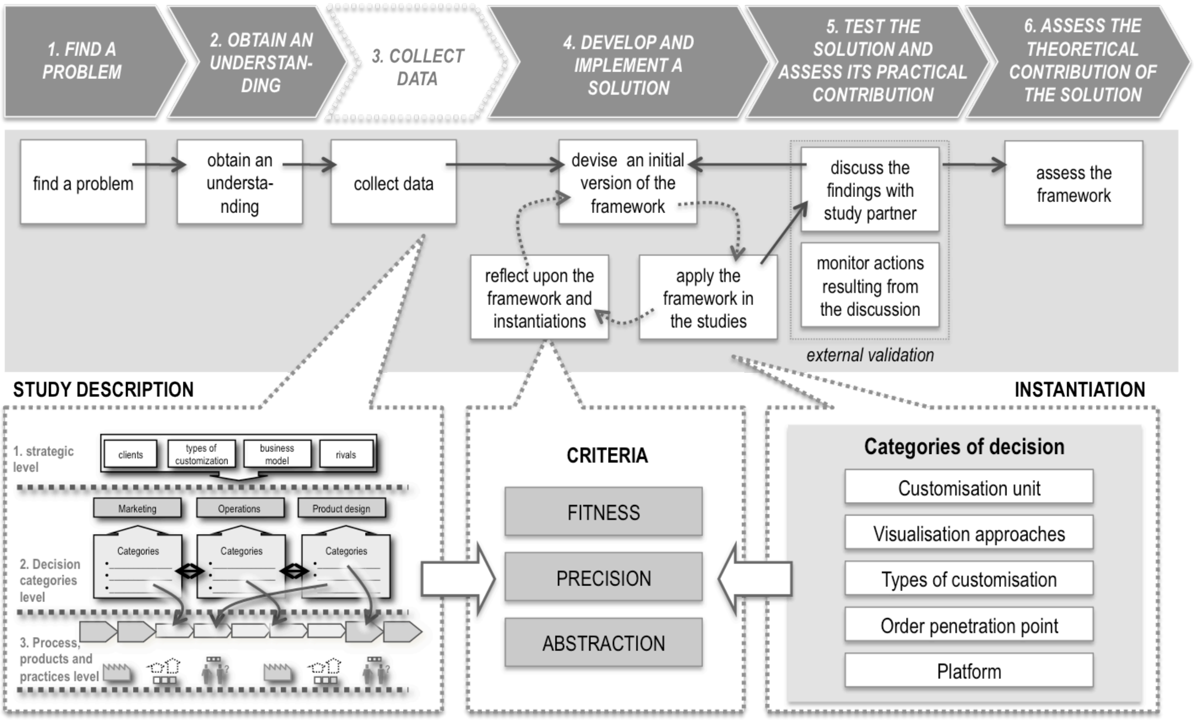

Figure 20: The solution development step in detail

4.2.3.3 Steps 5 and 6: test the solution and assess its theoretical contribution

The fifth step involved the presentation of the findings based on the critical examination of the instantiation to the organisations involved in the studies. In most case studies, the introduction involved several actions such as delivery of reports, meetings for presenting the findings, and discussions with representatives of the organisations. In some case studies, it was also possible to monitor the actions that unfolded from the presentation of the findings. Three criteria were used for the external validation or solution testing:

a) Usefulness in assisting the organisations in understanding their customisation strategies;

b) Usefulness in supporting decision-making and future actions;

c) Usefulness in identifying conflicts between: (i) the customisation strategy and the business opportunity and (ii) the customisation strategy and the organisation's processes.

The assessment of the solution utility falls into the weak market test (KASANEN *et al.* 1993) since it is based on the perception of the organisations involved and in realised actions. It does not fall into the semi-strong and strong market tests since it would be necessary to verify, respectively, if the solution was widely adopted or if its applications produced better results (KASANEN *et al.* 1993). The sixth step (Figure 20), assessment of the solution from a theoretical perspective, was carried out using the framework generated in the last cycle of the solution development, after the results of the external validation had been incorporated into the solution development loop.

As displayed in Figure 21, the solution is evaluated in three different levels. First, the solution is internally reviewed by the researcher in the reflection activity, during the solution development. Although it is an internal process of the researcher, and it is not rigours as required by Hevner (2004), it enables the necessary testing and application of the solution prior to its completion as argued by March and Smith (1995). In this assessment the organisations are not directly involved and thus the studies' description provides the basis for evaluating the framework and the instantiations. In addition to that, this internal evaluation, during in the solution development, is necessary for reaching a version of the framework, capable of providing a coherent instantiation that can be presented to the organisations. The second evaluation occurs after the solution development and involves the presentation of the findings, based on the critical examination of the instantiations, to the organisations (Figure 21). Such evaluation involves mainly the test of the solution in terms of its utility. As illustrated in Figure 21, the solution testing feds back into the solution devising, leading to a new cycle of solution development. Finally, the third level of evaluation is related to the application of the solution in the multiples empirical studies as it evolved throughout stages A, B, and C.

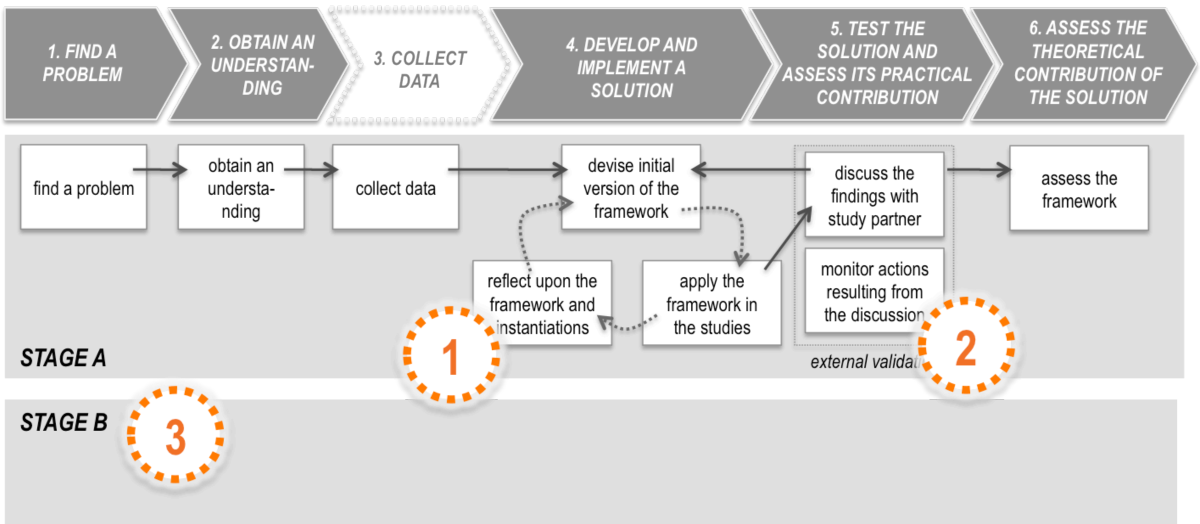

Figure 21: The three levels of evaluation

4.2.3.4 The role of the empirical studies in the solution development and testing

The separation of the solution development and solution testing steps enabled the empirical studies to be used for several purposes. In this investigation, the empirical studies were used for the solution devising, solution testing, or for both steps. The data of an empirical study already concluded was also used in the development of the solution in subsequent stages. Clearly, in this situation, it was not possible to assess the solution utility using the organisation involved in this study, since such study was already concluded.

Figure 22 summarizes the contribution of the four empirical studies in stages A, B, and C. As depicted in this figure, as the studies were developed they were incrementally added to the solution development step carried out in the three stages. Case study 1 helped to define and understand the research problem. It was also used for developing the solution in stage A, although due to its early stage in terms of the product development process, it was not used for assessing the solution utility. Case study 2 was used for the solution development in stages A, B, and C but was only used for testing the solution in stage A. When stages B and C were carried out, such study had been already concluded, hindering the presentation of the findings to Company 2.

	Stage A		**Stage B**		**Stage C**	
	Solution development and application	Testing (external validation)	Solution development and application	Testing (external validation)	Solution development and application	Testing (external validation)
CS1	X		X		X	
CS2	X	X	X		X	
CS3			X		X	X
CS4			X	X	X	

Figure 22: Contribution of the empirical studies in stages A, B, and C

The framework devised in stage B was applied in case studies 3 and 4. The instantiation using case study 4 and its critical examination were presented to the organisation involved in such study, enabling the assessment of the solution utility (Figure 22). The instantiation using case study 3 in stage B revealed that further developments were needed in the solution in order for it to provide a thoroughly understanding of the customisation strategy developed by Company 3. Such instantiation was not considered to be useful enough, from a practical viewpoint and, because of that, was not presented to Company 3 in this stage, but only after a second version of the solution was developed in stage C.

4.3 THE EMPIRICAL STUDIES

4.3.1 An overview of the empirical studies

Four empirical studies were developed throughout the three stages of this research. A main criterion in selecting the organisations for all four studies was their interest in the theme and the fact that they were developing or planning to develop customisation strategies. Another criterion is that the organisation should be involved in the development and production of products for the house-building sector. Also, all four studies were not outlined from the outset but were defined as this investigation evolved, based on the findings of the studies already developed.

As previously described, the company selected for case study 1 was chosen because of their early stage in the product development process. At that point, the problem framed focused on such stage of the product development process. Although such study was useful in defining the research problem and could be used for developing the solution, it was considered that selecting an organisation with a more consolidated business and product development process for the next study could produce richer data. Also, selecting a more mature organisation for the second case study would enable the solution to be tested.

A key criterion for selecting the third case study was the adoption of an off-site manufacturing system, introducing a construction method different from the ones investigated in the previous empirical studies. This would require the categories of decisions to be able to cope with different constructions methods, and potentially be used by a broader range of organisations of the house-building sector. Finally, the organisation for the fourth case study was selected because it provided a peculiar context for investigating the adoption of customisation strategies. Conversely to the previous studies, involving organisations that developed and produced the products in house, the organisation in this study was involved in the product design but did not have any production assets or facilities.

The organisations selected for the four empirical studies also differ in terms of years in the market, business model, scale of the product, and the nature of the customisation strategy (planned or realised). These dissimilarities were also expected to improve the quality of the solution devised once it would need to cope with the idiosyncrasies of the distinct contexts in which it was applied, as discussed by Holmstrom *et al.* (2009). The dissimilarities could also assist in defining the scope of applicability of the framework and its boundaries by analysing the extent that it could be applied in the four studies. Figure 23 locates the studies in terms of the scale of the customisable product, the years in the market, and the country in which the organisation was based.

	Housing component	**Dwelling unit**	**Housing scheme**
0 – developing the business	Case study 1 (Brazil)		Case study 4 (U.K.)
0 and 1 year			Case study 3 (U.K.)
More than 8 years		Case study 2 (Brazil)	

Figure 23: The empirical studies in terms of years in the market and the product scale

Case study 1 (CS1) was carried out with an organisation located in the South region of Brazil. This organisation had just started a new business: the development and production of modular prefabricated components for house building using recycled materials. The first family of products developed was floor tiles for external areas. Until 2008, Company 1 had its business focused solely on waste recycling. When the study was developed, they were setting up a factory for producing the prefabricated components. The products are housing components and when this investigation was developed they were not in the market yet (Figure 23). Case study 2 (CS2) was carried out with Company 2, a contractor and developer of apartment building projects for high-end clients. Company 2 is located in the Northeast region of Brazil and has been in the residential market for more than eight years. In CS2, the products are apartment buildings, yet clients can only customise the dwelling units (Figure 23).

Case study 3 (CS3) was carried out with a corporation from the construction sector that had developed a system for producing prefabricated dwelling units. This business, based in the northwest region of the U.K., is currently a join venture between this corporation, and a manufacturer of steel containers. When the study was developed, the factory had been operating and supplying the system for less than one year. Company 3, a contractor and regional branch of the corporation, develops and builds housing schemes for the social market using the system. The product in CS3 is a housing scheme. The customisable product is not considered to be only a dwelling unit, as in CS2, because in CS3 the client can define the mix and number of dwellings forming the scheme.

Case study 4 (CS4) was undertaken with a consortium set up in September 2010. The consortium is formed by four register providers, based in the northwest region of the U.K. Registered providers are responsible for the identification of social housing demands and for the development of housing schemes that meet those demands. They act as clients, commissioning schemes that are developed by contractors and consultants. While the study was developed, the consortium was devising a framework agreement[34] for procuring contractors and consultants for the development of housing schemes and the refurbishment of existing ones. This investigation focused on a set of standard floor plans for dwelling units set out by the consortium to be used in the new housing schemes commissioned by the registered providers under the framework agreement (Figure 23).

4.3.2 Product development process in the empirical studies

Another way to understand the differences among the empirical studies is to locate their stage in the product development, depicted in Figure 24. In this figure, a product development is broken down into two parts: the development of the customisation system and the development of products. The former starts with the definition of the business strategy that will provide directions in terms of the customisation to be offered. Next, the customisation system is developed, which entails the definition of the activities and capabilities in the areas of operations, product design, and clients' interface in order to support the customisation to be offered. This process results in the definition of the solution space, adequately supported by the activities in the three areas (Figure 24). Once the solution space and the activities necessary for properly delivering the options available are set up, the development process of products can be initiated. This process encompasses the design and production of customised products based on client orders, accordingly to the options available in the solution space (Figure 24).

As illustrated by 1, 2, and n in Figure 24, there can be more than one development process of products. This happens in CS2 and CS4 in which each product is a one-off, a temporarily supply chain is formed, and there are no permanent production facilities (factories). In such contexts, changes in the customisation options are likely to happen from one product to another. Alternatively, in CS1 and CS3, there are factories, creating a development process of customised products that is potentially more stable and less susceptible to changes. When this

[34] A framework agreement is a general term of agreement with suppliers, which set out the procedures, terms, and conditions under which call-offs (specific purchases) can be made during the agreement period (OFFICE OF GOVERNMENT COMMERCE, 2006).

investigation was undertaken, the empirical studies were at different stages in the process. Company 1 was defining the business strategy and starting the development process of the customisation system. The consortium, in CS4, was at an early stage of this process. The companies in CS2 and CS3 had already gone through the development of the customisation system and were currently developing customised products.

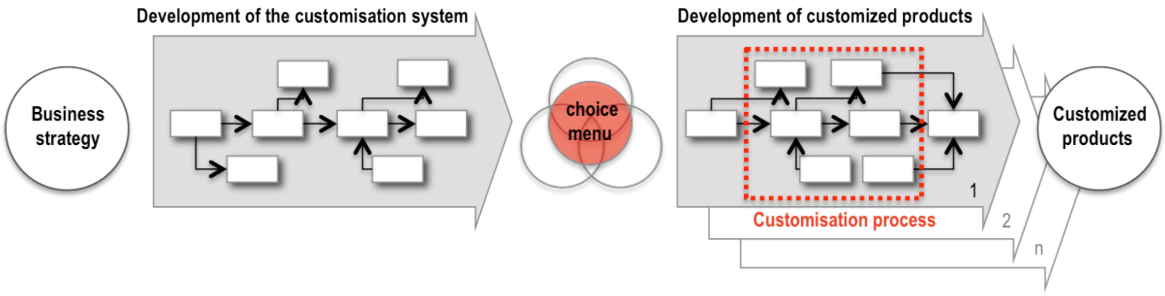

Figure 24: Product development process

The fact that the organisations in the empirical studies were at different stages in the product development process when this investigation was undertaken also had implications in the data gathered. Figure 25 shows the data collected, related to four main elements shown in Figure 24, and whether it was based on plans or realised actions.

	Case study 1	Case study 2	Case study 3	Case study 4
Business opportunity	Planned	Realised	Realised	Planned
Product and customisation options	Planned	Realised	Realised	Planned
Development process of products	Planned	Realised	Realised	Planned

Figure 25: Nature of data collected in the empirical studies

4.3.3 The empirical studies in stage A

Figure 26 shows the data collected in the two empirical studies in stage A. Due to the fact that each case study was at a different stage when this investigation was carried out, not all types of data could be collected in the two studies. For case study 1, it was only possible to collect data concerning planned strategies, and description of the planned product and customisation options. In case study 2, it was possible to collect data related to all levels of the hierarchical structure. As shown in Figure 26, the decision categories level did not have any type of data directly related to it. This is because it was proposed that the decisions could be inferred by looking at the other levels.

Level	Type of data	CS1	CS2
1. Strategic	1.1 Identification of the business model, competitive criteria, and clients	X	X
2. Decision categories	-		
3. Process, practices, product	3.1 Mapping of the development process of products		X
	3.2 Identification of practices		X
	3.3 Description of the product and identification of the customisation options	X	X

Figure 26: Data collected in case studies 1 and 2 according to the hierarchical structure

4.3.3.1 Case study 1

Description of the study according to the hierarchical structure

Case study 1 was carried out during May 2009 and May 2010. The sources of evidence used for data collection are presented in Figure 27. They are related to levels 1 and 3 of the hierarchical structure: 1.1 Identification of the business model, competitive criteria, and clients; and 3.4 Product description and identification of customisation options.

Level of the hierarchical structure	**1**	**3**
Type of data	1.1	3.4
Semi-structured interviews[35]		
One semi-structured interview with the operations director	X	X
One semi-structured interview with the sales director	X	X
Participant observation		
Introduction of the researcher to the design team (8th May 2009)		X
1st Product creation workshop with a brainstorming activity (1st June 2009)		X
2nd Product creation workshop using the 635 technique (9th June 2009)		X
Meeting with the directors of Company 1 for presenting partial results (3rd July 2009)		X
Meeting for analysing the product alternatives using the QFD technique (12th Aug 2009)		X
Meeting for preparing a report to be delivered to Company 1 (21st Sep 2009)		X
Presentation of results to the directors of Company 1 (9th Dec 2009)		X
Preparation of the focus group (29th March 2010)		X
Realisation of the focus group (8th May 2010)		X
Presentation of the focus group findings to the directors of Company 1 (24th May 2010)		X
Document analysis		
Design documents generated throughout the product development process		X

Figure 27: Sources of evidence (case study 1)

The data related to the strategic level was based on two semi-structured interviews with the two directors of Company 1. The participant observations involved the participation of the researcher in product development meetings held by the design team that was devising the housing components. It also involved the participation of the researcher in meetings with the directors of Company 1, in which the outputs of the product development process were presented. Several product alternatives were generated throughout the product development process. Floor tiles for external areas was selected as the focus of the investigation in this study because it was the first product family that Company 1 decided to launch in the market. Once this was defined, a focus group was carried out with low-income families, which was a segment of clients envisioned by Company 1 for this

[35] Key questions used in the semi-structured interviews in case study 1 can be found in Appendix A.

product family. The focus group aimed to identify semantic, symbolic, and functional requirements of low-income families for floor tiles that could be incorporated into this product family as customisation options.

4.3.3.2 Case study 2

Description of the study according to the hierarchical structure

This case study was divided into two parts. The first part of case study 2 was carried out during three weeks in November 2009, and entailed the data collection according to the hierarchical structure. The sources of evidence used are presented in Figure 28. They are related to levels 1 and 3 of the hierarchical structure: 1. Identification of the business model, competitive criteria, and clients; 3.1 Mapping of the development process of products; 3.2 Identification of practices; 3.3 Product description and identification of customisation options. As shown in Figure 28, most sources of evidences were used for collecting more than one type of data. Most semi-structured interviews were carried out with employees that worked in different areas of Company 2, except for the interviews with architects that were developing the interior design of apartments in a building project developed by Company 2. The preliminary findings of the first part of case study 2 were related to the description of the company and opportunities for improving their customisation strategy. Those were presented to the technical director and the quality manager in two meetings at the end of November 2009. A few months later, a report containing the findings of the case study and also some results of the critical examination of the instantiation were sent to Company 2.

Level of the hierarchical structure	**1**	**3**		
Type of data	1.1	3.1	3.2	3.3
Semi-structured interviews[36]				
One semi-structured interview with the technical director	X			
Two semi-structured interviews with two production managers		X	X	
One semi-structured interview with the architect (coordinator of the customisation process)		X	X	X
One semi-structured interview with the quality manager		X	X	X
One semi-structured interview with the projects' coordinator			X	
One semi-structured interview with the marketing assistant		X		
One semi-structured interview with the procurement manager			X	
One semi-structured interview with one architect of architectural practice 1 that was developing a customised design of an apartment in a building developed by Company 2		X		
One semi-structured interview with two architects of architectural practice 2 that were developing a customised design of an apartment in a building developed by Company 2		X		X
Participant observation				
Meeting with the technical director, quality manager, financial manager, contracts manager, and commercial manager to elicit the competitive criteria pursued by Company 2	X			
Document analysis				
Analysis of documents related to the customisation process		X	X	X
Analysis of documents related to the strategic planning	X			
Analysis of production documents such as lines-of-balance and weekly plans			X	
Analysis of design documents of the apartment building projects and information packages used by Company 2 for their promotion	X	X		X
Direct observation				
Two visits to a construction site		X		
Direct observation of a meeting with the quality manager and a client and his/her interior designer to discuss the customisation of the apartment		X		

Figure 28: Sources of evidence (case study 2)

[36] Key questions used in the semi-structured interviews in case study 2 can be found in Appendix B.

Presentation of the findings related to the instantiation and monitoring of actions

The second part of this case study was carried out during one week in August 2010. Its major goal was to discuss the findings of the first part of the case study and also to present the results of the critical examination of the instantiation. During that week, the researcher developed several activities (Figure 29) and meetings (Figure 30) with employees of Company 2. The activities were outlined by the quality manager of Company 2 based on the results of first part of this study. These activities focused on improving the customisation strategy developed by Company 2. As the researcher developed those activities, informal meetings were carried out to discuss their progress as presented in Figure 29. Three formal meetings, described in Figure 30, were also carried out during that week to present the outputs of the activities developed and also results of the first part of the study, summarized in the report previously submitted to Company 2. In the meetings, the outputs of the activities and the future actions to be carried out by Company 2 were discussed. The activities, their outcomes, and the future actions defined by Company 2 in the formal meetings were used for assessing the utility of the solution.

	Goal of the activity	**Participants of the informal discussions related to the activity**
1	Improve the communication with clients on the pros and cons of the different types of customisation offered in the building projects	The researcher, the quality manager, and the architect (customisation coordinator)
2	Improve the presentation of the customisation alternatives to clients	
3	Organise the database used for analysing the customisations carried out in project H in order for it to be used it in future projects	

Figure 29: Activities (case study 2)

	Goal of the formal meeting	**Participants**
1	Provide a general overview of the study findings (first part of the case study)	The researcher, the technical director, and the quality manager
2	Present the analysis of the customisation in the apartment building project H in order to identify opportunities for improvement in the next projects	The researcher, two architects of the architectural practice responsible for the architectural design of the apartment building projects, the technical director, the project coordinator, the quality manager, the architect (customisation coordinator), and the commercial manager.
3	Presentation of the outcomes of activities 1, 2, and 3	The researcher, the technical director, the commercial manager, the quality manager, the project coordinator, and the architect (customisation coordinator)

Figure 30: Formal meetings (case study 2)

4.3.4 The empirical studies in stage B

Figure 31 shows the data collected in the two empirical studies of stage B, according to levels of the hierarchical structure. In case study 3, it was possible to collect data related to all levels, except for 3.2 Identification of practices. This is due to the fact that Company 3 had just introduced their new product into the market and, because of that, did not have consolidated practices. In fact, even the mappings of the product development are tentative and are likely to change over time. For case study 4, it was only possible to collect data in terms of plans concerning the strategic level and the product.

Level	Type of data	CS3	CS4
1. Strategic	1.1 Identification of the business model, competitive criteria, and clients	X	X
2. Decision categories	-		
3. Process, practices, product	3.1 Mapping of the development process of products	X	
	3.2 Identification of practices		
	3.3 Description of the product and identification of the customisation options	X	X

Figure 31: Data collected in case studies 3 and 4

4.3.4.1 Case study 3

Description of the study according to the hierarchical structure

Case study 3 was carried out during December 2010 and May 2011. The sources of evidence used for data collection are presented in Figure 32. They are related to levels 1 and 3 of the hierarchical structure: 1.1 Identification of business model, competitive criteria, and clients; 3.1 Mapping of the development process of products; and 3.3 Product description and identification of customisation options. Semi-structured interviews were carried out with representatives of organisations that had been involved in the development of the system, clients, and representatives of Company 3. The document analysis encompassed the architectural drawings of the dwellings units and also information packages used by Company 3 to present the system to clients. The direct observation involved three visits to the factory and the attendance to a meeting held by Company 3 for presenting the system to potential clients.

Level of the hierarchical structure	**1**	**3**	
Type of data	1.1	3.1	3.3
Semi-structured interviews[37]			
One semi-structured interview with the new business manager, responsible for offering the system to potential clients and coordinating the schemes development processes	X	X	X
One semi-structured interview with a representative from the autonomous business unit involved in the factory management and the development process of schemes	X	X	X
One semi-structured interview with a representative of the architectural practice who developed the design of the dwelling units available on the system		X	X
One semi-structured interview with two architects of Architectural practice 1, responsible for developing the master plan of schemes using the system		X	X
One semi-structured interview with one architect of Architectural practice 2, responsible for developing the master plan of schemes using the system		X	X
One semi-structured interview with the production director of the factory		X	
One semi-structured interview with two representatives of a consultancy company that provided guidance in the development of the off-site manufacturing system		X	
Five semi-structured interviews with five representatives of five registered providers, that are potential clients of Company 3			X
One semi-structured interview with two representatives of the structural engineering practice, responsible for ground investigations and the design of foundations of schemes using the system			X
Document analysis			
Analysis of two booklets provided to clients to present the system	X		X
Analysis of design documents of the dwellings units such as floor plans, elevations, and details			X
Direct observation			
Three visits to the factory		X	
A meeting held by Company 3 to present the product to potential clients			X

Figure 32: Sources of evidence (case study 3)

[37] Key questions used in the semi-structured interviews in case study 3 can be found in Appendix C.

4.3.4.2 Case study 4

Description of the study according to the hierarchical structure

Case study 4 was carried out between October 2010 and July 2011. The sources of evidence used for data collection are presented in Figure 33. They are related to levels 1 and 3 of the hierarchical structure: 1.1 Identification of business model, competitive criteria, and clients, and 3.4 Product description and identification of customisation options.

Level of the hierarchical structure	**1**	**3**
Type of data	1.1	3.4
Semi-structured interviews[38]		
One semi-structured interview with an architect of Architectural practice 1, which developed most of the floor plans		X
Participant observation		
One meeting with the consultant	X	X
Eight meetings held by the four representatives of the four members of the consortium and the consultant	X	X
One meeting with one representative of one member of the consortium and an architect of Architectural practice 1	X	X
Document analysis		
Analysis of the floor plans drawings		X
Analysis of the presentation used by the Architectural practice 1 for explaining the set of floor plans		X

Figure 33: Sources of evidence (case study 4)

As shown in Figure 33, most sources of evidences were used for collecting more than one type of data. They involved mainly the participation of the researcher in meetings held by the consortium. Those meetings focused on the development of the framework agreement, which was being coordinated by the director of a consultancy organisation that provides services in development and regeneration process. This consultant had been commissioned by the consortium to assist them in setting up the framework agreement and assuring that it was compliant with the requirements and rules of the Office of Government Commerce for public procurement in the European Union. One semi-structured interview was also carried out with an architect of Architectural practice 1, which had developed most of the floor plans designs. The documents analysed included the floor plan drawings and also a presentation used by the Architectural practice 1 used for explaining the dwellings types.

Presentation of the findings related to the instantiation and monitoring of actions

The introduction of the results of the study examination occurred in a meeting on December 2010, which had the participation of representatives of the four members of the consortium and the consultant. The members and consultant agreed with the problems rose by the findings of the critical examination and agreed on developing future actions in order to address these. The main decision that resulted from this meeting was to look into alternatives to standardise kitchen, bathroom, and utilities rooms of the dwellings units in schemes to be developed under the framework agreement. The idea is that these could be pre-fabricated as pods, increasing

[38] Key questions used in the semi-structured interview in case study 4 can be found in Appendix D.

the housing quality and reducing whole life-cycle costs. Figure 34 summarizes the activities and actions that have unfolded from this decision, forming what was informally denominated as the pod project. Architects from three architectural practices that are currently procured by the registered providers for developing the design of dwellings units and schemes took part on those activities. Also, an architectural technologist that approached one of the registered providers, looking for some unpaid work, was also assigned for assisting in the pod project.

Date	Activities	Attendees or person that developed the activity
8th Dec 2010	Presentation of the examination findings to the consortium members	The researcher, a representative of each of the four members of the consortium, and the consultant
13th Jan 2011	Meeting with the architectural practices	The researcher, two architects of two architectural practices, the architectural technologist, a representative of one member of the consortium, and the consultant
Jan/Feb 2011	Analysis of housing schemes	The architectural technologist
22nd Mar 2011	Visit to a pod manufacturer	The researcher, the architectural technologist, a representative of one member of the consortium, and a researcher from the Univ. of Salford
Mar/April 2011	Survey of pod manufactures	The architectural technologist
Feb/Mar 2011	Preliminary design of the pods	The architectural technologist
Mar/June 2011	Detailed design of the pod	Three architects from the three architectural practices
15th Feb 2011	Meeting for discussing the pods designs progress	The researcher, three architects from the three architectural practices, the architectural technologist, and a representative of one member of the consortium
23rd Mar 2011	Meeting for discussing the pods designs progress	The researcher, three architects from the three architectural practices, the architectural technologist, and a representative of one of the member of the consortium
6th June 2011	Meeting for discussing the pods designs progress	The researcher, three architects from the three architectural practices, and representatives of two member of the consortium
30th June 2011	Meeting for discussing the pods designs progress	The researcher, three architects from the three architectural practices, the architectural technologist, and representatives of two members of the consortium
13th July 2011	Final meeting of the case study	The researcher, two architects from two architectural practices, the architectural technologist, a researcher from the Univ. of Salford, and representatives of three members of the consortium

Figure 34: Actions and activities that unfolded from the discussion of the instantiation

As a first step, the consortium called a meeting with the three architectural practices for also presenting the findings of the examination to them (Figure 34). Two of these architectural practices had devised the floor plans to be used in the schemes commissioned under the framework agreement. The meeting with the architectural practices led to the planning of two actions: (i) analyse the dwellings units used in schemes previously developed by members of the consortium and (ii) research into pods alternatives and manufacturers. The former provided several findings in term of the sizes of kitchen, bathroom, and utilities rooms that were used in the design of the pods. The latter evolved in a visit to the factory of a pod manufacturer in order to examine the overall features of a pod and also a search of pods manufactures that could supply products in the northwest region of the U.K. Around February 2011, the development of the design of the kitchens, bathrooms, and utilities room pods was initiated. Preliminary design studies were carried out by the architectural technologist and were later followed up by the three architectural practices. As these designs progressively evolved, they were discussed in meetings with the consortium members (Figure 34). Although, the outputs of the pod project were aimed at the consortium as a whole, most activities had only the participation of representatives from one or two members of the consortium. This is because these two representatives were enthusiastic in driving these activities forwards, whereas the other members did not express the same interest. Also, it was felt that they lacked technical knowledge concerning construction methods and the built environment in general in order to participate and effectively contribute to the activities.

Although the activities resulting from the examination findings are likely to carry on beyond July 2011, this case study was concluded at that point due to the termination of the overseas period of the researcher in the U.K. A final meeting was held on July for presenting the activities depicted in Figure 34 and also their outputs to the other members of the consortium. At the end of this meeting, the usefulness of the findings presented was also discussed with members of the consortium. The following questions were used for driving the discussion: (i) what was the role of the mass customisation theoretical background in this study; (ii) was is it useful, in which ways; and (iii) what are the key findings of this research that have contributed or will contribute to future actions. Additionally to the actions and activities that unfolded from the presentation of the examination findings, the results of this discussion were also used for assessing the utility of the solution.

4.3.5 The empirical study in stage C

This stage did not involve data collection for the solution development. The data gathered in stages A and B was used for such purpose. Nonetheless, the results of the critical examination of the instantiation using case study 3 were presented to Company 3 in order to assess the utility of the solution.

4.3.5.1 Case study 3

Presentation of the findings related to the instantiation

A meeting was arranged with Company 3 for presenting the findings of related to the instantiation. The business opportunity and the mappings of the company's processes were also presented in order to illustrate the implications of some problems identified in the instantiation. The points addressed in the presentation were also organised in a report with more detailed information, which was delivered to Company 3. Three representatives of Company 3 participated in this meeting: the area director, the representative from the autonomous business (involved in the factory management and the development process of schemes), and the business development executive. Two researchers from the University of Salford also attended the meeting in order to assist in the discussion and also to take notes on the key points discussed. At the end of the meeting, the attendees were asked to provide their perspective on: (i) the usefulness of the research findings and conclusions; (ii) if these findings and conclusions were going to guide future actions in the long and short term, and if so, what actions; and (iii) if they felt that something was missing and if there were important issues that had not been addressed in the research. The attendees' feedback on these questions and the discussion that emerged were used for assessing the utility of the solution.

5. DEVELOPMENT OF THE FIRST VERSION OF THE FRAMEWORK

This chapter is divided into five main sections. The results of case studies 1 and 2 according to the hierarchical structure are presented. Secondly, the inputs of the empirical studies in devising the solution are discussed, followed by the definition of the decision categories. The instantiations, namely the examination of the two empirical studies using the categories devised, are then described. As described in the previous section, a major contribution of case study 1 was to refine the scope of the research problem and define the profile of the organisation to be selected for upcoming studies. In spite of that, the data gathered in case study 1 was also used for testing the framework. The chapter concludes with a discussion of the utility of the solution and the instantiation from the perspective of the organisation engaged in case study 2.

5.1 DESCRIPTION OF CASE STUDY 1

As presented in chapter 4, only two types of data, related to levels 1 and 3 of the hierarchical structure, could be gathered in case study 1: (i) identification of the business model, competitive criteria, and clients; and (ii) description of the product and identification of the customisation options.

5.1.1 The business opportunity

The business opportunity explored by Company 1 is the production and retail of prefabricated components for housing using recycled materials. Floor tiles for external areas is the first line of components to be developed and marketed. The company foresees two types of client for this line of products: construction companies, and individual clients who intend to build or refurbish their own homes. The key competitive criteria pursued by Company 1 for this business opportunity are:

a) Environmental sustainability: the fact that the components will be made of recycled materials is viewed by Company 1 as a major source of competitive advantage and an asset for differentiating the product from conventional floor tiles for external areas.

b) Design: the design of the tiles, namely, the textures, colours, and shapes is another element to differentiate the products to be developed from the existing ones in the market.

c) Prices similar to the market price for floor tiles for external areas: although the use of recycled materials may create reductions in cost, price is not a competitive criteria that will be explored by Company 1. In fact, they aim to offer a differentiated product in regards to environmental sustainability and design, while keeping the price similar to other pavements for external areas available in the market.

5.1.2 Description of the product

The components' design plays a major in the business developed by Company 1. In terms of the floor tiles, Company 1 plans to use vivid colours and unique themes such as animals and plants that would be translated in the tiles shape. As the company is just starting this new business, only two or three themes and two or three colours are to be offered as customisation options. Company 1 expects to employ different approaches for promoting and marketing floor tiles to individual clients and construction companies. For the former, the company intends to place informational totems and small showrooms in building material stores. For the latter, sales representatives will visit potential clients, and show product samples. The minimal volume for an order is also expected to be different: small volumes will be available for individual clients, and large volumes will be required from contractors. Due to differences in volume, Company 1 is willing to offer a higher degree of customisation to contractors than to individual clients. Company 1 also stated that they would be keen on producing bespoke tiles in terms of colour and shape depending on the volume of orders placed by contractors.

The results of the focus group with low-income individual clients, a key segment within the individual clients market, indicated that they have particular interpretation of some features of the floor tiles, which should be considered in the product advertising. For instance, the participants of the focus group had a negative perception about the fact that the tiles would be offered at a price similar to the average market price for floor tiles for external areas. For the participants, this indicated that the product had an inferior quality compared to more expensive tiles, regardless if they indeed had a superior performance and durability. Based on the focus group findings, it was suggested that the floor tiles cost should not be used as selling point in marketing the product to those clients.

5.2 DESCRIPTION OF CASE STUDY 2

As presented in chapter 4, four types of data, related to levels 1 and 3 of the hierarchical structure, could be gathered the case study 2: (i) identification of the business model, competitive criteria, and clients; (ii) description of the product and identification of the customisation options; (iii) mapping of the development process of products; and (iv) identification of practices.

5.2.1 The business opportunity

Company 2 has been operating in the construction industry for more than thirty years. Until 2002, its main focus was commercial and industrial projects. In 2002, a decision was made to increase the operations in the residential building sector, and two years later 80% of the projects were in this sector. At that time, the company did not have a clear profile of their clients and followed the market trend in developing their products: apartment building projects with small apartments, with gross floor areas around 70m^2. In 2005, several house building companies competing with Company 2 shifted their focus to medium and low income housing market, driven by funds available in the social housing programs created by the Brazilian government. Foreseeing that the high-end housing market would not be targeted by other construction companies, Company 2 consolidated the higher-middle class clients as the target market for their products. Until 2008, Company 2 had developed only apartment building projects, although they were considering the development of houses in condominiums in the future. Based on the interviews and the participant observations, four competitive criteria pursued by Company 2 were identified:

a) Delivery: products should be handed over to clients within the contractual project duration.

b) Differentiated product: this includes not only the physical part of the product but also all services and interactions with clients throughout the product development process. The delivery of fully equipped communal areas of the building, such as swimming pool, fitness centre, barbecue areas, is an example of an approach adopted to differentiate the product. This enables householders to move in and start using those facilities right away.

c) Prices similar to the market price for high-end apartments in the region: the company seeks to offer this differentiated product while maintaining price similar to the ones practiced by the market.

d) Innovation: Company 2 is a leading company in the adoption of lean principles and tools in the development and construction of buildings. Additionally to the improvements in the company processes, such feature is also presented to clients as an asset of the company.

5.2.2 Description of the product

Figure 35 shows the residential building projects developed by Company 2 since 2001. Each bar in Figure 35 represents the duration of the construction phase of the project. Those projects can be divided into four product families, based on the apartment floor area, the profile of the residents, and the apartment average cost.

Product family I encompasses residential projects with apartments with a floor area of over 400m^2. They generally have three or four bedrooms with en-suite bathrooms, a kitchen, a social lounge, a dinning room, an intimate lounge, an office, a lavatory, a laundry area, a bedroom and bathroom for the housekeeper, and a deposit. The average cost is approximately 8Y[39]. The floor finishing is usually marble, granite and ceramic tiles with large dimensions (around 1.40m x 1.60m). Company 2 could not identify a particular client profile for this product family. It varies from small families, formed by a single couple, to large families, formed by a couple and three or four children. Projects within this family have common areas that include an extensive range of amenities

[39] Because of Company's 3 request, the average cost of apartments had to be replaced by the variable "Y" that only expresses the relationship in terms of cost among the different product families.

such as sport courts, landscaped gardens, barbecue areas, swimming pool, sauna, children play area, games areas, fitness area, and a communal area for celebrations. The floor finishing includes large ceramic tiles and granite tiles with standard dimensions. Until 2008, only one residential project developed pertained to this family: Project I (Figure 35).

Product family II encompasses residential projects with apartments with a floor area between 200m² and 300m². They usually have the same type and number of rooms of the previous product family, yet with smaller floor areas. The average price of these units is around 4Y. The clients profile for this product family encompass couples with young children or teenagers. These projects have the same range of amenities as the first product family. As depicted in Figure 35, projects A, E, F, and H fall into this family.

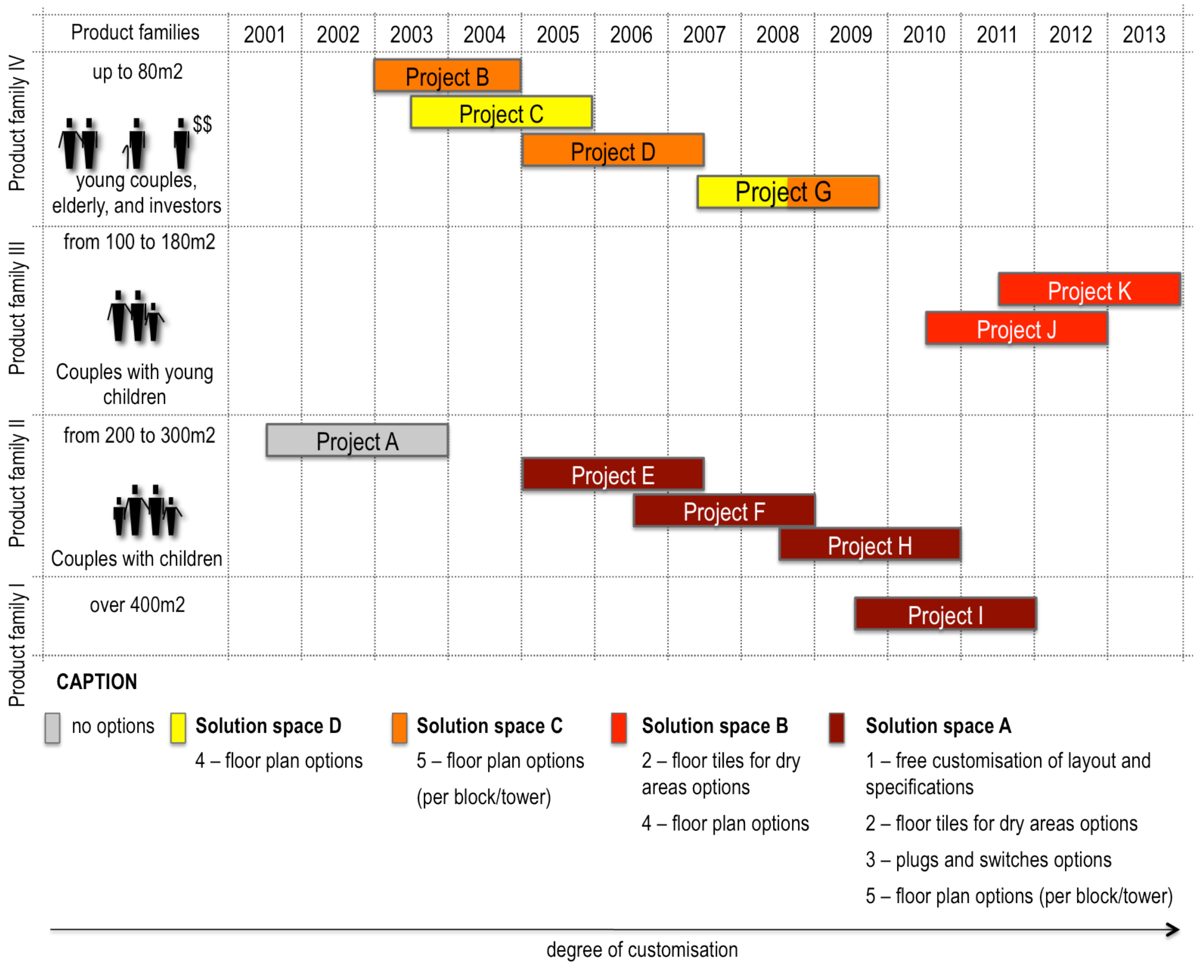

Figure 35: Residential building projects developed by Company 2

Product family III encompasses residential projects with apartments that have a floor area between 120m² and 180m². The apartments have three bedrooms, two of which have en-suite bathrooms, a kitchen, a deposit, a lavatory, a lounge, a laundry, and a bathroom and bedroom for the housekeeper. Their average price is R$ 2.4Y. The clients profile for these apartments are young couple with or without children. The floor finishing includes large and medium-size ceramic tiles. The common areas include swimming pools, landscaped gardens, barbecue areas, fitness areas, sport courts, home theatre area, and children playing areas. Company 2 was devising this product family while this investigation was carried out. The projects developed at that moment, to be handover in 2012 and 2013, fall into this family (Figure 35).

Product family IV encompasses residential projects with apartments that have a floor area under $80m^2$. The apartment has one or two bedrooms, usually one with an en-suite bathroom, a laundry, a bathroom, an open-plan kitchen, a lounge, a bathroom for the housekeeper. The average cost is Y and the clients for this product family include investors, elderly, and young people. The floor finishing are typically medium-size ceramic tiles, and there are only a few amenities in the communal areas such as landscaped gardens. As depicted in Figure 35, projects B, C, D, and G fall into this family.

Based on the analysis of the customisation offered in the projects developed since 2001, five alternatives of customisation were identified (Figure 36). Alternative 1 enables clients to commission an interior designer for developing a bespoke unit in terms of layout, finishing and fixtures, which is built by Company 2. There are some constraints in terms of what can and cannot be changed. These are defined as the part that remains standard in this alternative (Figure 36). Overall, the changes are limited to the interior design of the unit. They cannot cause changes to the building structural system, other dwelling units, to the building facade or alter the service systems (electricity, water, air conditioning, internet and cable television, security, and gas) outside the unit. In spite of these constraints, it is not possible to define the number of options available for this alternative since an unlimited number of designs can be created. Alternative 2 entails options of different floor tiles to be used in dry areas. The customised part in this alternative is only the floor tile specification; no expansions or reduction in the floor areas are allowed. Alternative 3 involves options in terms of colours and models for plugs and switches. Like alternative 2, it is only a customisation in terms of the specification, not entailing changes in the electrical system design.

Alternatives 4 and 5 are related to customisation in terms of the apartments layout. In the former, the apartments in each of the blocks or towers[40] forming the project has a different floor plan, so the floor plan is selected by the client at the moment of the purchase of the dwelling unit in a specific block. In the latter, the floor plan options are not specifically assigned to any tower or apartment. In this alternative, the client can first purchase the apartment and later select the desired apartment plan option. The alternatives shown in Figure 36 illustrate the general customisation alternatives used in the projects. Although the standard and customised parts apply in every project in which a given alternative was used, the options offered change depending on the project at hand.

Based on a cross examination of the customisation alternatives and the product families, a general pattern was identified (Figure 35): the degree of customisation offered increases as the price and the units floor area increase. The customisation alternatives used for the product families can also be organized into groups defined as solution spaces. Solution space A entails alternatives 1, 2, and 3 and is offered in projects with apartments

[40] A project may have different apartments in each floor. If the apartments in a floor form a single building, each of the apartments is part of a block. If they are organised into different buildings, each of these is a tower.

with a floor area over 200 m^2, namely product families I and II. In this solution space, a client can decide to have a bespoke unit. Conversely, a client may dismiss that alternative and choose alternatives 2 and 3. Company 2 was planning to use solution space B for product family III, including alternatives 2 and 5. Finally, there are solution spaces D and E, involving floor plans options, which have been usually adopted in projects with apartments with a floor area below 80 m^2. For this product family, Company 2 used one of the solution spaces or the other, except for Project G (Figure 35). In that project, four of the six blocks had a specific floor plan whereas for the two remaining columns the client had two floor plans to select from.

Alternative 1 – Free customisation of internal layout of the apartment and its specifications	
Standardised part	Position and dimensions of beams, pillars, slabs, and shafts. The position and specifications of external windows and doors, and finishing. The position of the apartment footprint and external walls Water points inlet and waste water outlets can be relocated within the areas with waterproof membranes
Customised part	Every other part of the apartment
Range of options	Unlimited
Alternative 2 – Floor tiles for dry areas (bedrooms, dinning, lounges, corridors, balcony and office)	
Standardised part	Area and footprint of the rooms
Customised part	Types of material
Range of options	Four or five options: granite 1, granite 2, granite 3, or large ceramic tiles
Alternative 3 – Plugs and switches	
Standardised part	Number and positioning of plugs and switches
Customised part	Plugs and switches model and colour
Range of options	Three options: white, beige, or snow white
Alternative 4 – Floor plan options	
Standardised part	Area and footprint of the unit
Customised part	The apartment layout
Range of options	Three options: 3-bedroom apartment with large living room, 3-bedroom apartment with standard living room, or a 4-bedroom apartment.
Alternative 5 – Floor plan options (per block or tower)	
Standardised part	The location of the apartment within the towers or blocks
Customised part	The apartment layout
Range of options	Two options: an apartment with an office or an apartment with a second living room

Figure 36: Customisation alternatives used by Company 2

The pattern of allocation of the projects within the solution spaces is defined as general in the sense that it is followed by most projects. Yet, there are exceptions such as Project A (Figure 35). Also, not all projects in product families III and IV have used all the alternatives in solution space A. This pattern summarizes the formal approach adopted by Company 2 towards customisation in the four product families. Nonetheless, in many situations Company 2 accepts the use of alternative 1 if a client requests to have the apartment bespoken, even in projects that are not part of families III and IV.

5.2.3 The development process of products

Figure 37 presents an overview of the product development process of residential projects undertaken by Company 2. The approximate duration and the relationship in terms of duration among the different product development stages are depicted in Figure 37. The bars represent the approximate duration of the stages, based on the scale presented in Figure 37. The strategic planning happens once every year, usually in January, and involves the assessment of the company performance in the previous year and the definition of goals for the upcoming year. The strategic planning provides inputs for the product development process since the alternatives and solution spaces to be offered in the residential projects to be developed during that year are also discussed. Each year, around ten feasibility studies are carried out, and only approximately three of these turn out to be successful. When a feasibility study is successful, Company 2 proceeds to the next stage, involving the purchase of the plots and initiates the development of a conceptual design containing the apartment plans and perspectives portraying the building. The conceptual design is also necessary for initiating other three stages that are developed concurrently: launch of the building and sale of the apartments; preparation of the legal documents for the project; and detailed design. Figure 38 shows the development process of customised products, from the offer of the alternatives to clients until the construction of the customised apartments. It also shows the differences in the development process involving alternative 1 and alternatives 2, 3, and 4. The development process associated to each of these is different because each of the solution spaces has a distinct mix of customisation alternatives. The construction process happens concurrently to the customisation process. Once the building is handed over, the five years warranty period starts.

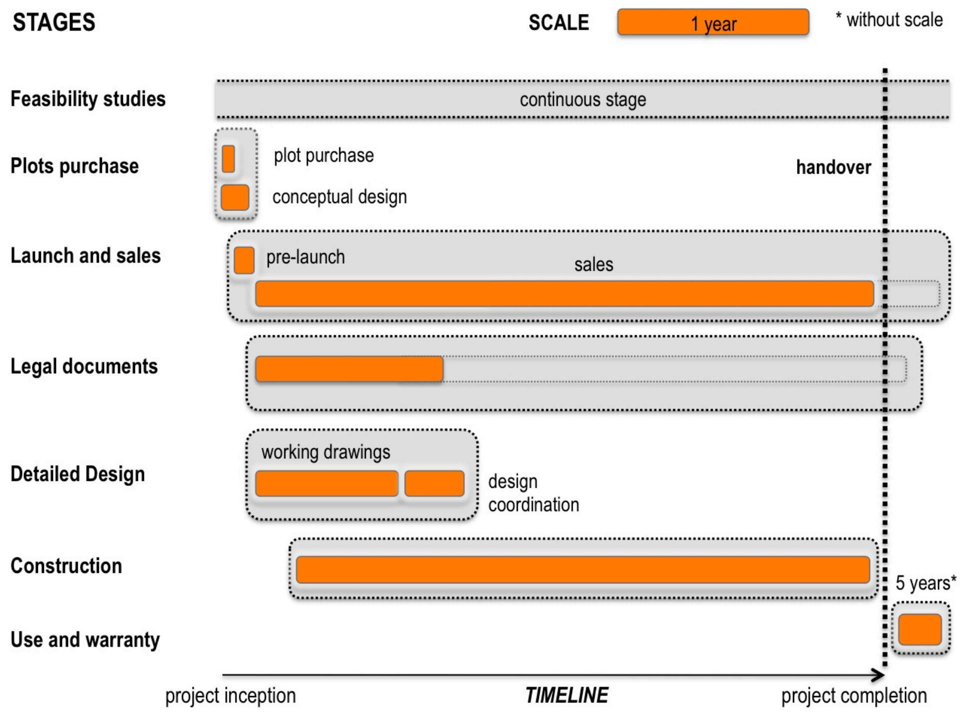

Figure 37: Development process of residential projects

In solution space A, the development process initiates when the kits containing information about the alternatives are sent do clients. The kit includes floor plans, sections, and details of the apartment and the list of the standard specifications used by Company 2 because alternative 1 is offered in such solution space. Information on the design of the services system is also provided (Figure 38). This kit provides the basis for the development of the bespoke unit by the interior designer commissioned by the client. A letter explaining the scope of this customisation alternative is also sent to the clients, informing that they will be responsible for the purchase and delivery to the construction site off any bespoke finishing and fixtures that do not follow the standard specification used by Company 2. There is also a list of specific fixtures and finishing that are not installed by Company 2. Clients are warned that if the design of the bespoke unit employs any of those, it is their responsibility to install them, after the apartment is delivered. Finally, the deadline for submitting the bespoke design of the apartment to Company 2 is also stated.

If the client decides to use alternative 1, the process follows the sequence of activities embedded in the dark grey rectangle in Figure 38. The interior designer or architect develops the design of the bespoke apartment accordingly to the client's requirements and delivers it to Company 2 within the timeframe defined in the letter. Once the bespoke design is received, the customisation team reviews it in order to check that it is not infringing the constraints set up. If it is trespassing the constraints, alterations are requested and the design is sent back to the client or to the interior designer for amendments. If it is not, Company 2 generates a quote for building the bespoke design. The client receives a credit for the cost of all materials and services associated to any items of the standard dwelling, which are excluded in the bespoke design. For instance, if a wall is removed from the standard apartment in the bespoke design, the client receives a credit related to the price of materials and services associated to the construction of that wall. Conversely, the client should pay for the materials[41] and services related to every item of the bespoke apartment that is not planned in the standard apartment. The cost related to these additional items involves mainly services costs once the client is responsible for the purchase of most materials. The quote for building the bespoke unit is generated by subtracting the total credit from the total debit and adding a percentage over the resulting value. Even if this value is negative (if the bespoke design involves essentially the removal of existing items), the percentage over this value is still charged for covering the administrative fees related to the management of the construction of a bespoke apartment.

The apartment quote is internally revised before it is presented to the client. The quote, organised in a list containing all items and their associated costs, is presented in a meeting held by the quality manager. In this meeting, all the items credited and debited are explained. In case the client is not satisfied with the quote, additional changes can be made in the specifications or even ask the designer for amendments in the interior design, going back to initial activities of the customisation process. Once the client agrees with the quote, an agreement is signed, confirming the acceptance of the layout and specifications to be used in the bespoke apartment. This activity triggers several processes. The quote and bespoke design is passed on to the procurement area, for the purchase of materials, and also to the subcontractor who develops the designs of the services systems (electricity, gas, water and sewage systems, internet and cable TV) for devising new designs that fit the bespoke design. Once the design of those service systems is ready, the design documents provided by the interior designer are printed and prepared as an information package to be sent to the production team.

[41] This is unless the client provides such materials.

The production team reviews this package to check whether all the necessary information for constructing the bespoke apartment is available and if there are inconsistencies among the different documents. If so, the customisation team and, in some cases, the interior designer are contacted for clarifications. If not, the bespoke design is fed into the master plan and into the look-ahead plans. The production manager analyses the bespoke design and plans its production based on the apartments currently available for production and the date that the bespoke materials should be delivered by the clients. The delivery of finishing and fixtures by the client within the timescale defined by Company 2 is a major constraint to be considered and removed in the look-ahead plan. The production team considers this barrier prior adding work packages related to bespoke dwellings into the weekly plan.

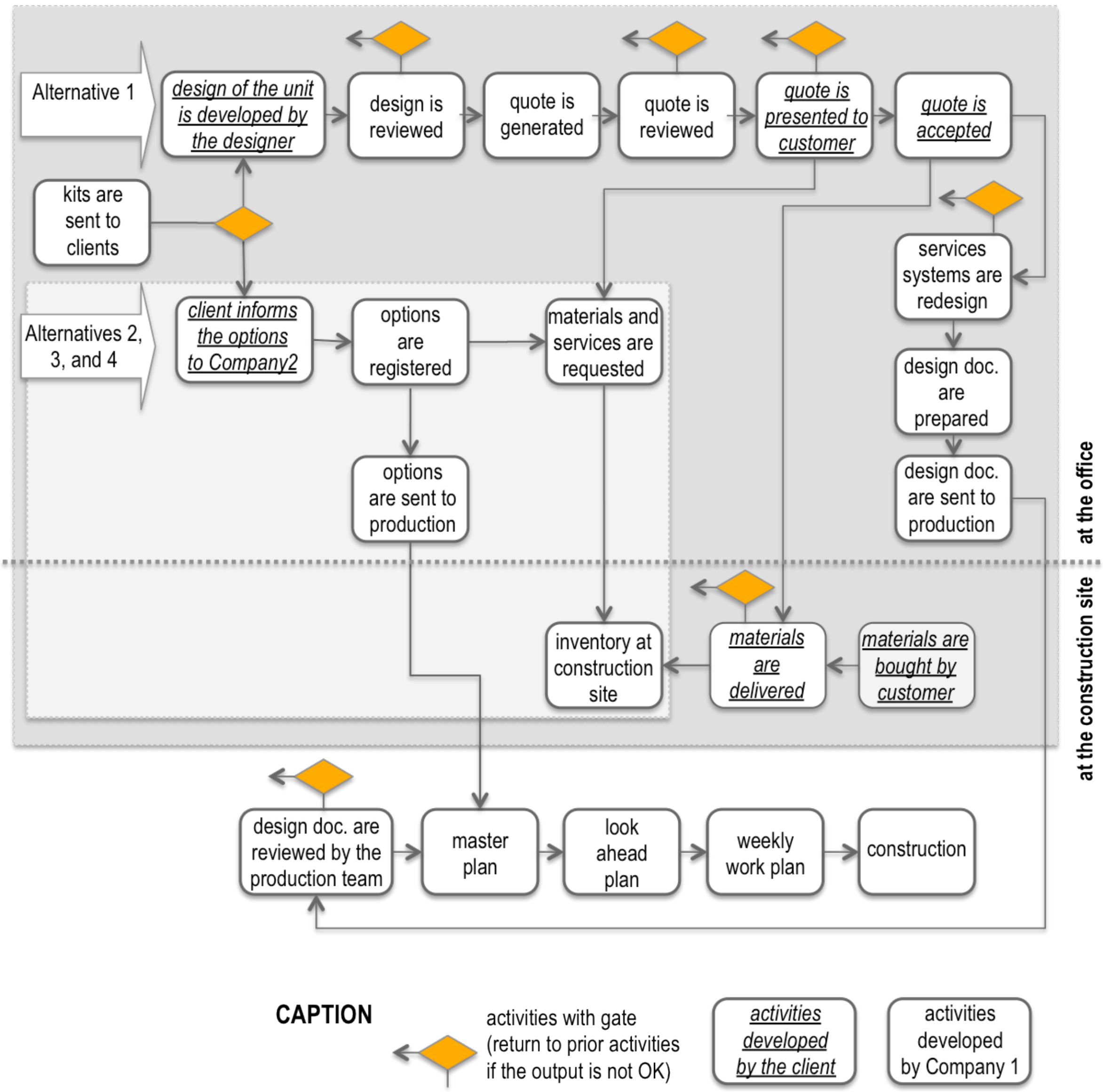

Figure 38: Development process of customised apartments

If the client does not opt for alternative 1, the development process becomes much simpler as depicted on the light-grey rectangle in Figure 38. This simplification yields from reductions in: (i) the number of activities performed in the process; (ii) the number of activities with gates; (iii) and in the degree of the client involvement, measured by the number of activities that require the client participation. This simplification is possible because all the other customisation alternatives in solution space A have a defined range of options, enabling Company 2 to anticipate and be prepared to cope with them. Solution spaces B and C also follow this simplified process once they also have customisation alternatives with limited options. In this process, the only two points of interaction between the client and Company 2 is when the options are communicated to clients and when they inform their decision. Solution space D is not addressed in the processes shown in Figure 38. This is because the client's selection of the desired option concerning alternative 4 has no implications in the customisation process. In fact, Company 2 executes the floor plan options based on a forecast, since each apartment has its layout already defined depending on the block or tower in which the apartment is located.

5.2.4 Practices

Based on the analysis of the development process of residential projects several customisation practices were identified (Figure 39). Those practices were described according to the group that they relate to. A practice can support one or more groups and, conversely, some groups are supported by one or more practices.

#	Description
1	Development of partnerships with suppliers and subcontractors
2	Installation of a limited range of finishing and fixtures
3	Purchase of a limited range of materials, finishing, and fixtures
4	The client is responsible for the purchase of any materials outside the list of standard specifications
5	Delivery of the materials purchased by clients according to a schedule based on the line-of-balance
6	Adoption of a platform-based approach in the apartments design
7	The internal walls of a apartment are built on top of the floor finish
8	Letter explaining the limits of the customisation offered is sent to clients
9	Showroom with key fixtures and finishing at the construction site is available for clients' visits
10	Use of images and detailed information for presenting the list of standard specifications to clients
11	Meeting with the client for presenting the quote for the bespoke design of the apartment
12	Company 2 regularly calls clients to enquiry if they have decided about the customisation of their apartment
13	Definition of the options for the alternatives based on the residents' demographic profile
14	Customisation kits are sent to clients according to the line-of-balance schedule
15	Deadlines for clients' decision concerning the customisation are established according to the line-of-balance
16	A defined a set of documents need to returned with information about the bespoke apartment
17	A colour coding and drawing conventions should be followed in design documents
18	List with the cost of materials and services is used for quoting the bespoke designs
19	All bespoke designs should follow the activities shown in Figure 38
20	Quotes for the bespoke designs should have a list of all items credited or debited
21	Design documents sent to the production team follow a standard format
22	A tool is used for facilitating the communication of the customisation to gang crews
23	A matrix with a list of materials and quantities is used for communicating the customisation to procurement
24	A list of apartments and their customisation status is circulated weekly to all teams
25	Dates for the delivery of materials purchased by the clients are established according to the line-of-balance

Figure 39: List of practices developed by Company 2

<u>Group of practices 1 – New product flexibility in the supply of materials and services related to alternative 1</u>: new product flexibility is required for the design of the service systems such as the electrical system and the water and sewage system for instance as these need to be tailored made accordingly to the bespoke design of the

apartment. It is required for all suppliers and subcontractors who provide services or materials that can be impacted by alternative 1 such as all finishing and fixtures of the internal unit. Company 2 has developed partnerships with those suppliers and subcontractors (Practice 1) in order to enable this flexibility to be developed. Such partnership includes the agreement that the amount of materials and services initially procured by Company 2 can increase or decrease depending on the number of bespoke design and their features. This is specially the case of the floor finishing for dry areas, which is often customised by clients who opt for alternative 1. Depending on the number of clients providing bespoke floor tiles, Company 2 will decrease the amount of standard floor tiles that will be purchased. As a counterpart, Company 2 usually commissions those subcontractors and materials suppliers for several residential projects.

Group of practices 2 – Usage of a limited range of services and materials: there is a defined range of materials that are purchased by Company 2 (Practice 2). If the design of the bespoke apartment has materials whose specification is different from the standard bill of materials used by Company 2, the client is responsible for their purchase and delivery at the construction site (Practice 4). Also, there are fixtures and finishing that are not installed by Company 2 (Practice 3). Having a limited range of materials and services enables Company 2 to efficiently cope with alternative 1. If Company 2 would install any finishing or fixtures, a wide range of subcontractors would be required. By limiting the types of finishing and fixtures that can be installed, Company 2 is able to have a defined group of subcontractors that are consistently hired throughout several projects.

Group of practices 3 – Mix flexibility in the supply of materials and services related to alternatives 2, 3, 4, and 5: suppliers and subcontractors who provide services or materials related to these alternatives need to be able to cope with the different options within each alternative. In other words, they should be able to provide the different options offered in by Company 2 in alternatives 2, 3, 4, and 5. This ability is also supported by the partnerships developed with these subcontractors and suppliers and their commissioning for several projects (Practice 1).

Group of practices 4 – Commonalities in the floor plan options used in alternatives 4 and 5: Company 2 adopts a platform-based approach in developing the apartments plans options (Practice 6). Although different apartment plans are offered in these alternatives, there is usually a platform or a core body that remains unchanged in the options. For instance, for a project with two apartment plans (a three-bedroom apartment or a two bedroom apartment with one office), the floor plans are the same except for the alterations required for converting one bedroom into the office and its en-suite bathroom into a lavatory. This approach enables a reduction in the delivery time, once the platform could be produced based on forecast and prior to the client's definition of the desired customisation options. Nonetheless, it is necessary not only to have a platform from a design viewpoint but also to produce it independently from the other parts of the apartment. So far, Company 2 has not explored this benefit once each dwelling is produced at once, as a single batch. In spite of this, it can be argued that increasing the commonality across the apartment plans can improve the learning effect of the work gangs, if compared to completely different apartment plans.

Group of practices 5 – Ease customisation at usage: Company 2 builds light-weight internal walls on the top of the floor finishing (Practice 7), contrasting with the traditional practice of building internal walls and then installing the floor tiles. This facilitates the customisation during the usage stage: clients can easily remove existing walls and build new ones without the need of changing or repairing floor finishing.

Group of practices 6 – Facilitate the client decision concerning the customisation options: Four practices are adopted for facilitating the decision of clients concerning the customisation options. First, a letter is sent to clients explaining the customisation process and the limits of the customisation offered by Company 2 (Practice 8). Such outline helps clients to understand it, and decide if they would like to use alternative 1 or if they would rather select an option in each of the other alternatives. Second, key finishing and fixtures of the list of standard specifications are presented in a showroom at the construction site (Practice 9), which can be visited by clients. Third, all the specifications used by Company 2 are listed and presented with images in the customisation kit sent to clients (Practice 10). Fourth, the quality manager of Company 2 holds a meeting with the client and his architect for explaining the quote for the bespoke design (Practice 11). Facilitating the client's decision concerning the customisation options enables the customisation process to be performed efficiently. It also enables the information concerning the bespoke dwellings to be quickly passed on to the construction team. Fifth, Company 2 regularly calls the clients after sending the kits to enquiry if they decided about the customisation of their unit (Practice 12) in order to facilitate the client's decision and also to make sure that the information concerning the customisation will be available as soon as possible. This is especially important since Company 2 has reported that in several situations clients decide about the customisation desired but forget to inform the company.

Group of practices 7 – Offer of options with value to clients: The definition of the alternatives to be used in a specific residential project is outlined at the strategic planning and is related to the product families. Yet, the definition of the options within the alternatives happens at later stages of the product development process and takes into consideration the client profile (Practice 13). For instance, there are alternative floor tiles offered for product families II, III, and IV. Yet, the options for family II include only large ceramic tiles with different specifications while for product families III and IV, large granite tiles are also offered. Besides providing options that increase the perceived value of the apartment, such practice also helps in limiting the number of clients opting for alternative 1 as they can have their requirements fulfilled by the options available in the other alternatives.

Group of practices 8 – Even flow of customisation information and materials into production: Figure 40 depicts the customisation process timeline for two hypothetical apartments (401 and 402) and its relationship with the production process, which are planned using the line-of-balance[42] technique. The customisation kits are sent in batches accordingly to the line-of-balance approximately a hundred and fifty days prior to the beginning of the

[42] The line-of-balance is a visual technique used for production planning and control. It uses lines to represent the different types of work undertaken by crews, in specific locations of a project (JONGELING, OLOFSSON, 2007).

construction of the concrete structure of the apartments under consideration (Practice 14). The deadline for clients' decisions concerning the customisation is seventy days after the kits are sent (Practice 15). The delivery of materials purchased by the clients also follows the line-of-balance (Practice 25): finishing for dry areas are delivered thirty days before the beginning of the installation of floor finishing (dry areas); finishing for wet areas are delivered thirty days before the beginning of the installation of floor and wall finishing (wet areas); and fixtures and finishing are delivered ninety days before the beginning of the installation of these materials (Figure 40). Company 2 requires the fixtures and finishing to be delivered earlier than the other materials because the work package in which they are used is one of the final packages in the line-of-balance. Hence, any setback in the delivery of these materials can cause delays in the building handover. The main goal of those three practices is to create an even flow in terms of materials and information concerning the customisations. Yet, it should be noted that the distribution of the kits and deliveries of materials follow the batches and rhythm established in the line-of-balance, but not the sequence defined in it. The customisation activities can be carried out only after apartments have been sold and there are residents assigned to. Clearly, the sales of the apartments do not follow the sequence established in the line-of-balance and, more often than not, the apartments in the first stories of a residential building are the last ones to be sold.

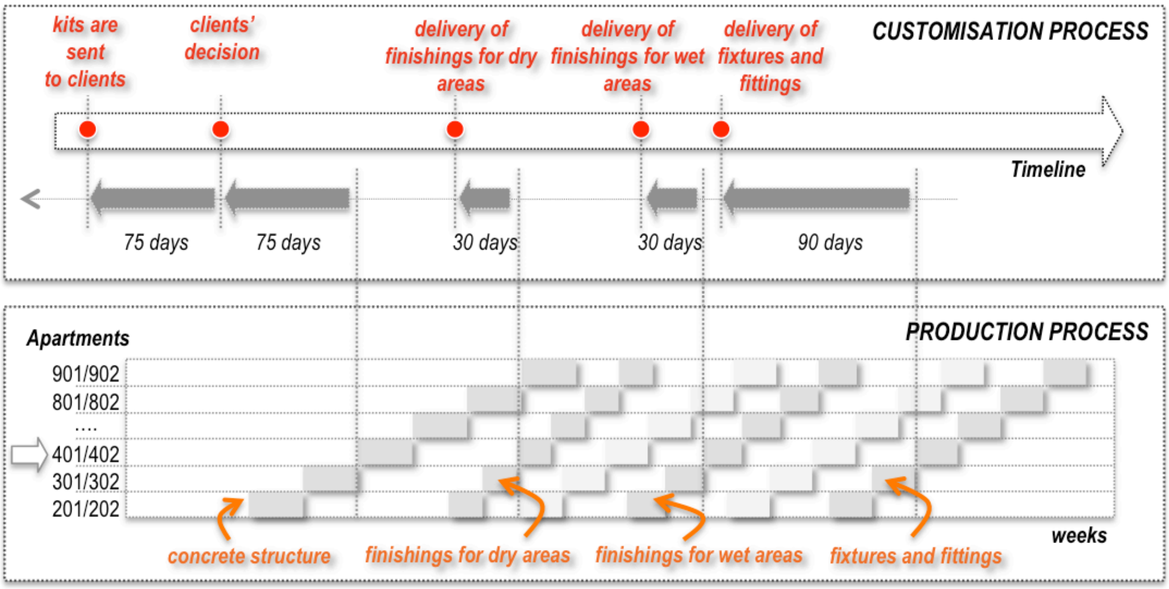

Figure 40: Keys dates of the customisation process and their relationships with the line-of-balance

Group of practices 9 – Standardisation of the information concerning the customisations: In order to have all the design information concerning the bespoke unit for carrying out its construction, Company 2 established a set of documents, including floor plans, details, and elevations, to be submitted by all clients opting for alternative 1 (Practice 16). The drawing conventions and colour coding, to be used in all the documents submitted is also described in the kit (Practice 17). All necessary information for reviewing, quoting, and executing the bespoke designs are received in a standard format, enabling Company 2 to process the customisations easily and quickly.

Group of practices 10 – Standardisation of activities and tools for processing the customisations: besides standardising the format in which the information concerning the bespoke designs should be delivered, Company 2 also established standard procedures for processing the customisations. For instance, there is a list with the cost of services and materials that is used by all the members of the customisation team in quoting the designs (Practice 18). Also, all bespoke designs should go through all the activities presented in Figure 38, design review, quotation, revision of the quotation, meeting for presenting the quotation, and signature of the agreement (Practice 19). These procedures assist in reducing mistakes and nonconformities in processing the customisations. Company 2 has also developed specific tools to be used in the customisations processing. For instance, all items that have been credited or debited and their associated costs should be listed in the quote (Practice 20). The documents on the bespoke apartments sent to the production team follow standards in terms of the format of the information and the way they are displayed (Practice 21).

Group of practices 11 – Agile processing of the customisations: Being able to rapidly process the customisation is a key ability developed by Company 2 for coping with the bespoke designs and reducing the lead-time for delivering the information related to these to the production team. Such ability is supported by *group of practices 9 – Standardisation of the information concerning the customisations* and *group of practices 10 – Standardisation of activities and tools for processing the customisations*.

Group of practices 12 – Facilitate the communication of customisations to all teams: Company 2 has devised several tools for easing the communication of information regarding the customisations to the different sectors of the company. One of the tools, exemplified in Figure 41, has been created for facilitating the communication of the bespoke design to the gang crews at the construction site (Practice 22). The fixtures and finishing of each the apartment are listed in the first column. In the second column a colour coding is used, for visually presenting the specification used for each item. Green signals that the specification is the standard one used by Company 2. Yellow signals the item is customised and will be installed by Company 2. Red signals that the item is not part of the list of materials installed by Company 2, indicating that the gang crews should not execute the item. If the specification for an item is marked yellow, more details are presented on a cell on the third column. The customisation team has also developed a matrix containing a list of material and the amount that needs to be purchased for each bespoke apartment (Practice 23). This matrix is a translation of some of the information contained in the design documents submitted by the interior designers, providing the procurement team with information in a format that can be readily used by them. A list with all the apartments and their customisation status is circulated weekly to all teams and sector of Company 2 (Practice 24). The list informs if an apartment was sold or if it is still available. If it is sold, it is informed if the client has defined the customisation desired or not, and in case the client has opt for alternative 1, on which stage of the customisation process is the apartment at. Again, the information concerning the customisations is summarized in a useful format for keeping all the teams updated.

ITEM	STATUS		Detail
Wall of the social hall	NONE	Item will be installed by the client afterwards *(red)*	
Floor of the lounge	CUSTOMISED	Please see details in the cell to the right *(yellow)*	Granite tile Y
Skirting board of the lounge	STANDARD	BEIGE COLOUR *(green)*	
Wall of the lounge	STANDARD	WHITE PAINTING *(green)*	

Figure 41: An extract of the tool for communicating the customisation to the gang crews

There are different relationships between the twelve groups of practices described and the four solution spaces once they entail different mix of in terms of the alternatives (Figure 42). Some groups of practices such as 2, 3, 4, 6, 7, 8, 9, 10, 11, and 12 support two or more alternatives. Others groups of practices support a single alternative. This is especially the case of alternative 1 which entails an unlimited number of options. Company 2 has developed several practices and groups such as 1, 2, 9, and 11 in order to be able to efficiently and effectively cope with the unlimited number of bespoke design created within alternative 1. For instance, new product flexibility in the supply of materials and service and the usage of a defined range of materials would not be required if alternative 1 did not exist. Likewise facilitate client decision concerning the customisation options (Group of practices 6); agile processing of the customisation (Group of practices 11); and standardisation of activities and tools for processing the customisations (Group of practices 10) are especially important for this alternative. In fact, almost all practices related to these abilities are actually supporting alternative 1. These abilities also support other alternatives as illustrated in (Figure 42). Yet, alternatives 2, 3, 4 and 5 are inherently simpler and easier alternatives to deal with because they entail defined ranges of options, making these abilities desirable for these alternatives and essential for alternative 1.

Customisation alternatives	1	2	3	4	5
Group 1 – New product flexibility in the supply of materials and services related to alternative 1	X				
Group 2 – Usage of a defined range of services and materials	X				
Group 3 – Mix flexibility in the supply of materials and services related to alternatives 2, 3, 4, and 5		X	X	X	X
Group 4 – Commonalities in the floor plan options used in alternatives 4 and 5				X	X
Group 5 – Ease customisation at usage					
Group 6 – Facilitate the client decision concerning the customisation options	X	X	X	X	X
Group 7 – Offer of options with value to clients	X	X	X	X	X
Group 8 – Even flow of information and materials related to the customisations	X				
Group 9 – Standardisation of the information concerning the customisations	X				
Group 10 – Standardisation of activities and tools for processing the customisations	X	X	X	X	
Group 11 – Agile processing of the customisations	X	X	X	X	
Group 12 – Facilitate the communication of customisations to all teams	X	X	X	X	

Figure 42: The five alternatives and the groups of practices that support them

Alternative 5, namely the option of different apartment plans per block or tower, is supported by a few groups of practices (Figure 42). This may be because the customisation process related to this alternative is minimal: the options are offered at the apartments' sales and once the client has purchased the apartment, the floor plan is automatically defined. More importantly, Company 2 can proceed to the production of the options in this alternative without any client input, once the floor plan of each apartment is already defined accordingly to the block or tower in which it is located. Conversely, *group of practices 5 – Ease customisation at usage* does not support any of the five alternatives (Figure 42). This is because the realisation of the selected options concerning these alternatives happens at the construction stage, prior to the building handover, whereas such group of practices is related to a customisation after such stage. In a way, this group could be considered as a sixth alternative of customisation. Yet, similarly to alternative 1, it does not have a defined range of options once it is not possible to identify all the possibilities in terms of personalisation that clients can carry out.

5.3 THE FIRST VERSION OF THE SOLUTION

The first version of the framework encompassed six decision categories. The sequence of decisions in defining these categories is shown by the numbered-arrows in Figure 43. It initiates with the definitions of the customisation units, which are the building blocks of a customisation strategy. In brief, each block stands for one customisable element of the product. Once the customisation units have been defined, it is necessary to define the type of customisation and the visualisation approach to be used for each of those. The former relates to the process through each customisation unit is delivered, and the latter to the way it is presented to the client and to the organisation. The second step is to define the solution spaces, namely how the customisation units are combined. For each solution space defined, there is a platform and an order penetration point. A platform is the product part that remains unchanged throughout the different configurations of a product within a solution space. The order penetration is the product development stage in which the client's makes a decision concerning a customisation unit.

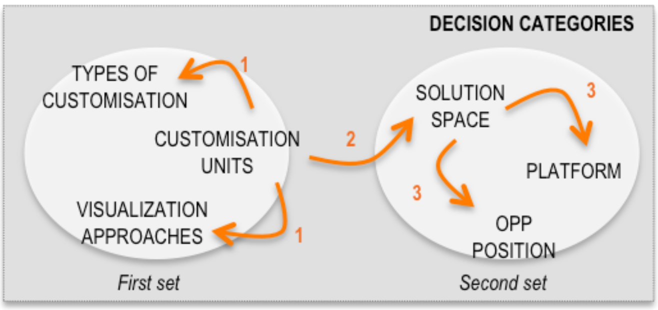

Figure 43: Categories of decision (first version of the framework)

5.3.1 Customisation units

Each customisation unit entails a set of items for a given customisable element of the product. For instance, the options of red, blue, and green for a product can be described as a customisation unit with three items. Another customisation unit for this same product could involve three sizes of the product: small, medium, and large. These customisation units entails a range of items related to different elements of a product, respectively, colour and size. Besides, providing a range of options for a particular element of the product, a customisation unit also has a specific type of customisation, depending on the point in the value chain in which the customisation is performed. It is important to assign the type of customisation for each customisation unit as just defining the items within it does not automatically defines the point in the value chain where the customisation happens.

5.3.2 Types of customisation

Ten types of customisation are proposed based on the stage in the value chain in which the customisation is performed: design, fabrication, installation, delivery, distribution, packaging, labelling, retailing, usage, and segmented standardisation. These types build upon the eight generic levels of mass customisation proposed in taxonomy developed by Da Silveira *et al.* (2001). This taxonomy was selected because it is broad and systematizes key taxonomies previously developed by other authors. Figure 44 depicts the relationship between the generic levels and the types of customisation used for this category.

The customisation at the design and the fabrication stages remains similar to what has been proposed by Da Silveira *et al.* (2001). Only a discussion of how they are translated to the construction context was added. Customisation at the design stage happens when a product is entirely built to order, meeting the specific requirements of a given client. Differently from the other types of customisation, in the customisation at the design stage there is not a pre-defined set of options for the client to choose from, since these are unlimited. The development of a design of a house commissioned by a dweller is an example of a customisation at the design stage.

MC generic levels (Da Silveira *et al.*, 2001)	**Types of customisation**	**Examples of the types of customisation**
Design	Design	Design of a bespoke house commissioned by the dweller
Fabrication	Fabrication	Building of different layouts built using masonry walls
Assembly	Installation	Building of different layouts using a post-and-beams steel structure
Package and distribution	Packaging (Volume) Distribution (Location)	Offer of different sizes of dwellings Produce properties in different locations
Additional custom work Additional services	Delivery (Time) Labelling Retailing	Handover of a dwelling at different moments in time Use of different brand for standard apartment buildings Use of different advertising for standard dwellings units
Standardisation	-- Excluded	
	Segmented standardisation	Schemes with different mix of dwellings build based on forecast
Usage	Usage	Movable partitioning on a dwelling

Figure 44: The generic levels proposed by Da Silveira *et al.* (2001) and how they are adapted into the types of customisation

Customisation at the fabrication stage occurs when parts of a product are manufactured following pre-defined designs. The options of pre-defined designs within a unit with a customisation at the fabrication stage can encompass alterations of forms, alteration of specifications, or both of these. If a customisation unit offers three colours of paint for the walls of a bedroom, it is only an alteration of the specification of the wall finishing, namely, the colour. If a customisation unit entails two different layouts for a room, either as an office or a bedroom, it is a customisation with alteration of form, since, depending on the function of the room, there may be different positions for plugs and switches. Alterations of specification and form can also occur within a single package, for example, different layout for a room with specific colours.

The assembly level proposed by Da Silveira *et al.* (2001) was replaced by a customisation at the installation stage, although it addresses a similar idea (Figure 44). The latter term was used because it provides a more appropriate description concerning the processes by which building components are assembled for creating a building or a part of it. The fittings of different types of windows or assembly of prefabricated concrete beams into a building are examples of customisation at the installation stage.

Customisation at delivery, distribution, packaging, labelling, and retailing are related to changes in the services of a product surrounding the goods. The generic level related to package and distribution proposed by Da Silveira *et al.* (2001) is broken down in two types of customisation as showed in Figure 44. Customisation at the distribution stage occurs when products can be shipped to different locations based on a client order and thus, it is a customisation in terms of space. Customisation at the packaging stage occurs when a product is offered in different amounts and thus, it is a customisation in terms of volume. Additional custom work and additional services in the generic levels proposed by Da Silveira *et al.* (2001) are translated into three types of customisation as depicted in Figure 44. These generic levels were modified because there was not a clear definition of the scope of the customisation involved in these or the difference between them. Customisation at the delivery stage happens when the time of delivery of a product is performed based on a client order and thus, can be defined as a customisation in terms of time. Customisation at the labelling stage occurs when different labels are used for a standard product. Customisation at the retailing stage happens when attributes and features are communicated or emphasized differently for distinct clients when marketing a standard product.

The standardisation level proposed by Da Silveira *et al.* (2001) was not used because it seems unnecessary to have that category if the goal of the model is to describe types of customisation. Customisation at usage address the same idea proposed by the generic level proposed by Da Silveira *et al.* (2001). It occurs when a standard, but customisable product is provided, and it is customised by the user. Movable partitions in a dwelling that enable different layouts to be created is an example of a customisation at the usage stage (Figure 44). Segmented standardisation occurs when a set of standard products are offered based on an anticipation of clients orders, although not directly catered to them (LAMPEL; MINTZBERG, 1996). This approach was associated to the distribution and packaging level by da Da Silveira *et al.* (2001). Yet, it is argued that it should be considered as a separate type of customisation since not all segmented standardisation are related to distribution and packaging. For instance, having a mix of different dwelling types in a scheme, produced based on anticipation of the dwellings preferred by clients (Figure 44), is an example of a segmented customisation. It is relate to the changes in the mix of the physical product and not to their distribution or packaging.

It can be argued that the segmented standardisation cannot be associated to a particular stage of the value chain, unlike other types of customisation. This is because a segmented standardisation does not involve a change in the physical goods of the product or services, but rather on the mix of the products. Hence, it is related to a strategic decision rather to a modification of the product at a particular stage. The customisation at use is also distinct from the other types in the sense that it happens in a stage that is outside of the scope of activities that are performed by the organisation. Those two types of customisation also have particular feature once they can be combined with the other types of customisations. For instance, the offer of three sizes of apartments based on anticipation of clients' orders configures a segmented standardisation. Yet, it also involves a customisation in terms of the volume. Nonetheless, in terms of the types of customisation category, it can be still classified as a segmented standardisation, since customisation is not performed at the packaging stage. Likewise, expanding or reducing the area of a room by using removable partition operated by the dweller is a customisation in use. Nonetheless, it also involves changes in amounts or sizes, which is related to a customisation in terms of packaging. Yet, it is also a customisation at usage since it is carried out by the user.

5.3.3 Visualisation approaches

A customisation unit can be perceived differently by clients and by the organisation offering the product, depending on the way it is displayed. This investigation suggests that there are three visualisation approaches (Figure 45): collaborative, transparent, and do-it-yourself (DIY). Those approaches are based on three of the four customisation approaches proposed by Gilmore and Pine (1997): collaborative, transparent, and adaptive.

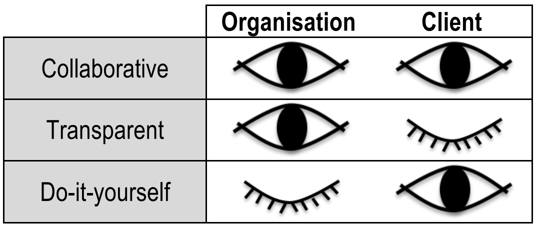

Figure 45: Visualisation approaches

In the collaborative approach both clients and the organisation are aware that a customisation is happening. For that reason, it is graphically represented with two opened-eyes (Figure 45). Examples of such approach include interfaces that allow clients to simulate options for a product, such as the toolkits that have been discussed by Franke and Piller (2004) and Von Hippel (2001). Such an approach is suitable when clients value the process of selecting the features of a product, and this becomes part of the benefits of the customisation. This idea is addressed by the concepts of experience and prosumption, proposed respectively by Pine and Gilmore (2000) and Xie *et al.* (2008). It is also an adequate approach if an organisation is capable of developing dialogues with individual clients to help them articulate their needs, and to identify the precise offering that fulfils those needs (GILMORE, PINE, 1997).

The transparent approach happens when an organisation offers a customisation unit that is not acknowledged or perceived by the client. It is represented with a closed-eye from the client perspective, since it is not visualized by the client but only by the organisation (Figure 45). Such an approach is appropriate when the requirements of clients are predictable or can easily be deduced, and especially when clients do not want to state their requirements repeatedly (GILMORE, PINE, 1997). Moreover, as clients do not know that the product has been customised for them, problems related to client choice can be reduced. The hotel studied by Gilmore and Pine

(1997) that stores client information concerning habits and preferences in a database and uses it to tailor the service for each client in their next visit is an example of the transparent approach of customisation.

Finally, the DIY approach occurs when an organisation offers a standardised product that is later customised by clients. This approach is represented with a closed-eye from the organisation perspective, since it is provided as a standard product, and thus customisation is only visible from the client perspective (Figure 45). It can be said that all customisations at the usage stage have a DIY approach. Although such approach is more intuitively associated to customisations at that stage, it is not restricted to it and can be adopted in other stages. For instance, if an organisation provides a carpentry kit with tools and materials for a client to build a house, it can be considered a customisation at the fabrication stage with a DIY approach. A key distinction between the DIY approach and the customisation at usage stage is that in the former the customisation is not reversible while in the later it usually is. A couch bed is a customisation at the use stage, which entails a DIY approach. Yet, a kit of components that enables a client to assemble a couch or to assemble a bed is a customisation at the assembly stage with a DIY approach.

5.3.4 Solution space

After the customisation units, and their respective types of customisation and visualisation approaches have been defined, the combination of the units should be considered. The grouping of one or more customisation units is defined as a solution space (SS). The underlying idea of this category is similar to the one presented by Von Hippel (2001), Salvador *et al.* (2009), and Kumar (2005). Alike these previous studies, this category is concerned with the boundaries set in terms of the customisation offered. However, conversely to previous studies, this investigation proposes that each solution space is made of different building blocks, namely, customisation units. In fact, it is suggested that by mapping the customisation units used by an organisation and how there combined to be offered to clients, outlines the solution spaces used in a customisation strategy. By having different solution spaces, it is possible to adapt the customisation strategy to different clients, contexts, families of products and so on. In fact, this investigation suggests that a customisation strategy can entail more than one solution space.

The solution space category can also be used to define the scope of the product variants that can be created within a customisation strategy. A product variant is created when one or more items in each of the customisation units that form a particular solution space is defined. In some situations, it is possible to determine the total number of product variants. Consider a solution space with three customisation units, one with two items and the other two with four items each. If only one item in each of the customisation units can be selected, the total number of product variants in this solution space is thirty-two (2 x 4 x 4 = 32).

5.3.5 Platform

The customisation units encompass all the customisable parts, including goods and services, while the substantial part of a product that remains unchanged in a solution space is defined as a platform. Each solution space has one platform as it depends on the customisation units that form it. In some cases, two or more solution spaces can share a platform. For instance, if the customisation unit used in one solution space is option of large ceramic tiles and in the other is other includes options of wood flooring, they are still installed over the same concrete slab, forming a platform. This decision category adopts an idea similar to the one presented by Mahmoud-Jouini and Lenfle (2011), Muffato (1999), and Blecker and Abdelkaf (2006), that a platform is a large part of a product that is used in different product variants. In the proposed framework, the change across the different product variants is created by the selection of different items in the customisation units that form a solution space. Conversely, the product parts that are not affected by the items selected in the customisation units are defined as the platform. The main difference in using this concept in the framework, compared to previous studies, is that it assumes that a customisation strategy can have more than one platform. This is because a customisation strategy can have more than one solution space and each solution space can have a particular platform.

5.3.6 Order penetration point

Each solution space also has a specific order penetration point (OPP) that hinges on the customisation units that form such solution space and their respective customisation types. The OPP can be located in different positions within the continuum of activities necessary for converting raw materials into final products, delivered to clients. The order penetration point marks the division of the activities in the value chain that are forecast driven from the ones that are demand driven. In this category, it is proposed that the OPP position is determined by the customisation unit whose customisation occurs at the earliest stage in the value chain. For instance, if a solution space has two units, one with a customisation at the assembly stage and the other at the distribution stage, the OPP is likely to be located at the former, since it is the first point where a client requirement enters the value chain. Although customisations related to other units can be performed at later stages, from this point on the product has been differentiated according the requirements of a specific client or a segment of clients. It is not possible to numerically compare the OPP of the different solution spaces. However, these can be arranged in an ordinal sequence (first, second, third and so on) in terms of their proximity to raw materials or to clients. Again, the main difference in using the order penetration point concept in this framework compared to previous studies, that it assumes that a customisation strategy can have more than one order penetration point once a customisation strategy can entail more than one solution space and each of this can have a particular OPP.

5.3.7 Graphic representation of the decision categories

For the illustration the application of the decision categories, consider a chair manufacturer. It offers three customisation units (Figure 46): colours (C1); styles of the chair support and base (C2); and labelling (C3). C1 is a customisation at the fabrication stages, once the painting is applied on the chair components based on a client order. C2 is customisation at the assembly stage once a support and a base are added to the chair seat according to the client selection. C3 enables the furniture retailers to select the label to be placed on the chairs, and thus is a customisation at the labelling stage.

Customisation units	C1 – Colours	C2 – Style of the chair's support and base	C3 – Labels
Items	Red Yellow Green	Organic line Straight lines	Label A Label B Label C

Figure 46: Customisation units

This product is provided to two different market segments: end-clients and furniture retailers. For the former, the manufacturer offers C3 and C2 and for the latter, it offers C2 and C1, configuring two solution spaces (Figure 48). The seat of the chair remains unchanged throughout the use of the different items in the three customisation units and because of that is defined as the platform. Each solution space has six product variants, once each of them has two customisation units, one with three items and the other with two items. The platform is called AB' and is located in the intersection of SSA and SSB (Figure 48) to show that is shared by the two solution spaces. For the representation of the order penetration point, a triangle on a line, linking raw materials and clients is used as depicted in Figure 48. It represents the point in the value chain in which the client's decision in terms of customisation is first needed. The SSB has an order penetration point that is closer to raw material than SSA. This is because in SSA the client information is only required at the assembly stage, whereas in SSB it its required for the components painting which is performed prior to the assembly. Clearly, the position of OPP depends on the production process adopted by the organisation under considerations. If the paint was applied after the components assembly, than SSB and SSA would have the OPP at the same point in the value chain.

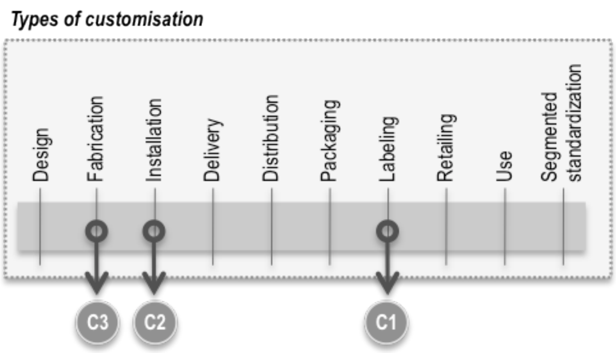

Figure 47: Graphical notation of customisation units and types of customisation

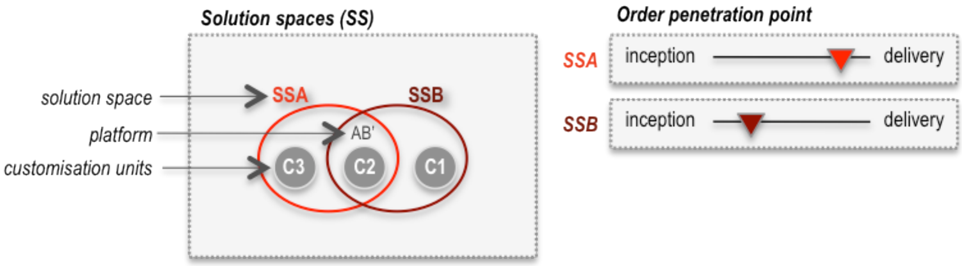

Figure 48: Graphical notation of solution spaces, platforms, and order penetration point

5.4 INSTANTIATIONS

5.4.1 Instantiation of the first version of the solution using case study 1

According to the description of case study 1, Company 1 plans to develop a customisation strategy with five customisation units (Figure 49):

a) Customisation unit 1 (C1): includes a pre-defined mix of tiles, in terms of colours and shapes to be picked off-the-shelf by clients. Because of that, it has a collaborative approach. Since these options will be produced based on a forecast of orders of clients, but not pulled by individual orders, this unit is considered to be a segmented standardisation.

b) Customisation unit 2 (C2): includes two modes of promotion and, thus, it is a customisation at the retailing stage. In the case of the contractors, promotion will be done through individual visits to them. For the construction materials stores, which will be the retailers of the product to the individual clients, a small showroom and totem with information about the product will be used for advertising.

c) Customisation unit 3 (C3): encompasses two different package sizes. The small package will be targeted at individual clients, as they will acquire tiles for relatively small areas. The large package will be offered to contractors, as they are likely to use the product in a whole project or even in several projects. As the items in this package will not be selected by clients, but rather assigned by Company 1, it is a customisation with a transparent approach.

d) Customisation unit 4 (C4): entails options of colours to be selected by clients. As there is a predefined set of pigments to be used in casting the tiles, it is a customisation at the fabrication stage.

e) Customisation unit 5 (C5): entails a set of tiles shapes to be selected by clients. Similar to C4, it is a customisation at the fabrication stage with a collaborative approach.

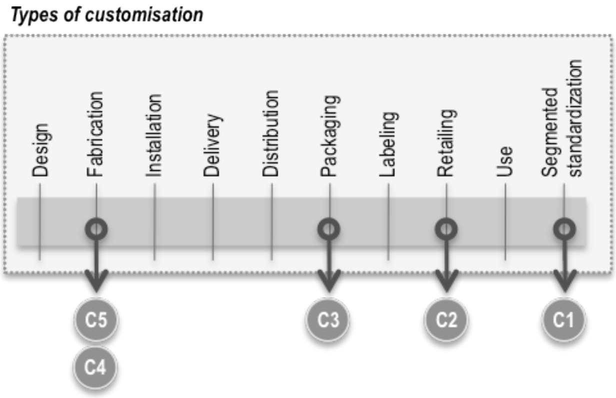

Figure 49: Customisation units and types of customisation (case study 1)

Company 1 is likely to combine the five customisation units into two solution spaces (Figure 50): solution space A (SSA) and solution space B (SSB). SSA is formed by C1, C2, and C3 and is the solution space presented to individual clients. They will be able to pick tiles' mixes of the shelf, which will be packaged in pre-defined amounts and retailed through a specific mode of promotion. SSB is formed by C2, C3, C4, and C5 and is the solution space presented to contractors. They will be able to select the tiles' shape and colour, but these will be packaged in pre-defined amounts and retailed through a specific mode of promotion. Although the product in SSA and SSB is made from the same material, namely concrete mixture, they actually have different platforms. For SSB, the mixture will need to be plain in order to be pigmented and moulded according to a client order, while for SSA it can be already moulded and pigmented according to the items of C1. The OPP for SSB is located closer to raw materials, whereas the OPP for SSA is located closer to clients.

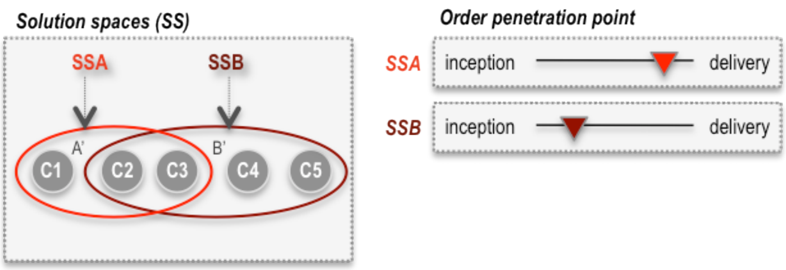

Figure 50: Customisation units and solution spaces (case study 1)

The two solution spaces planned by Company 1 will have different implications in terms of the delivery time and degree of customisation. In SSB, clients will have a wide range of product variants to meet their requirements, but would have a longer delivery period compared to SSA. This is due to the fact, that in order to enable clients to select the tiles' colour and shapes, the OPP for SSB has to be placed in an upstream position, at the fabrication stage. Inversely, for individual clients, who will buy smaller amounts of product, a segmented standardisation is offered which enables the OPP to be positioned closer to clients. Although the SSB has a narrow number of product variants, it enables clients to pick the product off-the-shelf and without a delivery time.

5.4.2 Instantiation of the first version of the solution using case study 2

According to the description of case study 2, Company 2 has five customisation units in their customisation strategy. All these customisation units adopt a collaborative approach, since the items in all units are explicitly chosen by clients (Figure 6). A summarized description of each unit is presented bellow:

a) Customisation unit 1 (C1): includes options of apartment plans options. In this customisation unit each plan is pre-assigned to a specific block or a column in the residential project. For instance in a given residential building, block X has apartments with a two-bedrooms and one office, whereas block Z has apartments with a three-bedroom. Thus, the client selects the floor plan at the moment of the purchase. This unit is a segmented standardisation since there are no customisations on the product itself, namely the apartment, but rather on the mix of apartment plans offered to clients.

b) Customisation unit 2 (C2): encompasses options of colours for plugs and switches to be used in the apartment. It is a customisation at the assembly stage since different items are placed in the walls according to the client order.

c) Customisation unit 3 (C3): offers different types of floor ceramic tiles for the dry rooms of the housing, namely bedrooms, office, living room, closet, hall and corridor. C2 is considered a customisation at the fabrication stage since the floor tiles are built into the housing unit based on the client order.

d) Customisation unit 4 (C4): alike C1, this alternative entails apartment plan options for the apartment. Yet, in this customisation unit, the client first purchases a apartment and later decides the floor plan to be built in it. The floor plans should have the same area and perimeter in order to be interchangeable. Such unit is a customisation at the fabrication stage since different layout types are built into the units.

e) Customisation unit (C5): enables clients to have an unlimited customisation of the apartment internal layout and its finishings, fixtures, and finishings. In this customisation unit, a designer hired by the client develops a bespoke design, which that is built by Company 2. As discussed previously and summarized in Figure 36, Company 2 sets up some limitations in terms of what can and cannot be changed in the dwelling. Nonetheless, this customisation unit allows an endless number of designs to be created, configuring a customisation at the design stage.

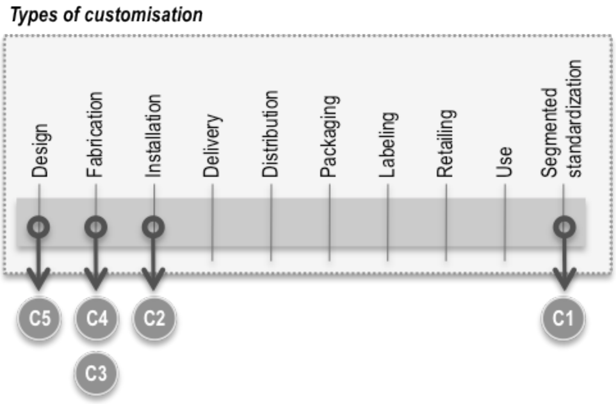

Figure 51: Customisation units and types of customisation (case study 2)

The five customisation units are combined in four solution spaces, used for the four product families (Solution Space A (SSA), Solution Space B (SSB), Solution Space C (SSC), and Solution Space D (SSD). SSA is the simplest solution space as it is formed by only one unit (C1) that is a segmented standardisation. As the product itself cannot be altered, since it is a segmented standardisation, no platforms are needed. This solution space has the closest OPP to clients, once the product itself is not customised in any stage of the value chain. SSB also has only one customisation unit (C4), which entails options of apartment plans. Only some rooms vary from one plan option to the others and the rooms that remain unchanged configure a platform (B') that could potentially be built prior to the clients order. Due to that, SSB has an OPP position slightly upstream, if compared to SSA. SSB and SSA are used for apartments with less than 100 m^2.

SSD is the most complex solution space once it is formed by several dependent units, which have different types of customisations. The units are considered to be dependent because if a client decides for C5 (*i.e.*, to have a bespoke design), the client can select one of the tiles items offered on C2 or specify another one. Yet, if a client does not pick C5, an item in each of the other customisation units of SSD should be selected. SSD is usually used for apartments with more than 200 m^2. Due to C5, the platform of this solution space is limited basically to the elements of the apartment whose alteration is not allowed by Company 2, such as slabs, pillars, shafts and position of external walls among others. SSC encompasses C3 and C4 (Figure 52) which have non-dependent items as a client can pick a item in one unit and then pick any other on the second unit, regardless of the first item selected. Company 2 defined this solution space during the development of the case study, once the product family II had been just introduced. The platform for this solution space is composed by all parts of the apartment, except for rooms that vary amongst the apartment types and for the floor finishings for the dry areas. Thus, all rooms that are common across the apartments types could be built prior to a client order. Nonetheless, this is not possible since Company 2 builds walls on the top of the floor finishings in order to ease future refurbishment and renovations. Therefore, SSC and SSD have the same platform (CD') and the same OPP position, although the former could have a larger platform if the interface between walls and floor finishings was redesigned. Nonetheless, this would also need to be considered from a production perspective in order to assess the alterations required such as the re-organization of work packages in the line-of-balance.

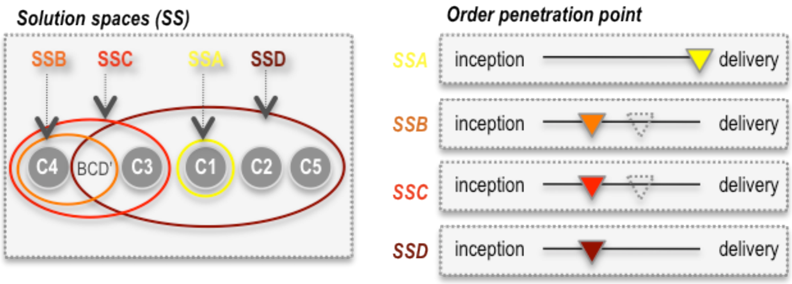

Figure 52: Customisation units and solution spaces (case study 2)

5.5 EVALUATION OF THE UTILITY OF FIRST VERSION OF THE SOLUTION

The discussion of the utility of the first version of the solution is organised according to the three constructs defined for assessing its utility, depicted in Figure 53. The presentation of the findings based on the application of the framework in case study 2, clarified the company's understanding of their customisation strategy concerning four elements. Firstly, they realized that all solution spaces have pros and cons from the client's perspective, even SSD that entails C5. Although this customisation unit provides the client with the broadest scope of customisation, its associated customisation process is time consuming and requires a considerably involvement of the client. Also conversely to the other customisation units, C5 has a premium associated to it, which cannot be defined prior deciding for it. In fact, the value of the premium is only defined after the bespoke design is developed and quoted by Company 2. Company 2 also recalled that some clients that had opted for C5, regretted this during the customisation process because of the involvement required and/or the resulting premium. Company 2 also mentioned that in some cases, clients gave up after they received the quote and decided to undertake the simplified customisation process, without C5.

The second point raised by the examination findings and recognised by Company 2 was that SSD, and more specifically C5 increased the complexities of the company's processes once it entailed a limitless number of items. The decision to limit this customisation unit to projects with apartments with a floor area above 200m^2 was reinforced by this understanding as shown in Figure 53. Thirdly, Company 2 realised the need to assess the customisations selected by the clients and to feed this information back into the development process of residential projects. This information could also assist Company 2 in devising solution spaces, customisation units, and items with more value to clients.

Company 2 already did some assessments of the customisations performed, but adopted a level of detail that provided limited information to be used subsequent projects and in the eventual re-definition of the customisation strategy. In particular, there was a need to further understand the bespoke designs developed by the interior designers under C5 and their characteristics in terms of layout and specifications. An analysis of the bespoke designs could reveals if there were recurrent customisations that could be incorporated as new customisation units or as items in existing customisation units. Besides increasing the value of the customisation offered, this could assist in reducing the number of clients opting for C5. To demonstrate the utility of assessing the customisations, the researcher analysed the customisations carried out under C5 in project H.

Further understanding of the customisation strategy	**Decision and future actions**	**Evidences that emerged from the monitoring of actions**
Each unit and solution spaces has pros and cons.	Enhance the communication of pros and cons of the different customisation units and solution spaces to clients.	(i) Web-based choice menu for project J with detailed information on the customisation units and items. (ii) Company 2 discussed with the researcher the new version of the letter explaining the pro and cons of the customisation units
Need to further understand the customisation carried out in previous projects in order to improve the projects and increase the value of the customisation offered.	Feedback information concerning the customisations undertaken in previous projects in the development of new projects and in the definition of the solution spaces and the customisation units.	(i) A meeting with the architectural practice was called to present the findings of the analysis of project H (ii) A copy of the database created for project H was provided to Company 2.
Customisation unit 5 increases the complexity of the processes.	C5 should be offered when the floor area of the apartment exceeds 200m^2.	(i) Project J (with apartments with a floor area between 120 and 180 m^2) do not use C5.
Alignment between the customisation strategy, the strategic goals, and the processes		
Despite the complexities introduced by C5, it is an important element of the customisation strategy for meeting strategic goals.		
There are several practices for coping with C5 and minimizing its negative implications on the processes.		

Figure 53: Decisions and future actions that unfolded from the instantiation (case study 2)

The analysis of project H was divided in two parts: the customisations in terms of the dwellings' layout and the customisation in terms of specifications. For the former, the researcher did a preliminary analysis of the floor plans of the bespoke units and created a set of categories of layout alterations per room. The modifications were then quantified by analysing their occurrence in the bespoke designs. Figure 54 shows the analysis of the en-suite bathroom of the main bedroom in blocks A and B of the residential project H, in order to illustrate the type of analysis that was undertaken. For the latter, the researcher used the tool employed for communicating the customisations to the gang crews and also its colour coding.

The colour coding functioned as an indirect indicator of the clients' acceptance of the specifications provided by Company 2. Green signals that the client used the specification provided by Company 2, indicating that he/she was satisfied with it into some extent. Yellow indicated that the client had altered the specification but used a finishing or a fixture that was installed by Company 2. These customisations presented an opportunity to incorporate specifications that would be preferred by the clients as an item within existing customisation units or as new units. Red indicates that the client had specified a finishing or fixture that was not installed by Company 2. These customisations could signal services that could potentially be offered by Company 2 in order to meet the clients' requirements. Figure 55 depicts an example of the analysis performed concerning the customisations in terms of the specifications.

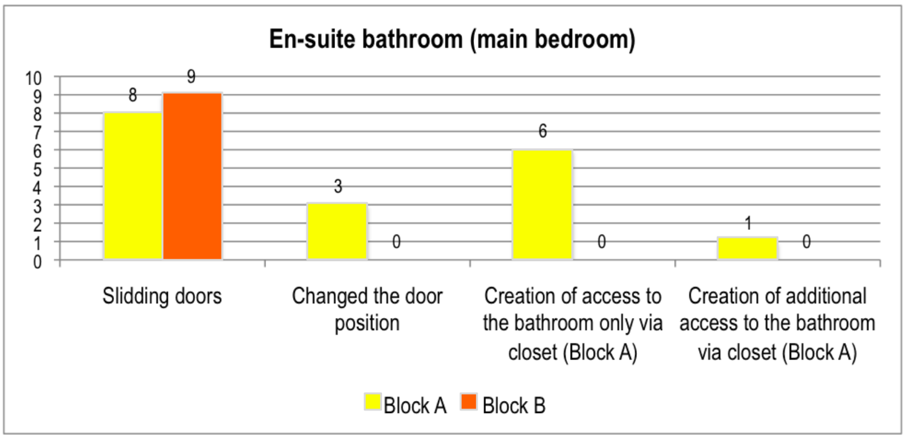

Figure 54: Example of analysis of the layout modifications (en-suite bathroom of the main bedroom)

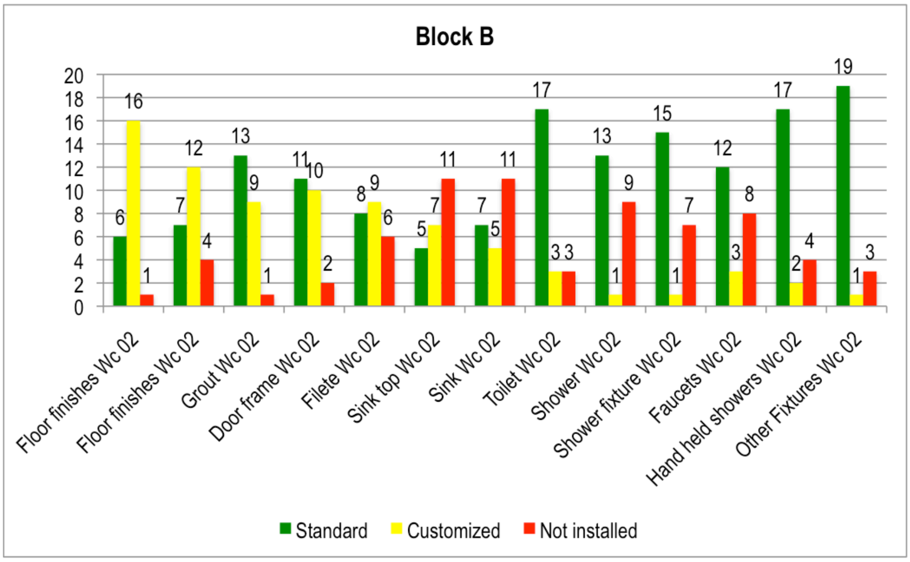

Figure 55: Analysis of the customisation of specifications (bathroom 2)

The analysis of the customisation in project H provided useful information to Company 2 for developing new residential projects in family II and customisation units and items for this family. For instance, the analysis of the customisation of the kitchen in terms of specifications revealed that an customisation unit encompassing options of large floor tiles and granite tiles should be offered once a considerable number of clients had specify these materials. The analysis also revealed that the majority of clients did not customise kitchen and bathroom fixtures (Figure 54) indicating that they were satisfied with specifications offered by Company 2. In term of the layout customisations, the analysis also revealed opportunities for improvements. One example is the connection between rooms such as the closet and the bathroom (Figure 55) that could be addressed in subsequent projects or offered as an item if a customisation unit in terms of layout is offered.

The presentation of the findings also enabled Company's 1 to verify the alignment of the customisation strategy and the their strategic goals. They recognized that despite the complexities introduced by C5, it still was an important element of the customisation strategy for meeting the company's strategic goals, specially considering its target market and the price of the apartments. Furthermore, Company 2 had developed several practices that enabled them to cope with C5, minimizing the negative implications of such customisation unit in the company's processes.

The understanding of the customisation strategy and the verification of its alignment with the company's processes and strategic goals provided by the instantiation led to a definition of future actions and decision to be undertaken by Company 2, as shown in Figure 53. This figure also depicts supporting evidence for each of the decision, based on the monitoring of the company's actions. Company 2 altered the letter that presented and explained the solution spaces to clients in order to clarify the pros and cons of different decisions concerning the customisation units. They also created a web-based interface for showing the customisations units and items available for the apartments in Project J, in order to improve their communication. In terms of the importance of feeding back the information concerning the customisation in new residential projects, they carried out three actions. First, they called a meeting with the architectural practice that develops the design of the building projects for the researcher to present the results of the analysis of the customisations in project H. Company 2 also requested a copy of the database that had been developed for such analysis in order for it to be adapted and used for analysing upcoming projects. In terms of limiting the use of C5, the fact that such customisation unit was not formally[43] offered in project J provides an evidence that Company 2 intends to follow through with this decision.

5.6. INITIAL ASSESSMENT OF THE FIRST VERSION OF THE SOLUTION

Five main points, which emerged in describing the two empirical studies, contributed in the solution development. The first one is that more than one customisation unit can be used in a product, as observed in case study 2 and illustrated by the four solution spaces. Likewise, in case study 1, Company 1 foresees a customisation strategy involving more than one customisation unit. Although this might seems obvious, the literature on customisation taxonomies does not provide explicit indications that this could happen. For instance, the taxonomies proposed by Pine (1995), Lampel and Mintzberg (1996), Gilmore and Pine (1997), and Da Silveira *et al.* (2001) describe the different types of customisation and sometimes provide examples, but overall fail to provide empirical examples where more than one type was used.

A second point is that the solution spaces can de devised for different reasons. In case study 2, the product families are the basis for devising different solution spaces. In case study 1, it seems that the different clients are

[43] As described in previous sections, Company 1 may allow a client to use C5, if the client specifically requests it, even in projects in which that customisation unit is not formally offered.

the starting point for establishing the two solution spaces. Also the mapping of the customisation processes for the different solution spaces in case study 2 showed that the solution spaces might require different degrees of client's involvement, depending on the mix of customisation units embedded in them. The customisation process related to *C5 – free customisation of layout and specifications* is longer, has several activities with gates, and requires much involvement from the client, whereas the other alternatives have much simpler processes.

A third point is that the customisation units can be described using a standard set of concepts, such as the ones displayed in Figure 36: standardised parts; customised parts; and range of options. In fact, using a particular set of concepts facilitates the understanding of the nature of the customisation embedded in the alternatives and facilitates comparisons. For instance, the subtle difference between the customisations involved in alternative 4 (options of apartment plan) and 5 (options of apartment plan) becomes evident when using this set of concepts. Overall, using that set of concepts provides an initial indication on the usefulness of defining parameters such as the standardised and customised parts that can accommodate the description of distinct customisation alternatives.

A fourth point is that each solution space has a distinct order penetration point (OPP), or point in the production process in which the information concerning the option selected by the client is needed. The order penetration point varies depending on the alternatives in each solution space. For instance, solution space D, in case study 2, in which customisation was limited to floor plans, had an order penetration point in closer to final clients once the apartments can be entirely built based on forecast. Conversely, solution space A had an order penetration point located in a position close to the product inception since it entails alternative 1, which enables clients to customise the internal layout and specifications of the apartment. The order penetration point can also be made explicit in the line-of-balance, by connecting it to the timing of production processes. It needs to be located some time before the first work package that requires the client's decision concerning customisation, enabling the activities within this package to be performed according to the client's order.

A fifth point raised by case study 1 is that, even in the house building sector, the customisation can entail not only the physical goods but also the services surrounding a product. This became apparent when Company 1 was discussing the marketing and sales approach to be used for individual client and contractors. The focus group with the low–income residents further reinforced the importance in considering the customisation of the intangible elements surrounding a good, once clients can have diverse interpretations of these.

6. DEVELOPMENT OF THE SECOND VERSION OF THE FRAMEWORK

This chapter presents the second stage of development of the framework. Initially, case studies 3 and 4 are described using the hierarchical structure and also using the first version of the solution. Next, an assessment of the first version of the solution is presented considering its application in the four case studies. After that, the new decision categories are defined. Then, all four empirical studies are examined, using the second version of the solution, generating four instantiations. This chapter concludes with a discussion of the utility of the solution considering the perspective of the organisations involved in case studies 3 and 4.

6.1 CASE STUDY 3

6.1.1 The business opportunity

The business investigated in case study 3 is the joint venture between a large corporation of the construction sector in the U.K. and a manufacturer of steel containers. This business entails an off-site manufacturing system that consists of a set of timber-framed boxes, that are combined vertically or horizontally for creating different dwelling types. Each box corresponds to one floor of a dwelling unit and has all the rooms fully fitted, with the windows and doors in place as displayed in Figure 56. The system is produced at a factory, which was previously used to build ships, owned by the manufacturing partner.

The idea of creating a business unit around an off-site manufacturing system for producing volumetric solutions for housing emerged in 2005. This happened after a branch of the corporation completed a pilot scheme using a concept similar to the one currently adopted. At that point, the corporation recognized that such concept could increase quality, reduce costs, and comply with most regulations and standards for social housing, introducing a better housing product into the market. The idea was then brought to the board of the corporation, discussed at length, and they agreed to go ahead. A team of about eight persons was put together, including an off-site manufacturing consultant and an architectural practice. The consultant assisted the corporation in developing a system that could be produced off-site within a defined target cost, while the architectural practice developed a design, which complied with the codes, standards, and regulations[44] for social housing. Another role of the consultant was to assist the corporation in selecting the right manufacturing partner. Early in the process, the

[44] The codes, standards, and regulations include the HCA Design and Quality Standards, HCA Quality Indicators, NHF Standards in Quality Development, Joseph Rowntree Lifetime Homes, and Wheelchair Housing Design Guides.

corporation identified that they had knowledge about the social housing market, but not about manufacturing. Hence, the key requirement for their partner was to have manufacturing skills and the willingness to learn how to build houses in boxes. Three manufacturers were selected after analysing thirteen candidates. One of them found the idea difficult to implement and withdrew; another was interested, but had a production line width that could not suit the dimensions of the system devised. The third one was found to be the most suitable partner.

Figure 56: Prototype at the factory: two boxes combined vertically

The business unit responsible for the system is independent from the corporation, but the boxes are not sold individually but incorporated in residential schemes developed and produced by Company 3. As shown in Figure 57, Company 3 is a contractor and the branch responsible for the region in which the factory is based. They carry out all activities related to the development of a residential scheme using the system and are responsible for its management and coordination. In terms of the construction process, they build the foundations prior to the delivery of the boxes on site. After these are assembled, the facades and the roof are built, completing the dwelling units. Considering the perspective of the business unit that produces the boxes, there are three mains clients (Figure 57): Company 3, registered providers, and householders. Company 3 uses the volumetric solution for developing housing schemes and is an internal client. Registered providers are external clients. They procure Company 3 for developing and producing residential schemes. These schemes are delivered to householders: another external client and also the end-user of the product (Figure 57).

From the perspective of Company 3, the system is a set of timber-framed boxes that are combined in different ways to create dwelling units. Company 3 also produces residential schemes using masonry or timber framed built on site. Hence, the system of timber-framed boxes produced off-site is an alternative method of construction that can be employed depending on the requirements of particular schemes. Overall, it is a low cost solution, yet it cannot be used if bespoke designs are required or if a plot has steep slopes since the schemes can become too expensive. Also, it cannot be used on sites with neighbouring roads that do not allow the boxes to be transported.

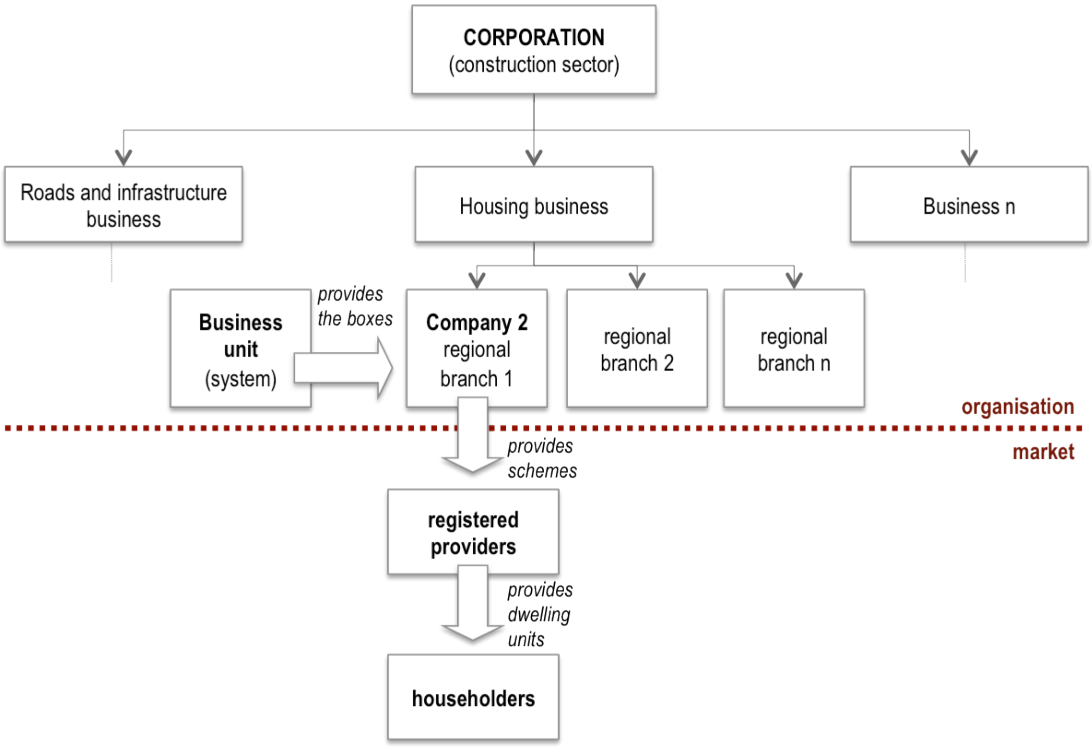

Figure 57: Organisational structure (case study 3)

From the registered providers' perspective, the system is a solution for efficiently delivering affordable housing. The boxes are not provided isolated, but are incorporated as part of a complete turn-key approach: the schemes are delivered to the registered providers ready for handover. As clients, registered providers have to specify the plot and make decisions at key stages of the development process. From the householders' perspective, the system is an alternative construction method that should be able to deliver a similar or superior quality compared to traditional construction methods such as timber frame or masonry.

The three main competitive criteria pursued by Company 3 in this turn-key approach are: cost, reduced delivery time, and product quality. Overall, the dwelling units that are built with this system have a cost lower than the average cost of dwellings in the social housing market. Nonetheless, this is mainly due to the cost of the boxes and significant increases in the cost can occur depending on the ground conditions of the plot or its distance from the factory. As a result, in some situations the cost of a scheme using this system might not be competitive. Another competitive criterion pursued is reductin in the project duration. This enables cost reductions related to site preparation and temporary facilities and the anticipation of the collection of rents by the registered providers. Product quality is related to the system compliance with most regulations, standards, and codes required for social housing.

6.1.2 Description of the product

Figure 58 shows the six customisation alternatives offered by Company 3 for schemes: dwelling types, bathroom fit-outs, kitchen fit-outs, windows and doors, roofing, and external cladding. It was possible to identify the range of options and the nature of changes offered on the three first alternatives, but not for the other ones. Overall, there is not a clear definition of the changes offered in alternatives 4, 5, and 6. Some questions that arose in trying to identify the options for those alternatives are summarized in Figure 58. For example, an enquiry concerning alternative 5 was "Is the customisation offered related to the size, number, and position of windows and doors, or all of the above?". When this and other similar questions were posed to different representatives of Company 3, they were not able to clearly state the scope of the customisations, demonstrating a lack of definition of the customisation strategy.

In terms of the alternative 1, the interviewees stated that three box sizes (short, small, and large) are needed for creating the five options available in this alternative (Figure 59). As shown in this figure, each combination of the boxes creates one dwelling, except for the 2b4p flat that has one dwelling unit in the ground floor and another one in the second floor. The design of the boxes resulted from the consideration of four requirements set out for the system: (i) compliance with codes, standards, and regulations for social housing; (ii) reduced cost; (iii) compliance with transportation standards; and (iv) maximization of commonalities across the boxes.

Alternative 1 – Dwelling types	
Standard part	The dimensions (footprint and height of the three boxes)
Customised part	Every other parts of the three boxes
Range	Five options: 2b3p bungalow, 2b4p flat, 2b4p house, 3b5p house, and 4b6p house
Alternative 2 – Bathroom fit-out	
Standard part	Layout of the bathroom
Customised part	Specification of finishes and fixtures
Range	Four options
Alternative 3 – Kitchen fit-out	
Standard part	Layout of the kitchen
Customised part	Specification of finishing and fixtures
Range	Six options
Alternative 4 – Windows and doors	
Standardised part	Not possible to define
Customised part	Not possible to define (Amount? Positioning? Specification? Size?)
Range	Not possible to define
Alternative 5 – Roofing	
Standardised part	Not possible to define
Customised part	Not possible to define (Specification? Type? Number of plans?)
Range	Not possible to define
Alternative 6 – External cladding	
Standardised part	Not possible to define
Customised part	Not possible to define (Specification? Addition of gables and balconies?)
Range	Not possible to define

Figure 58: Customisation alternatives used by Company 3

The three first requirements are mandatory in order to achieve the strategic goals set for the system, whereas the fourth criteria was viewed as a means for reducing the complexity of the production process. Such requirements are conflicting and have created opposing forces in designing the system. In terms of transportation, the most effective size is the large box since it uses the full capacity of a truck, compared to the small and short boxes. Yet, if only the large box was adopted for creating the five combinations, the resulting dwellings would be too large and expensive for households with three or four people. Likewise, the requirement to maximize commonalities was hindered by the standard and spatial requirements required for social housing. According to the consultant involved in the system development, the area of most rooms in a dwelling unit usually needs to increase as the number of householders increases. In order to increase the boxes' commonalities, the large rooms, designed for the 3b5p or 4b6p houses would need to be used as a standard. This is because they meet the requirements for large households and exceed the requirements for the small ones such as the 2b3p and the 2b4p houses. Yet, if they were adopted, the cost of the smaller dwelling units would exceed the cost threshold set for them, jeopardizing the competitive criteria of reduced cost.

Despite the fact that the system was designed with the aim of establishing commonalities among the boxes, a detailed examination of the internal layouts of the dwelling units, depicted in Figure 60, revealed that such commonalities are fairly limited. Although the boxes have common widths, depths, and heights, they have distinct layouts. Even boxes that accommodate the same functions such as boxes 3 and 4 (Figure 60) have differences in their internal layouts. As shown in Figure 60, which shows the approximate location of different functions of the dwellings, ten types of boxes are needed for creating the five dwellings units.

Figure 59: Footprints of the combinations

The system had been designed with the rationale of providing customisation within defined boundaries, by mixing and matching ten boxes in different combinations. In spite of that, Company 3 allowed the layout of the dwelling units to be customised beyond the boundaries defined in alternative 1, introducing slight changes in the design of the ten boxes. An example mentioned by one of the workers at the factory was an alteration in the specification of the staircase required by a client. This had led to alterations in the design of the boxes. According to some interviewees, such compromises were being made because the system had just been launched and these were viewed as necessary for it to succeed. Although such compromises can help in introducing the system in the market, it creates misconceptions in terms of the scope of the solution space offered by the company.

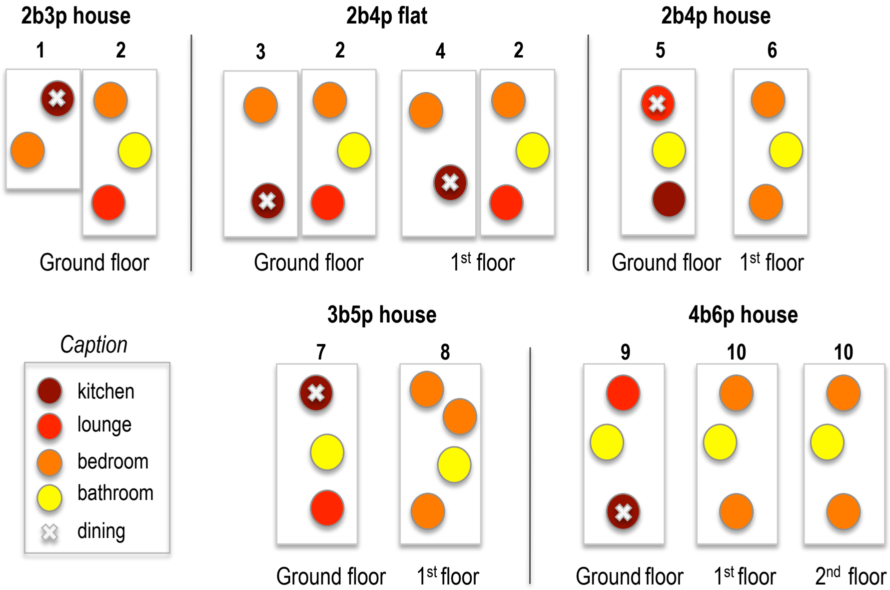

Figure 60: Floor plan of the boxes showing the location of the different rooms

Such compromises summed up with the lack of definition of the scope of alternatives 4, 5, and 6 indicate that the dwelling units is a one-off and is not limited to the five dwellings options defined by Company 3 and their internal layout. The fact that each of the dwellings unit produced by Company 3 is accompanied by a set of detailed drawings and specifications, used for guiding the production process at the factory (Figure 61) is an additional evidence that the boxes are engineered-to-order. This information would not be required if the boxes followed controlled and previously defined customisation alternatives. In that case, only a list with the options selected for each of the six alternatives (dwelling type, kitchen fit-out, bathroom fit-out, windows and doors, roofing, and cladding) would provide sufficient information for producing the dwellings according to a client order.

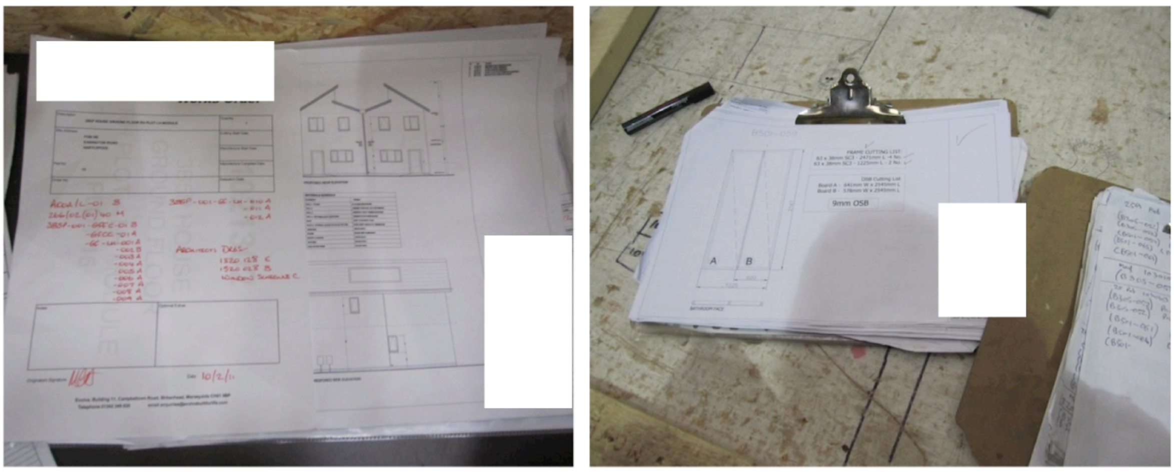

Figure 61: A set of detailed drawings and specifications used at the factory

6.1.3 Development process of a residential project

Figure 62 presents the development process of schemes using the system, from inception to delivery. Such representation does not intend to be a comprehensive representation of the process but intends to show how the decisions concerning the customisation alternatives in the course of this process. The development process starts when a registered provider supplies Company 3 with a red line drawing, defining a plot for a residential scheme. At that stage, the registered provider also states the number and types of dwelling units expected for the plot. The architectural practice that works in partnership with Company 3 generates a feasibility study, containing a master plan that outlines the number and mix of dwelling units. At that point, the architects visit the plot or liaise with planners to discuss the types of external cladding, roofing and, windows and doors that are appropriate for the region where the plot is located. Once the feasibility study is completed, it is presented to the registered provider who can eventually require alterations. In some cases, the number of units that fits in the plot is smaller than what was expected by the registered provider and the development process is terminated. It is usually difficult to increase the number of dwelling units in a scheme because they standard footprints are used.

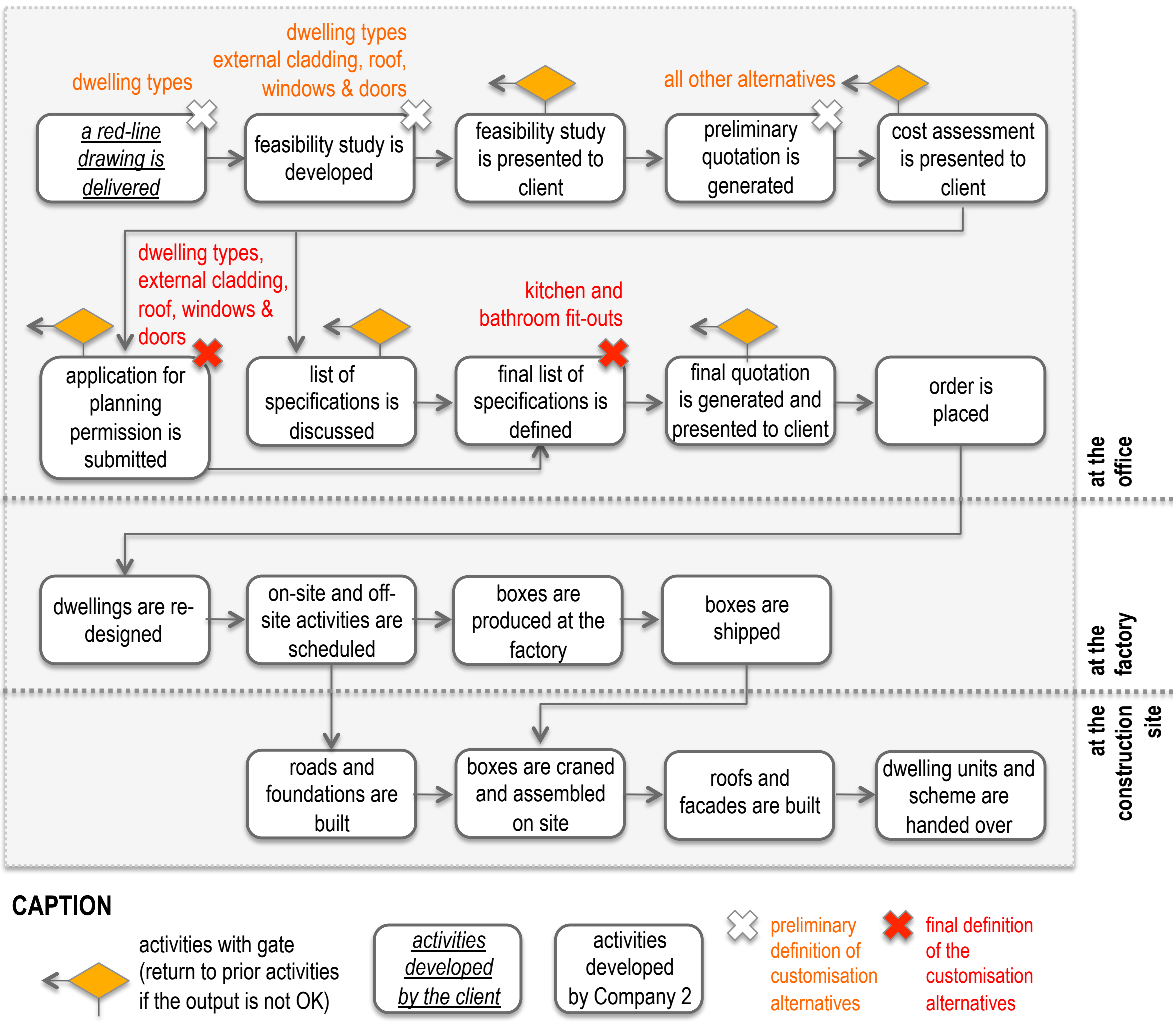

Figure 62: Development process of a residential project

Afterwards, Company 3 generates a preliminary quotation, assuming average costs in terms of roads, landscape, and foundations, and costing the boxes, external cladding, windows and doors, and roofing according to the specifications of the master plan (Figure 62). A second meeting is held with the registered provider to present the master plan and the preliminary quote. If the registered provider agrees with what is presented, the process moves forwards and a more detailed cost assessment is carried out, encompassing the ground investigation and the cost assessment of abnormalities or ground remediation that may be required. If the registered provider does not agree and asks for alterations in the master plan, mix of dwelling, or number of units, a new feasibility study is generated.

Once the client agrees with the master plan, the outline of the specification, and the preliminary cost estimate, a planning application is submitted. At that stage, the options for the external cladding, roofing and windows and doors of the dwellings are defined, as they need to be defined in the documentation submitted to the planning authorities. Parallel to the planning application, there is a series of meetings for discussing the internal specifications and the options available such as the alternatives for bathroom and kitchen fit-outs. These discussions are undertaken until reaching the final list of specifications. If the client requires a particular supplier that is not usually procured by Company 3, the necessary arrangements are made and a cost assessment is generated. Depending on the output of these discussions, other cost assessments need to be produced to address changes in the specifications eventually required by the registered provider. A final quotation in then generated, incorporating reliable information based on the ground investigation. In some situations, schemes can prove to be economically unfeasible due to abnormalities or unsuitable ground conditions, terminating the development process. Once planning permission is granted and there is an agreement in terms of the master plan, the list of specifications, and the final quotation, the order is placed at the factory and the scheduling of on-site and off-site activities is produced (Figure 62). A re-design of the dwelling units might be required if the client defines specifications that are not part of the customisation alternatives offered by Company 3. For instance, in an interview it was mentioned that in an order the layout of the boxes had to be re-design to accommodate the staircase chosen by the client. Although the layout customisation was suppose to be provided by mixing and matching the ten standard boxes, creating five dwelling types, Company 3 was accepting the clients requests for layout alterations.

As depicted in Figure 62, the points in the scheme development process in which the client needs to make decisions happen at different stages and there are no specific stages at which those decisions should be made. Company 3 does not have a systematic approach in presenting the customisation alternatives to clients and collecting the client's decision concerning these. For instance, some of the registered providers interviewed mentioned that they had to ask Company 3 for the customisation alternatives suggesting that the company has a reactive approach. Other registered providers perceived the product overall as a standardised solution. Clearly, the unsystematic approach in the customisation process adopted by Company 3 contributes to the clients' lack of knowledge concerning the scope of the customisation available.

6.1.3.1 The presentation of the customisation alternatives

Company 3 uses three main approaches for presenting the product and customisation alternatives to clients: (i) meeting with potential clients for explaining the system; (ii) distribution of a booklet with information on the system (Figure 62); and (iii) visits to the factory for showing the production process. In spite of these approaches, the information provided to clients concerning the customisation alternatives is limited. On the one hand, it can create misconceptions that the product is standardised as perceived by some registered providers. On the other hand, it does provide client with a clear understanding of the customisation alternatives that that the system is able to efficiently provide.

Figure 63 shows the description of the customisation alternatives in the booklet, which is also used in the presentations held by Company 3. Except for alternative 1, there is limited information on the range of options available for the alternatives. Even in alternative 1, there is a problem in communicating the options available (Figure 63): the bullet-points suggest that there are six options when in fact there are only five. Although the last two options refer to two dwellings, these are provided as a single product: a flat in the ground floor and another one in the first floor. The two flats should not be presented as two options because they are not independent: if the client decide for one of the flat, the two of them will be delivered. Also, the showroom available at the factory does not help in communicating the product or the customisation alternatives (Figure 64) and creates a negative image of the system. As depicted in this figure, the boxes were left without external cladding and roofing, resembling a container and not a dwelling. Moreover, the client cannot enter the boxes because of structural problems.

Client options

- *Kitchen and Bathroom Choices*
- *Fixtures and finishing*
- *Windows and doors*
- *Roofing*
- *External cladding*

Dwelling Types

- *5 house types*
  - *2b4p house*
  - *3b5p house*
  - *4b6p person house*
  - *2b3p person bungalow*
  - *2b4p person ground floor flat*
  - *2b4p person first floor flat*

Figure 63: The presentation of the customisation alternatives in the booklet

Figure 64: Boxes with scaffolding outside the factory are the showroom

6.1.3.2 The production process of the boxes

The production of the modules is undertaken in a factory, which has approximately twenty-five workstations. The factory is divided in five main areas (Figure 65): panel framing, panel assembly, boxes assembly, boxes fit out, and cutting shop. Figure 65 and Figure 66 provide a general overview of the factory layout and workstations. However, it was not possible to accurately map the activities undertaken in each of the workstations since they were varying according to daily requirements. This is because the factory was operating for a few months and the production sequence, workstations, and activities were not yet structured.

The first, second, third, and fourth areas form the main production line (Figure 65). The fifth area should be regarded as a separate one because it provides components that are fed into different workstations of the main production line. It encompasses the cutting and storage of wood elements that will be used for assembling roof, ceiling, and wall panels (Figure 66). It is the most mechanically equipped area of the factory since all workstations have machines, especially compared to the boxes fit-out area in which the activities are similar to the ones carried out in construction sites. Nonetheless, the machines in the cutting shop are not automated and the crews need to rely on paper-based drawings and specifications for preparing and controlling the activities, alike the workstations of the main production line.

The main production line starts with the assembly of floor or ceiling panels (Figure 65). First, the joists and plates are assembled, forming the frame of the panels. The service systems are installed in the panels and wood-boards are added to enclose them. The external walls panels are built in secondary workstations, adjacent to the main production line, and then assembled into the floor panel. Later, the ceiling panel is craned on to the top of the box. Once the box is assembled, the installation of finishing and fixtures take places throughout nine workstations. The boxes are sealed and then sent to the construction site. Two boxes are produced per day and the cycle-time is uneven: it ranges from four and a half hours to nine hours. No activities at the factory are performed based on forecasts but they only start if there is an order from a client.

The factory has been operating since September 2010. At the time of this investigation, it had produced three units for one project and was producing sixty-eight units for a second project. Approximately twelve units had been produced for the second order and the factory had stopped processing this batch to produce a smaller order that was placed for four dwelling units. In terms of dwelling types, the factory has produced 2b4p houses and 2b3p bungalows and was developing prototypes for the 3b5p and 4b6p houses, before producing these types of dwellings.

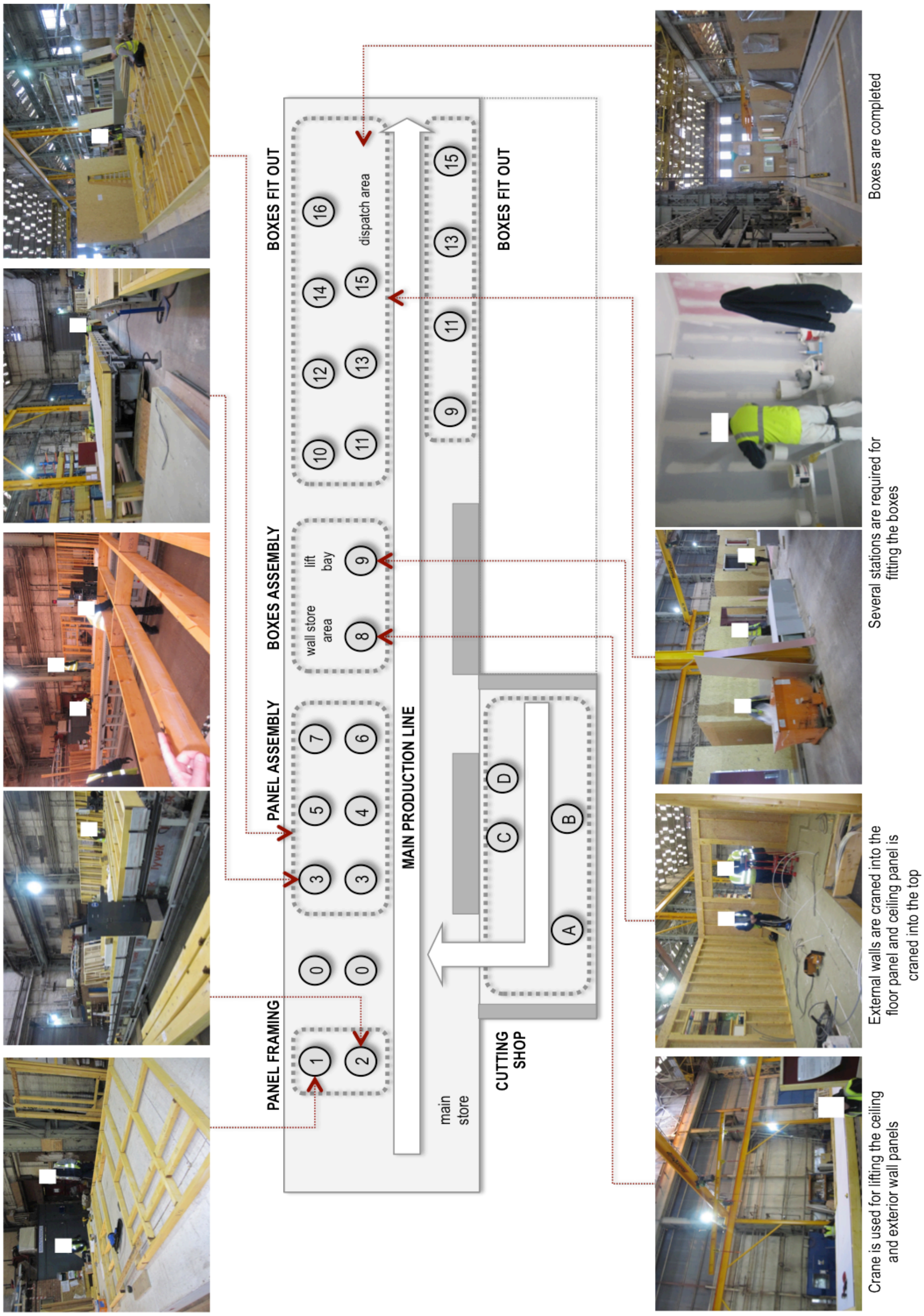

Figure 65: Overview of the main production line

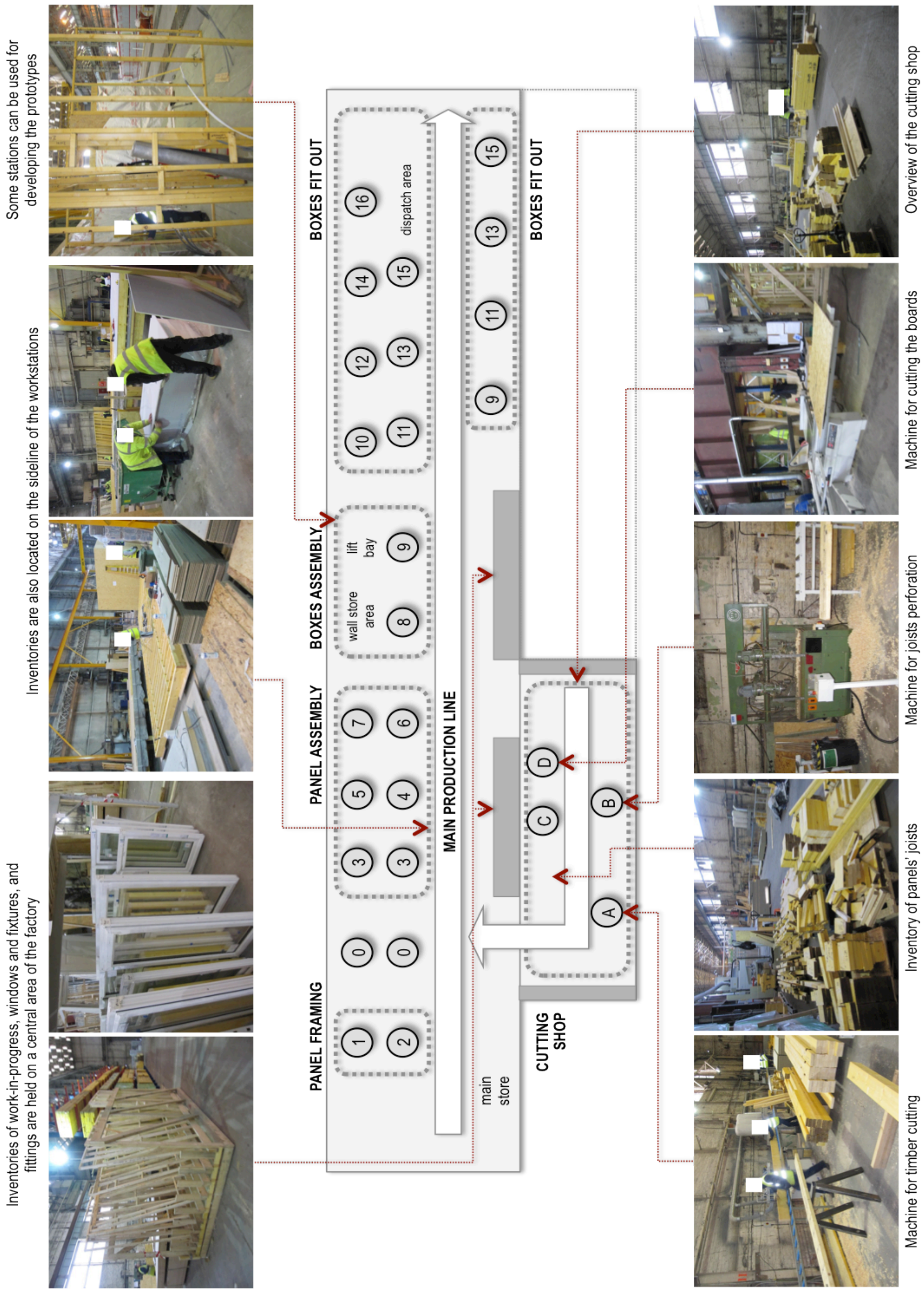

Figure 66: Overview of the cutting shop and inventories

6.1.4 Instantiation of the first version of the solution using case study 3

According to the description of case study 3, the customisation strategy developed by Company 3 entails six customisation units. All customisation units have a collaborative approach, once the clients explicitly choose the items in each of these. A summarized description of the customisation units is presented as follow:

a) Customisation unit 1 (C1): includes external cladding options such as bricks, render, and stone, among others. It is a customisation in terms of specification and form because it involves different finishing and also spatial alterations by adding gables and dormers, for instance. Because there is a not a defined range of items for this customisation unit, it is not possible to define if it is a customisation at the fabrication or assembly stage once it hinges on the items and the construction methods adopted.

b) Customisation unit 2 (C2): encompasses options of roofing. It seems to entail a customisation in terms of form and specification since different types of roof can be added. Yet, similarly to C1 it can be a customisation at the fabrication or assembly stage, depending on the items and the construction methods used.

c) Customisation unit 3 (C3): includes options of windows and doors. Alike the previous customisation units, it was not possible to define the type of customisation of this customisation because the items and scope of the alterations involved were not clearly defined.

d) Customisation unit 4 (C4): involves six options of kitchen fit-outs. Because it only involves alterations in the colours of the fit-out that are built using traditional construction methods, it is classified as a customisation in terms of specification at the fabrication stage.

e) Customisation unit 5 (C5): encompasses four options of fit-out for the bathrooms. Similarly to the previous customisation unit, it only encompasses alterations in the colour and is also defined as a customisation in terms of specification at the fabrication stage.

f) Customisation unit 6 (C6): includes five dwelling types: 2b3p bungalow, 2b4p flat, 2b4p house, 3b5p house, and 4b6p house. It is a customisation at the design stage since each dwelling has a unique layout and spatial arrangement.

In terms of the solution space, Company 3 only offers one solution space, which includes all six customisation units (Figure 67). The items in each of the customisation units need to be defined for each scheme commissioned. Furthermore, there are no differences in terms of the customisation offered for different clients, as observed in the previous studies. In case study 3, all clients have to define the items desired for all six customisation units. Because there is not a clear definition of the items and the nature of change involved in C1, C2, and C3 it is difficulty to examine the platform and OPP categories in this study. Overall, it can be argued that the OPP happens in an early stage of the value chain since C6 entails a customisation at the design stage.

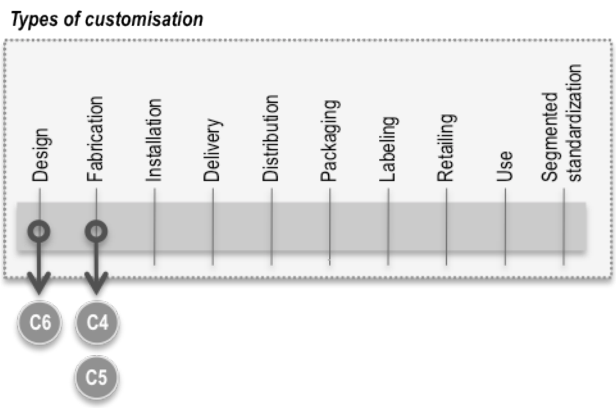

Figure 67: Customisation units and types of customisation (case study 3)

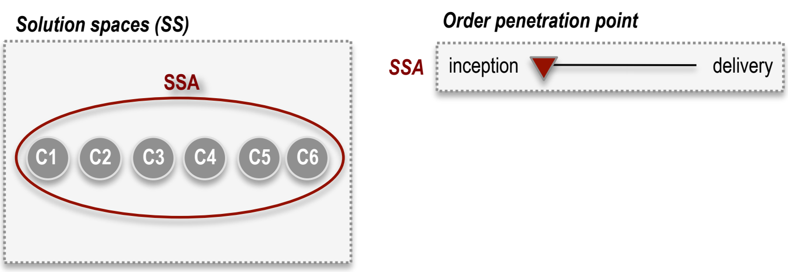

Figure 68: Customisation units and solution space

6.2 CASE STUDY 4

6.2.1 The business opportunity

This case study presents a different context for the development of a customisation strategy, compared to case studies 1, 2, and 3. In the previous studies, the customisation strategies were devised by the organisations and generally offered to external clients. In this case, the customisation strategy was devised by the consortium to be used afterwards by its members, namely the four registered providers, in developing residential schemes. The rationale for establishing the consortium was to increase the bargain power by organising the purchases of the register providers under a single framework. The consortium also defined specific goals to be met. Based on the documents elaborated by the consortium, those goals involve the achievement of predictable and consistent cost across the lifecycle of the framework agreement[45] and the gain of further efficiencies in the projects management process.

In terms of the residential schemes, the customisation strategy undertaken involves a set of standard dwelling types to be used by the registered providers across the lifecycle of the framework agreement. The set of standard dwellings would be used by the architectural practice commissioned for developing a particular scheme. This set

[45] A framework agreement is a general term of agreement with suppliers, which set out the procedures, terms, and conditions under which call-offs (specific purchases) can be made during the agreement period (OFFICE OF GOVERNMENT COMMERCE, 2006).

involves the definition of the spatial arrangement of the rooms in the dwellings but not the construction methods and specifications to be used. There are suggestions for the windows and doors sizes and positioning, but even these can be changed by the architectural practice commissioned. For those reasons, the consortium considered that the set of standard dwellings would not jeopardize the development of bespoke schemes in terms of architectural styles. Moreover, it was envisaged that a scheme could use only dwellings from the set or could also have bespoke dwelling units, designed to meet specific needs of the scheme at hand.

The set of standard dwelling types was developed considering the need to reduce the duration of the schemes development process and design fees since the dwelling units would not need to be re-designed for every scheme. The set would also eliminate the need for compliance checks in each scheme developed concerning standards, codes, and regulations for social housing. This is because the standard dwelling types had already been assessed by the architectural practices that designed them.

6.2.2 Description of the product

The set of dwellings types is divided in two sub-sets, depicted in Figure 69 and Figure 70. The first one had been developed to comply with specific standards and regulations required by the local authorities of a specific location in the northwest of England. The second one was designed to be used in schemes in other locations in the northwest of England, where those standards and regulations do not apply. As shown in Figure 69 and Figure 70, there are different kinds of dwelling in terms of the number of rooms, householders, and type of building. The house type is a two or three-story building occupied by a single household. A bungalow is a one story-building also occupied by a single household. The flat type encompasses a floor plan that can be repeatedly used for creating buildings with varying number of stories. The floor plan does not contain a staircase and assumes it will be located in an external area.

	3 persons	**4 persons**	**5 persons**	**6 persons**	**7 persons**	**8 persons**
2 bedrooms	Flat A	Flat B Bungalow A				
3 bedrooms			House A House B House C			
4 bedrooms						House D House E
5 bedrooms						

Figure 69: Dwellings types for the specific location

	3 persons	**4 persons**	**5 persons**	**6 persons**	**7 persons**	**8 persons**
2 bedrooms	Flat C Flat D	Bungalow B House F House G				
3 bedrooms			House H House I			
4 bedrooms						
5 bedrooms						House J

Figure 70: Dwellings types for elsewhere

As shown in Figure 71 and Figure 72, the set is formed by dwellings designed by two architectural practices. Architectural practice 1 developed most of the dwellings, using a standard front-to-back depth, indicated by the dashed lines in those figures. Although parts of some dwelling units such as gables and bay windows trespass the lines, their core part is still limited by those lines. This standard dimension was used because it facilitates the combination of the dwellings and the design of roofs covering two or more dwelling units. It enables the roof design to be simple, without intricate details. Only the flat developed by Architectural practice 1 does not follow the standard front-to-back depth, since it was designed to be used separately from the other dwelling types. And, for that reason, do not need to be constrained by a standard depth. A few dwelling units developed by Architectural practice 2 did not follow the standard front-to-back depth either. This further reinforces the findings that the set of dwellings was not devised by the consortium considering particular goals and seems to be a pool of the dwellings types preferred by each of the registered providers.

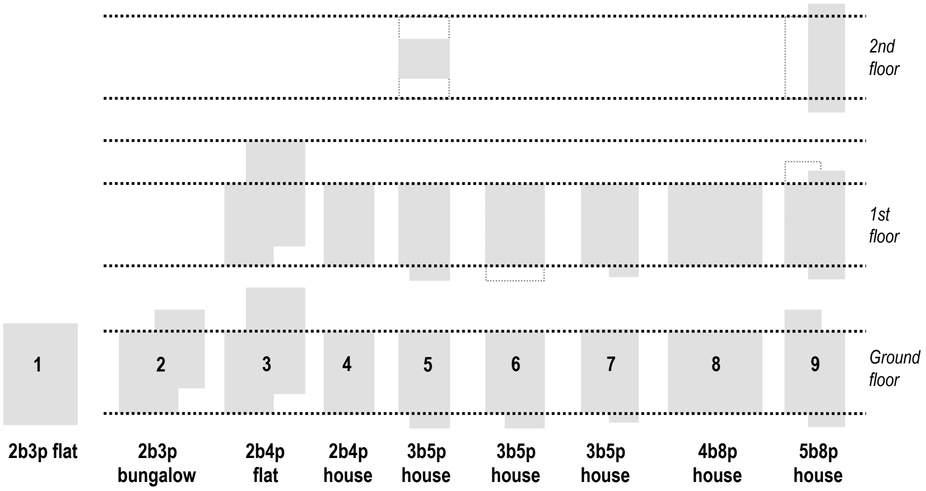

Figure 71: Footprint of the dwellings types for the specific location

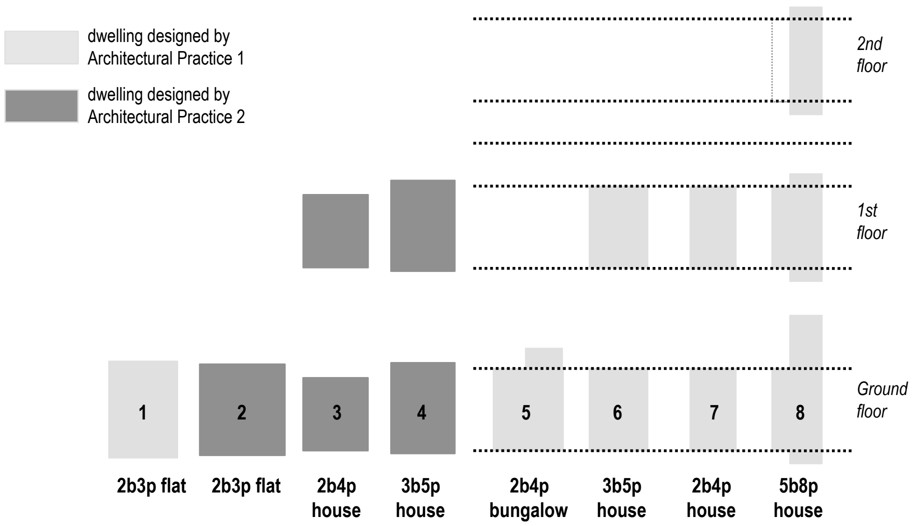

Figure 72: Footprint of the dwellings types for elsewhere

6.2.3 Instantiation of the first version of the solution using case study 4

Two customisation units form the customisation strategy developed by the consortium. The consortium adopts a collaborative approach since the registered providers explicitly chooses the items within each customisation unit:

a) Customisation unit 1 (C1): includes nine sets of floor plans for nine dwelling types that comply with specific standards and regulations for social housing required by the local authorities of a particular location in the northwest of England. It is a customisation at the design stage because each dwelling type has a unique layout and spatial arrangement.

b) Customisation unit 2 (C2): includes eight sets of floor plans for eight dwelling types that can be used in schemes in the other locations in the Northwest of England. It is also a customisation at the design stage because each dwelling type has a unique layout and spatial arrangement.

The customisation strategy has two solution spaces with one customisation unit in each of these (Figure 73). This is because a scheme would use floor plans from one customisation unit or the other, depending on its location. The only commonality within the customisation units and across the two solution spaces (SSA and SSB) is the dwellings units' front-to-back depth (AB') that is shared by both customisation units. Regarding the OPP, it is located in an upstream position, since the customisation of the units happens at the design stage.

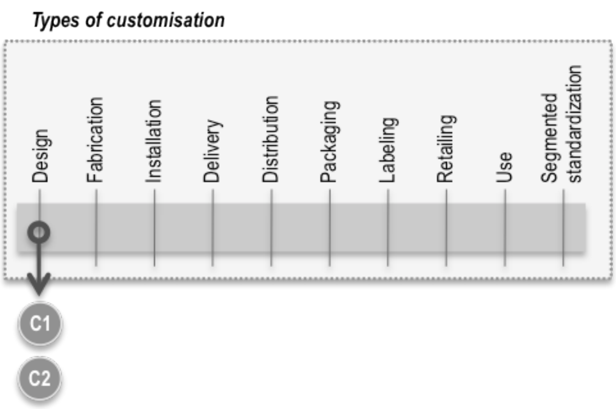

Figure 73: Customisation units and types of customisation (case study 4)

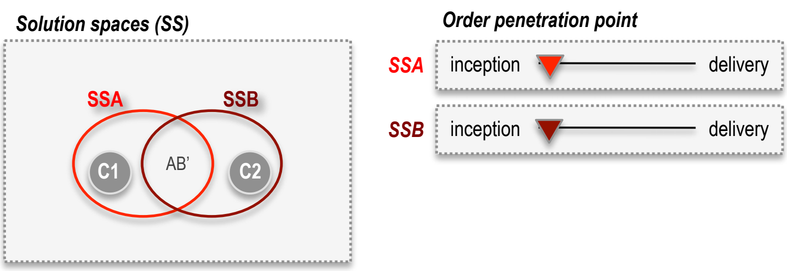

Figure 74: Customisation units and solution spaces (case study 4)

6.3 ASSESSMENT OF THE FIRST VERSION OF THE SOLUTION

The findings of the four case studies and the instantiations of the first version of the solution using those studies enabled the identification of key points that guided the development of the second version of the framework. Figure 23 presents the points that emerged from (i) the four instantiations and the discussions that were carried out with the organisations involved in the studies and (ii) insights that emerged from the data gathered, using the hierarchical structure[46], that were not addressed by the first version of the solution.

	Points that emerged from the framework and instantiations	**Points that emerged from the data gathered**
Case study 1 Case study 2	Platform and order penetration point categories hinge on decisions on other categories and for that reason could be improved.	-
Case study 2	-	In case study 2, C5 has particular features, which makes it different from the other customisation units.
Case study 2		There is a sequence for selecting the items in the different customisation units forming a solution space.
Case study 3		In case study 3, C6 has particular features, which makes it different from the other customisation units.
Case study 3	-	The lack of definition of the scope of the customisation has negative implications in the company's processes.
Case study 3	-	Misconception of product modularity and its underpinnings has negative implications in a customisation strategy.
Case study 3 Case study 4	There are difficulties in applying the platform and the order penetration point categories in case studies 3 and 4.	-

Figure 75: Limitations of the first version of the framework in the case studies

The instantiations using case studies 1 and 2 revealed that all decision categories, except for the platform and the OPP categories are relatively independent from each other. In a way, the decisions in those two categories seem to be highly dependent on the decisions taken in the previous ones. For instance, there is not a specific decision concerning the platform extent. Based on the definition proposed for this category in the framework, it is defined as the product part that remains unchanged in the different product variants available in a solution space. Once the customisation units and the solution spaces are defined, the platform is also defined. Likewise, once the types of customisation are assigned to the customisation units and they are organised in solution spaces, the order penetration point for each of these is almost defined. Their positions can vary slightly depending on the sequence of activities used for providing the customisations within that solution spaces. It is recognised that a decision in one category has implications over the decision in others. Yet, the decision concerning each of the categories should be taken by the organisation. It should not be entirely defined by the decisions taken in the other categories, otherwise it would not a decision category but only the by-product of other decisions. The

[46] The hierarchical structure, described in chapter 4, was used for organising the data collection and analysis in the four case studies. It encompassed three levels: (i) the business opportunity, (ii) the decision categories, and (iii) the product development process, practices, and products.

difficulty in applying those categories in case studies 3 and 4 further reinforced the need to review them in the second version of the framework.

In case study 2, the customisation units were described as dependent or independent, introducing the idea that there is a sequence in selecting the items in the different customisation units within each solution space (Figure 23). The decision categories developed so far were able to map the scope of the customisation strategy but did not provide an overview of the sequence of decisions. In case study 2, C5 that entails the customisation of the internal layout and the specification of a dwelling unit seems to differ from the other customisation units used in that case study (Figure 23). The study description also revealed that C5 had considerably more implications in the organisation' processes and practices than the other customisation units, requiring specific groups of practices to support it. In case study 3, C6 also had peculiar features that were not addressed by the decision categories: the client could choose one or all items and also define the amounts for each item. For instance, the client could define a scheme with two 2b3p bungalows, one 2b4p house, and six 3b5 houses. Such customisation unit is different from the others used in that case study since the client can select more than one item. In the other customisation units in case study 3, the client can select only one item. For instance, in *C4 – kitchen fit-out,* the client will not be able to select two types of fit-out for the same kitchen. Those findings suggested that a category that expresses the different features of the customisation units could be devised in the second version of the framework.

The description of case study 3, based on the hierarchical structure, indicates that Company 3 had problems in defining the scope of the customisation units (Figure 23). This creates difficulties in communicating the customisation to clients and also causes drawbacks in the production process, as discussed in section 6.1. Yet, those findings emerged from the case study findings and were not addressed by the decision categories. The framework did not provide a basis for understanding and critically examining this customisation strategy. For that reason, the instantiation of the first version of the framework using case study 3 was not presented to Company 3. The description of case study 3 according to the hierarchical structure also shown a misconception held by Company 3 in terms of what is a module and the features that it should have for the product design to achieve the benefits of a modular architecture (Figure 23). Although the first version of the framework had the platform category, it was not able to address the problems identified in this study. This suggested that such category could be improved and expanded.

The examination of case study 4 using the first version of the framework provided an instantiation that addressed some critical points of their customisation strategy and, hence, was presented to the consortium. Nonetheless, as in case study 3, it was considered that such instantiation could be improved by incorporating decision categories related to the product architecture.

6.4 THE SECOND VERSION OF THE SOLUTION

This section describes the five new categories proposed in the second version of the framework: (i) classes of items; (ii) configuration sequences; (iii) modules; (iv) module combinations; and (v) module interfaces. It also presents the modifications of the order penetration point category, which was initially proposed in the first version of the framework. Figure 76 depicts the relation between the categories proposed in the second version of the framework and the ones used in the first version.

1st version of the framework	2nd version of the framework	Rationale for the new category
Customisation units	Customisation units	(Remains unchanged)
Solution spaces	Solution spaces	(Remains unchanged)
Types of customisation	Types of customisation	(Remains unchanged)
Visualization approaches	Visualization approaches	(Remains unchanged)
-	Classes of items	Expresses the particular features of the customisation units
-	Configuration sequence	Addresses the sequence of decisions concerning the items
Order penetration point	Order penetration point	Addresses the limitations identified in the instantiations
Platform	Modules	Incorporate the product architecture theoretical background
	Module combinations	
	Module interfaces	

Figure 76: The decision categories in the first and second version of the framework

Customisation units, solution spaces, visualisation approaches, and types of customisation remain unchanged (Figure 76) since they were useful in examining and understanding the customisation strategies in the four case studies. The classes of items category aims to describe the particular feature of some customisation units, observed in case studies 2 and 3. The configuration sequence category is concerned with the order that the decisions concerning the customisation units forming a solution space should be taken. The order penetration point category aims to address some limitations identified in the instantiations using the first version of the framework. The modules, module combinations, and module interfaces categories aim to incorporate the product architecture theoretical background into the framework. They expand the platform category devised in the first version of the framework (Figure 76). The six categories proposed in the second version of the framework are presented in more detail in the following sections.

6.4.1 Classes of items[47]

This decision category was developed to express the different properties of the customisation units based on the items contained in them. Unlike the previous categories, this category is not based on the existing theoretical background related to mass customisation, but was devised in order to address the limitations encountered in analysing the customisation strategies in the case studies. The items contained in a customisation unit can be organised in five classes: (i) binary items, (ii) categorical items, (iii) ordinal items, (iv) discrete items, and (iv) metric items.

[47] The underlying notion proposed in the classes of items build upon the types of variables or scales of measurements studied by Statistics.

A customisation unit with binary items occurs when it is: (i) formed by two and only two items; and (ii) one of these items indicates the acceptance of the customisation unit under consideration while the other indicates its refusal. For instance, some computer manufacturers offer extended warranties for their products. Extended warranties can be an example of a binary customisation unit because clients have to decide they want this customisation unit (the warranty) or not. If there is more than one type of warranty, these can be displayed as items in another customisation unit to be presented subsequently. In that situation, the customisation unit with the different types of warranty is only presented if the client has previously accepted the binary customisation unit. In general, a customisation unit with binary items is followed by a customisation unit with categorical, ordinal, discrete or metric items.

A customisation unit with categorical items happens when the items have no-numerical meaning or intrinsic ordering. For instance, the colours, blue, green, and yellow in a customisation unit are examples of categorical items. A customisation unit with ordinal items occurs when the items have no-numerical meaning but have an intrinsic ordering. A customisation unit with items entailing different sizes (small, medium, and large) is an example of such class of items.

A customisation unit with discrete items happens when the items are quantifiable, have a numerical meaning and have a space between them if a line is draw and the items are numerically placed in it. For example, in a modular system of kitchen cabinetry, it is possible to combine different number of cupboards, creating several combinations. Nonetheless, the combinations will encompass entire numbers: a cabinetry can have 1, 2, 3 or 4 cupboards, and so on, but not 3,1376 cupboards for instance.

A customisation unit with continuous items occurs when the items are quantifiable, have a numerical meaning, and there is no space between the items if a line is draw and the items are numerically placed in it. For instance, a candy shop where the client serves himself and is charged based on the candy weight is an example of a customisation unit with continuous items. The items in this unit can assume any value, differently from a customisation unit with discrete items that have an interval between every two items. The manufacturing of garments based on 3D-body scans is another example of a customisation unit with continuous items.

Besides the five classes of item, there are two additional types of items that can happen in a customisation unit: the “other” and the “none” items. The “other” item enables clients to specify the desired item, within the attribute addressed by the customisation unit under consideration. For example, in some paint shops there is a pre-defined range of colours to be selected. Alternatively, the client can specify a particular mix of pigments creating a bespoke colour. This option is defined as the “other” item. If a customisation unit has the “other” item, it is described as open since it entails a limitless number of items; if not, it is described as closed. In some cases, a customisation unit might have only the “other” item. For instance, if no pre-defined range of colours was offered in the previous example but only bespoke colours were produced.

The "none" item stands for the non-acceptance of any of the items offered in a particular customisation unit. It is similar to a unit with binary items since it involves the client refusal of a customisation unit. Consider a window manufacturer, which offers a customisation unit involving options of colours as finishes for windows. If the "none" item is available it means that the client can either select one of the pre-defined colours or keep the windows plain, without any colour finishing.

Figure 17 presents four quadrants to illustrate the use of the "none" and the "other" items in the five classes of customisation units (binary, categorical, ordinal, discrete, and continuous). This investigation holds the hypothetical assumption[48] that the "other" and the "none" items can occur separately or jointly in any of the five classes, apart from two exceptions. The exceptions are the binary and the continuous items. Customisation units with binary items have a strict definition: they are always closed, since they must have two and only two items, and they always have the "none" item. Because of that, only the second column in Figure 17 meets this definition. The other exception is the customisation unit with continuous items. Because it is impossible to foresee and present infinite values as a range of items for the client to select from, these units entail either (i) only the "other" item or (ii) only the "other" and the "none" items. In other words, it is unlikely that a pre-defined range of items is presented in customisation units with this class of items.

	Without the "other" item (closed)		**With the "other" item (opened)**	
	Without the "none" item	**With the "none" item**	**Without the "none" item**	**With the "none" item**
Binary	-	yes or no	-	-
Categorical	Blue or green	Blue, green, or "none"	Blue, green, or "other"	Blue, green, "none" or "other"
Ordinal	S or M	S, M, L, or "none"	S, M, L, or "other"	S, M, "none" or "other"
Discrete	1 or 2	1, 2, 3, or "none"	1, 2, or "other"	1, 2, 3, "none" or "other"
Continuous	-	-	only "other"	only "other" or "none"

Figure 77: Examples of the "other" and the "none" items in the five classes

It could be argued that the "none" item would not be necessary in customisation units with discrete or continuous items because there is the value 0, that embodies the semantic of such item. Nonetheless, the implications that the value 0 has in terms of the customisation strategy are different from values such as 1, 2, 3 and so on. The value 0 implies that the organisation should be able to not produce or realise a customisation unit, which is different than producing different amounts of items. In fact, the "none" item conveys the idea that the organisation is able to reduce the client's sacrifice, in case the client does not want to a particular customisation unit. Consider the following hypothetical example: in a residential development, the client can define the function for a spare room of the apartment, as a third bedroom, a playing area, or an office. The "none" item is incorporated in such customisation unit if the client is presented with the option of not having this spare room in the apartment, yielding a reduction in the dwelling area and its cost.

[48] The term hypothetical used in the sense that it is logically possible to have these combinations, although they may be unlikely to happen in the real world.

When the “other” and “none” items are adopted in a customisation unit they modify the nature of change embedded in such a customisation unit. When the “other” item is adopted in a customisation unit, it is not possible for an organisation to foresee and anticipate the items that can be selected in that particular customisation unit and the organisation should be prepared to cope with a limitless number of items. If the “none” item is adopted, the organisation should be prepared to not deliver that specific customisation unit. Overall, customisation units with the “none” and “other” items are likely to be more difficult to manage than customisation units without them since the organisation should be prepared to not deliver that specific customisation unit and also to cope with unlimited items.

In this category, when a customisation unit is described as more difficult to manage than another, this is based only on the customisation unit and the properties of the items contained. It does not consider the interfaces and technologies used in the customisation process, for presenting the customisation units to the clients, for processing the desired combination of items, or for manufacturing the product variants. Clearly, those interfaces can amplify or reduce the implications that the customisation units (and the properties of the items contained in these) have over a company’s processes. An example is the 3D body scan and CAD/CAM systems for producing garments. It entails a customisation unit, that involve continuous items with only the “other” item since the clothes will be made according to bespoke body measurements. Yet, due to the technology adopted, the properties of the items have a limited impact on the production process: it is not more difficult from a production perspective to manufacture a standard or a bespoke garment. A similar situation could happen in the construction industry if a CAD/CAM system could automatically process the information concerning bespoke dwellings and manufacture these. Nonetheless, the analysis of the customisation units using the classes of items category can assist an organisation in understanding the nature of the items and the implications that they will have over its processes.

6.4.2 Configuration sequences

This category is concerned with the sequence of decisions adopted for defining a product variant[49]. Although this category is especially important when using customisation units that are presented using with a collaborative approach, it is also important even when all customisation units are presented using a transparent approach. Analysing the configuration sequences enables an organisation to establish the chain of decisions concerning the customisation units, even if this is followed by the organisation in defining the product variants according to the clients’ requirements.

Figure 78 shows the graphic notation that has been used for representing this category. There are three key elements: tree, branches, and number of levels (horizontal and vertical). A tree represents the sequence of decisions for creating a product variant. In the hypothetical example presented in Figure 78, the client needs first to define the item in customisation unit X (CX), and later define the items in customisation unit W or customisation units Y (CY) and Z (CZ), depending on the decision on the first level. The horizontal and vertical levels express

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[49] A product variant is generated when the items in all customisation units forming a solution space are defined.

the interdependency among the customisation units. The horizontal level is concerned with the number of branches that one needs to go through until making all the necessary decisions for creating a product variant. As illustrated by Figure 78, the decision in branch 1, concerning CX, has to be done before the decision in branch 2.1, concerning CW. The vertical level is concerned with the number of customisation units that need to be considered in each branch. If a branch contains two customisation units, such as branch 2.2 in Figure 78, it means that the decisions concerning those units does not need to follow a particular order and can be done in parallel. As illustrated in Figure 78, each branch has a particular number of vertical levels: branch 2.2 has two vertical levels, whereas branch 1 and branch 2.1 have only one vertical level. A main difference between the horizontal and vertical levels is that the former indicates the sequence of decisions to be followed whereas the latter does not indicate a sequence but the amount of customisation units that need to be considered simultaneously at each branch.

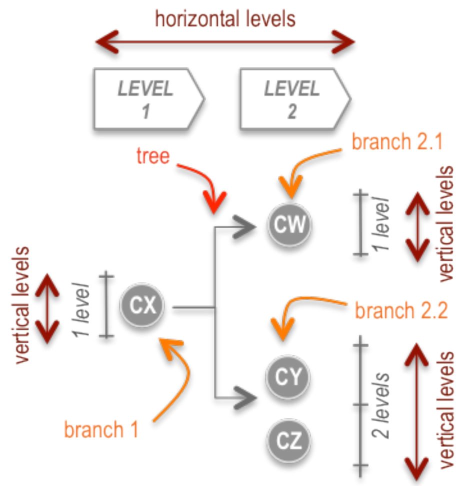

Figure 78: Graphic notation for the configuration of the sequence category

Considering the four elements that form this category, four hypothetical types of configuration sequences are proposed (Figure 79). They are defined as hypothetical because they might not exist in the real world, but illustrate the implications that distinct decisions concerning the dimensions can have in the configuration sequences. Also most configuration sequences in the real world cannot be strictly categorised as one type or the other, but as a combination of those types. Type 1 involves only one customisation unit, implying that there is only one vertical and horizontal level (Figure 79). This is the simplest configuration sequence. Type 2 has several horizontal levels but only one customisation unit to be considered at each level (Figure 79). The advantage of this type of configuration sequence is that the decision process is simple because it only involves one customisation unit at the time. Its drawback is the fact that clients might not have an overview of the scope of the customisation at the outset once it is gradually communicated as they go through the configuration process. Type 2 is appropriate when there is an interdependency or hierarchy among the customisation units. In those cases, sequentially presenting the customisation units facilitates the configuration process. This would be appropriate for the extended warranties example, in which first the binary unit concerning the warranty is presented and only if the client accepts it, the customisation unit related to the types of warranties is presented.

Type 3 has a single horizontal level and several vertical levels (Figure 79). In this type, the client has to consider several customisation units at the same time. The advantage is that the client can have an overview of the scope of the customisation offered and also go back and forth in defining the customisation units until reaching the desired product variant. Nonetheless, this process can be time consuming and perceived as difficult by the client. Finally, type 4 would be a combination of the types 2 and 3 in which there are several levels, each one with several customisation units to be considered. This configuration sequence may present a challenge to clients in configuring product variants since there are several horizontal levels to be considered with several customisation units in each of those levels.

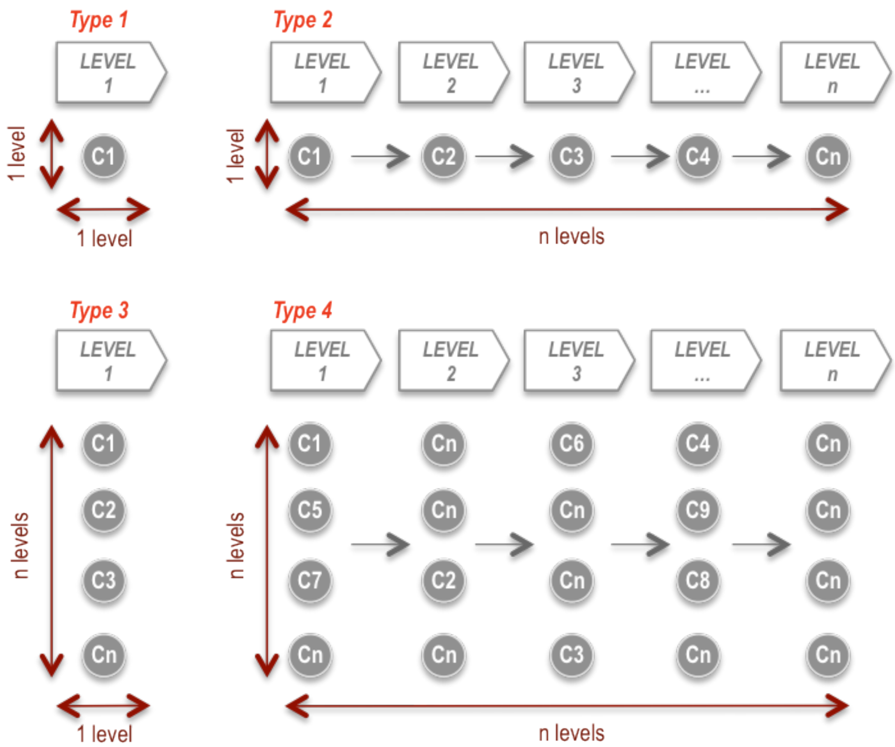

Figure 79: Four types of configuration sequences

6.4.3 Order penetration point

As described in the first version of the framework, the order penetration point category is concerned with the point in which the client order first enters the value chain. A major contribution of this decision category as conceptualised in the first version of the framework is that the position of the order penetration depends upon the customisation units and their types of customisation forming each of the solution spaces. An underlying assumption in comparing the OPP of different solution spaces is that, usually, the closer this point is from the product inception, the higher the degree of the customisation involved and also the difficulties in managing the processes that provide such customisation. Nonetheless, such conceptualisation has some limitations. For instance, when this category was used in case study 2, the instantiation generated indicated that solution space C (SSC) and solution space D (SSD) had similar OPPs position, indicating that those solution spaces had similar implications in terms of the production process, which was not correct. Yet, as discussed in section 5.2, SSD has far more implications over the production process compared to the other solutions spaces, since it entails *C5 – customisation of layout and specifications*. In fact, Company 2 had to developed several practices related to several activities to support such customisation unit.

A major change introduced in this category in the second version of the framework is to analyse the set of activities developed by an organisation in providing a customised product, from inception to completion, and to identify the activities that are impacted by customisation. This impact can be graphically represented by marking the activities that are affected by one or more customisation units (Figure 80). This representation also shows the order penetration point, as defined in the first version of the framework: it is the point in which the client order first enters the value chain. In other words, it is the first activity within the set of activities deployed for providing a customised product, in which information concerning the customisation is needed for performing a particular activity. For instance, if there is a customisation in terms of the labels of a product, the manufacturer should have the information concerning the desired labels at the labelling activity. Mapping the activities affected by the customisation provides an overall understanding of the implications that the customisation units have over the activities involved in providing customised products, instead of identifying a single order penetration point.

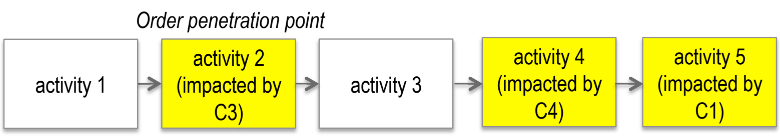

Figure 80: Graphical notation for the order penetration point category

In this category, an activity is defined as affected by the customisation if it requires information about the select items to be carried out. An activity is defined as directly affected when it entails the production of an item offered in a customisation unit. For instance, the work package involving the installation of floor tiles is affected if there is a customisation unit involving different options of tiles. It is indirectly affected, when the information about the item selected is needed in one or more work packages for supporting the realisation of the work package directly impacted. Consider the previous example. If different types of mortar are required for preparing the surface for the different tiles options, the work package that entails the preparation of the surface is indirectly affected by the customisation. If an activity is affected (directly or indirectly) by customisation it means that such an activity should be performed based on demand and requiring information concerning the items selected. Conversely, if an activity is not affected it means that it can be performed based on forecast, namely, without information concerning the items selected in the customisation units.

In order to analyse the activities affected by customisation, it is necessary to first identify how the activities undertaken to provide a customised product are organised. They can be organised, for instance, in terms of the work packages in a line-of-balance or workstations in a factory. Clearly, the set of activities that should be considered in this category will depend on the types of customisation involved in a solution space. For instance, if the types of customisation are related to the customisation of the physical parts of the product than the focus should be on the activities that form the production process. Differently, if the customisation is related to the services surrounding the physical goods such as retailing or distribution than other activities should be considered.

Based on the number of activities affected by customisation, a metric can be used for roughly assessing the impact of customisation (Formula 3): the percentage of activities affected by customisation (PAC). This assessment can provide the basis for modifying the position of the OPP or the organisation of the set of activities that provide the customised product in order to meet particular goals such as a delayed product differentiation, for instance. Alike the order penetration point, each solution space is likely to have a specific PAC since it hinges on the customisation units embedded in it. Clearly, the PAC provides an indication of the implications that the customisation units have over the activities: as the amount of activities affected (over the total number of activities), so do the difficulties in managing those activities. Nonetheless, it should be noted that the PAC is an indicator and can be changed by re-defining those activities and the way they are organised[50]. Also, some activities can be more or less critical than others and this is not reflected by the PAC. For those reasons, it is important to analyse the implications that the customisation units have over the activities rather than simply apply the indicator. Also, the PAC is dependent upon the specificities of the activities involved in providing a customised product and how those activities are organised. Hence, only solutions spaces that use a same of set of activities for providing the product variants can be compared in terms of their PACs.

$$PAC = \frac{\text{Number of activities affected}}{\text{Total number of activities}}$$

Formula 3: Percentage of activities affected by customisation (PAC)

6.4.4 Modules

In this category, modules are conceptualised as the product parts that are combined in different ways for creating product variants. Considering this conceptualisation, a platform is a particular type of module that accounts for a considerable part of a product and that remains unchanged within the set of product variants provided in a solution space. The conceptualisation of modules adopted in this category differs from the definitions of module or modular architecture proposed by Ulrich (1995), Muffatto (1999), Clark and Baldwin (1997), and Pahl *et al.*

[50] This is similar to the problems encounter with the performance indicator, percentage of plans completed (PPC), used in the Last Planner System of Production Control.

(2007), which have two underlying aspects: (i) a modules is a set of components consistent as a sub-assembly (ii) that have some degree of independence from other modules. Such conceptualisation was adopted for this category because it can be more readily used in analysing product architectures in the context of customisation strategies. In such a context, the role of a modular architecture is to provide customisation by mix and matching a number of standard modules in different combinations. Hence, it seems adequate to define what constitutes a module based on the product variants offered in a customisation strategy. Also, by adopting such a conceptualisation, the problems of defining (i) the degree of independence or decoupling among modules, and (ii) the hierarchical level adopted in a product architecture[51] are separated, which is appropriate since those problems refer to independent notions. The former is addressed by the module interfaces categories, whereas the latter is addressed by the modules category.

Since this category is concerned with the hierarchical levels forming a product architecture, it is important to define two key perspectives that can be adopted when devising or analysing the product architecture of buildings. A product architecture can be viewed in terms of its physical parts (from a components perspective) or in terms of the spaces created (from a spatial perspective). Such perspectives address the two fundamental types of parts[52] that form a building: spatial voids and physical mass. Those two types are parts are defined as fundamental parts since a built environment cannot exist without both of them: the physical mass is necessary for creating the spatial voids and, conversely, the physical mass is worthless if is not configuring a space or fostering its use by people.

Different hierarchies can be created under the spatial or the components perspectives, as illustrated by Figure 81 and Figure 82. In fact, a limitless number of hierarchies can be devised within each of those perspectives. A building can be organised in different hierarchies depending on the objectives of the project at hand. Also, different hierarchies may be necessary at the different phases of a project development process. For instance, during the concept development, the functions of a building can be grouped under zones such as wet and dry areas, whereas in the detailed design those groups need to broken down in terms of rooms and their sub-functions. Finally, different professionals such as structural designer, air conditioning designer, electrical service designers, and architects are likely to devise distinct hierarchies depending on their understanding of a building or their design process.

In those hierarchies, two types of functions should be highlighted: primary functions and secondary functions. Primary functions are the functions performed by people in the spatial voids. In the context of residential buildings, the primary functions can be grouped, for instance, as bedroom, living room, bathroom, as illustrated in Figure 81. For instance, in the case of a bedroom, it should enable the core sub-functions such as reading, sitting, writing, sleeping, and watching TV to be carried out. Secondary functions are necessary for the spatial

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[51] According to Salvador *et al.*, (2002), Fixson (2005), and Salvador (2007), a product architecture has several hierarchical levels and the unit of analysis to look at when analysing or devising a product modularity needs to be clearly defined.

[52] This builds upon the ideas of spatial void and solid mass used by Ching (2007) for discussing composition principles in architecture.

voids of a building to exist and to provide a suitable environment for the primary functions to be carried out. Secondary functions are usually performed by the physical mass of a building. For instance, the loads support function is fulfilled by the structural system of a building. In fact, a wide assortment of interconnected components is required to create spaces that enable people to perform the primary functions comfortably and adequately. In the case of a bedroom, for example, a floor, a ceiling, and walls are needed for creating this space. It is also necessary to have windows and doors to control the entry of agents (weather, persons, insects) into the space to create a comfortable environment. It is also necessary to have building services, such as electricity, cable TV, and fixtures and finishing. Furniture such as a bed, a shelf, a desk, a chair are also necessary to enable the primary functions to be adequately carried out.

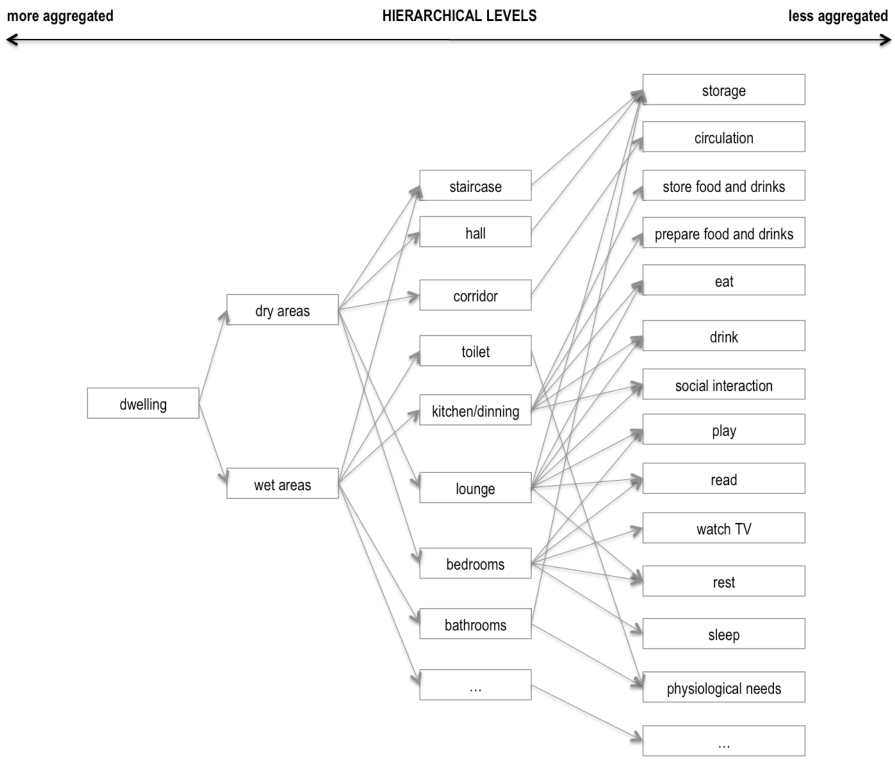

Figure 81: A hierarchy based on a spatial perspective

Conceiving a modular architecture in which the modules are organised around primary functions can be difficult. A central problem in devising such an architecture is that usually there is not a direct correspondence between the physical parts and the spatial parts forming a building. For instance, a wall (physical part) may be associated to two rooms (spatial parts). Furthermore, a one-to-one correspondence between the primary functions and the physical parts, which will create the space for those functions to be carried out, is necessary. Consider a modular architecture with three modules, (each of them is a room) which can be combined two by two. If for each two rooms that are combined there is a single wall, the modules cannot be produced as independent entities prior to the client order since they can only be built once the combination of modules is defined. This exemplifies a many-to-one correspondence between functional elements and physical components discussed by Ulrich (1995)[53]: the functions of two rooms are allocated in a single physical part, which is not a suitable organisation for a modular architecture.

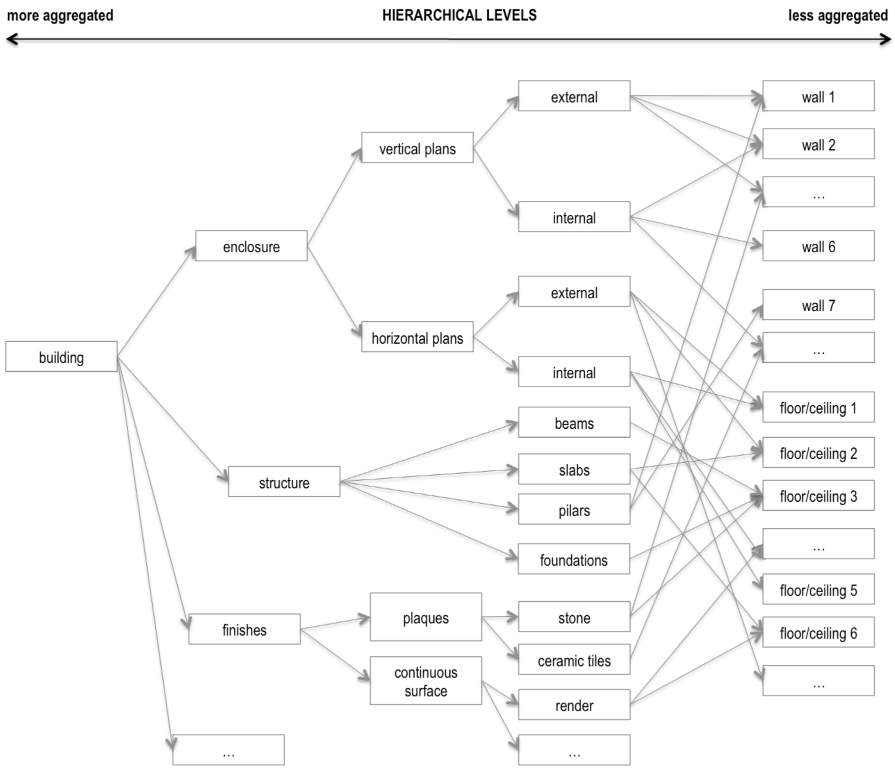

Figure 82: A hierarchy based on a components perspective

A modular architecture can also be conceived around secondary functions, which are performed by the physical parts of a building. Those functions are usually performed by a more defined set of components than the primary functions. Consider for instance the structural function. It is performed by columns, slabs, beams, and foundations of a building. Alike, the enclosure function is performed by walls, floors, and ceilings. Hofman *et al.* (2009) provides an example of a product architecture organised around secondary functions. It involves modules for the columns and exterior walls and modules for the floor, which are available in three sizes. In such product architecture, different buildings are created by mixing and matching the floor modules, creating different footprints, and combining them with the columns and exterior walls modules.

6.4.5 Module combinations

This category focuses on how the modules in a given product architecture are combined for creating the product variants. Alike the previous category, this one is concerned with the product architecture and how it relates to a customisation strategy. The combinations of modules can be undertaken by the organisation or by the client. In the former, the organisation only presents the product variants, which have pre-defined combinations of modules,

[53] Ulrich (1995) also proposes the one-to-many allocation of functions into physical parts.

for the client to select from. Thus, the client is not involved in combining the modules. In the latter, the client creates his own product variant by mix and matching the different modules. In such situation, the configurations rules, namely guidance on how the modules should be combined, should be clearly presented in order to avoid inadequate product variants to be created.

By analysing the module combinations used in the product variants, it is possible to calculate the reuse of modules across and within the product variants, which contributes in creating economies of scope. This is measured by the modules reuse index (MRI) that is the ratio between the reuse of modules over the total number of modules used in a product architecture (Formula 4). The total number of reuses is the sum of the reuse of each module within a product variant and across the product variants. For example, if module X is used two times and module Z is used three times in a product architecture, the total number of reuses is five (two plus three).

$$\text{MRI} = \frac{\text{Total number of reuses}}{\text{Total number of modules}}$$

Formula 4: Modules reuse index (MRI)

Analysing the module combinations also lays the basis for evaluating the extent that a delayed product differentiation approach can be pursued in a customisation strategy, from a product design perspective[54]. Overall, this approach is supported in terms of the product design if there is a high MRI. In such product architecture, a large number of product variants is created using a limited number of modules, favouring the production of these modules based on forecast since it is likely that they will be used in an upcoming order. Conversely, if each product variant in a product architecture uses a particular set of modules and there are no reuse of modules across the product variants, it might not be feasible to produce all these modules based on forecast. Clearly, the degree of physical independency between interacting modules, addressed by the module interfaces category, also plays an important role in supporting a delayed product differentiation approach.

6.4.6 Module interfaces

Module interfaces are concerned with the physical connections among interacting modules (ULRICH, 1995). It expresses the degree of physical independence between modules and where the product architecture under consideration is placed within the continuum between modular and integral architectures. The literature on modular architecture states that the interface between interacting modules should be decoupled or that the modules should have some degree of independence (ULRICH, 1995; MUFFATTO, 1999; CLARK, BALDWIN, 1997; PAHL *et al.*, 2007). Such conceptualisation is abstract and provides limited guidance for devising a modular architecture. Hence, a pragmatic conceptualisation and that is also suitable for devising or analysing the architecture of products of the built environment is proposed for this category. An interface is defined as loosely

[54] A delayed product differentiation approach requires an adequate product design but also a production process that is able to cope with it. The MRI provides an appraisal concerning the former.

coupled when modules are interchangeable and no physical alterations are required for creating the module combinations. It is defined as tightly coupled when the modules are not interchangeable and physical alterations are required to create the module combinations.

This conceptualisation is suitable for products of the built environment since the degree of coupling between modules is not associated to the extent that these can be produced as independent parts and later assembled into combinations. If this was adopted, then the module interfaces would be mainly determined by the construction method adopted. For instance, a building made of masonry could not have a modular architecture since it is unlikely that parts of such a building would organised as modules that are firstly produced and assembled later. Although some benefits[55] arise only when modules are first produced and later combined, key benefits of adopting a modular architecture from a customisation viewpoint arise from the use of standard parts that are interchangeably used for creating several product variants. For instance, if a company uses a set of standard rooms in terms of layout and specifications that can be interchangeably combined for creating different dwellings, this creates benefits that are related to the simplification of the design, management of the production process and of the value chain.

Clearly, modules should be coordinated to be interchangeably used in several combinations. They should be coordinated in terms of dimension, position, and also in terms of connections (CUPERUS, 2002). Two modules can be only fit together in the building site if their dimensions and connection are well coordinated; if they lack coordination it is hard to fit them together, maintaining the same quality level (CUPERUS, 2002). In fact, the notion that modules should be coordinated is addressed in the definition proposed for the module interfaces category: modules are loosely coupled only if no physical alternations are required for creating the different module combinations.

The problem of interfaces among interacting modules is clear when looking at product architectures whose modules are organised around secondary functions, since they are clearly performed by physical parts. Yet, even if a product architecture is organised around primary functions, it is necessary to look at the secondary functions and the physical parts in which they are allocated in order to assess their interfaces. Finally, it should be highlighted that the module interfaces category proposed in this investigation focuses only on the mechanical or physical connection among modules, although it is recognized that other forms of connection, described by Fixson (2005) and Pimmler and Ulrich (1994) also apply. Such type of connection was selected as a starting point for analysing the module interfaces because it is the most basic and intuitive form of interaction. Nonetheless, it is acknowledged that other forms interaction should be incorporated in subsequent studies investigating module interfaces.

[55] For instance, benefits related to the adoption of a delayed product differentiation.

6.5 INSTANTIATIONS

This section presents the instantiations of the second version of the framework based on the customisation strategies developed by the organisations involved in the four case studies. All six decision categories (classes of customisations units, configuration sequence, order penetration point, modules, module combinations, and module interfaces) could be used to analyse case studies 2 and 3. It was not possible to analyse some decision categories in case studies 1 and 4, because the product development process was still at its early stages. The modules, module combinations, and module interface categories could not be used to examine in case study 1. Also, the new constructs (the PAC indicator and the analysis of the activities affected by the customisation) proposed for the OPP category could not be used to examine case studies 1 and 4.

6.5.1 Case study 1

6.5.1.1 Classes of customisation units and configuration sequences

As shown in Figure 83, the customisation units *C1 – off-the-shelf mixes, C2 – promotion mode*, *C4 – colour*, and *C5 – shape* have categorical items since they cannot be ordered and have no numerical meaning. *C3 – packages sizes* is a customisation unit with ordinal items because the items can be ordered: small and large. The customisation strategy planned by Company 1 does not involve the offer the “none” and “other” items, which is aligned with strategic goals to offer a limited number of customisation options since they were just starting the business of components for housing.

	Without the “other” item (closed)		**With the “other” item (opened)**	
	Without the “none” item	**With the “none” item**	**Without the “none” item**	**With the “none” item**
Binary				
Categorical	C1, C2, C4, and C5			
Ordinal	C3			
Discrete				
Continuous				

Figure 83: Classification of the customisation units in case study 1

In terms of the configuration sequence (Figure 84), there is one branch in the first level and two branches in the second level. The decision in the first horizontal level involves *C3 – package sizes* and *C2 – promotion modes*[56]. The decision in the first level is carried out by Company 2 which decides how the items in these two customisation units should be combined before proceeding to the second level: (i) large customisation units will use mode of promotion 1; and (ii) small customisation units will use mode of promotion 2. Branch 2.1, entailing *C4 – colour* and *C5 – shapes*, will be offered to contractors, and branch 2.2, involving *C1 – off-the-shelf mixes*, will be offered to individual clients. The fact that Company 1 undertakes part of the configuration process

[56] More information on the two modes of promotion can be found in section 5.1.

facilitates such process from the clients' perspective. They only need to make a decision concerning one or two customisation units at one the second horizontal level. Such a configuration sequence is similar to type 1 of the hypothetical configuration sequences.

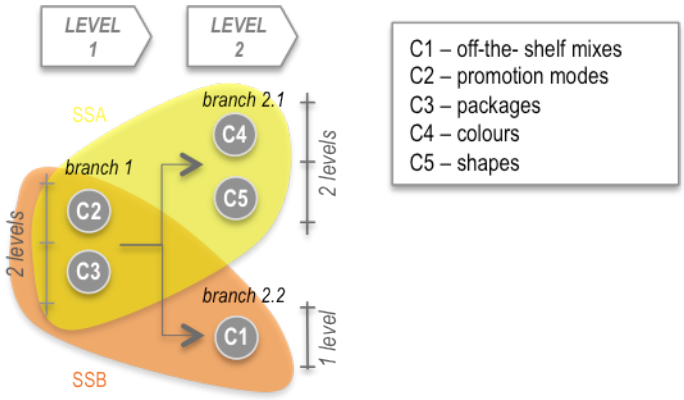

Figure 84: Configuration sequence (case study 1)

6.5.2 Case study 2

6.5.2.1 Classes of customisation units, configuration sequences, and order penetration point

The customisation units *C1 – floor plan (per tower or block)* and *C4 – floor plans* have ordinal items because it is possible to order the floor plans in terms of the number of bedrooms. These customisation units do not have the "none" and the "other" items since the client must select one of the items available in each of the units. As shown in Figure 85, *C5 – customisation of layout and specifications* has only the "other" and the "none" items. This is because Company 2 does not offer a pre-defined range of items for this customisation unit. As a result, the client should provide the bespoke interior design for apartment, configuring an "other" item. Alternatively, the client can dismiss C5, configuring a "none" item, and opt for items in the other customisation units (C3, C2, and C1) forming the solution space D (SSD).

	Without the "other" item (closed)		With the "other" item (opened)	
	Without the "none" item	With the "none" item	Without the "none" item	With the "none" item
Binary				
Categorical	C3 and C2 (used for SSC and for SSD, if C5 is dismissed)		C3 and C2 (used for SSD if C5 is accepted)	C5
Ordinal	C1 and C4			
Discrete				
Continuous				

Figure 85: Classification of the customisation units in case study 2

C3 – floor tiles options and *C2 – plugs and switches* have categorical items. When C2 and C3 are used in SSD and the client does not use *C5 – customisation of layout and specifications*; C2 and C3 do not have the "none" and the “other” items once the client must select one item from the pre-defined range offered by Company 2 for each of those customisation units. Differently, when the client decides to use C5, a different specification of plugs and switches and floor tiles can be defined, configuring an “other” item. As shown in Figure 85, the properties of C3 and C2 change as they are used in solution space C (SSC) and solution space D (SSD).

The difficulties in classifying C2, C3, and C5 in terms of their items as indicated in Figure 85, suggest that they could be re-conceptualised as two new customisation units: one with the “other” item and another without the “none” and the “other” items. It also seems that Company 2 should re-conceptualise *C5 – customisation of layout and specifications* as a customisation unit with a binary items followed by a customisation unit with only the “other” items. In the binary customisation unit, the clients decide if they would like to have the design of the dwelling bespoken. If so, they should provide the bespoke designs, which would be the “other” item in the subsequent customisation unit.

In terms of the configuration sequences, there are four trees, one for each solution space (Figure 86). SSA, SSB, and SSC have simple configuration sequences given that they only have one horizontal level with one or two customisation units to be considered. Conversely, SSD has two horizontal levels and one of these entails three customisation units, requiring additional effort of the clients in creating the product variants. SSD has two levels because the client first selects the apartment plan (C1), when the apartment is purchased, and later receives the letter from Company 3 explaining the other customisation units (C2, C3, and C5) as depicted in Figure 86. The decision concerning C2, C3, and C5 are located in the same horizontal level because these are presented to the client at the same time, when a letter is delivered. A major difficulty in this configuration sequence is that the different properties assumed by C2 and C3, depending whether the client uses C5 or not, are not clearly communicated to clients. If the client decides to have a bespoke design for the apartment, the “other” items are offered in C2 and C3, which are not offered if the client does not opt for C5.

Figure 87 proposes an alternative configuration sequence for SSD that aims to address the problems related to the configuration sequence adopted by Company 2. C5 is broken down in two customisation units: C5.1 and C5.2. The former is a binary unit, presented at the first horizontal level to the client, whereas the latter is a customisation unit with only the “other” item, which is presented at the third horizontal level. Alike the configuration sequence used by Company 2 for SSD, the client selects the item in C1 at the first level, when the apartment is purchased. At the second level, the clients are offered C5.1 and decide if they would like to have such customisation unit. If so, at the third level, the “other” item is offered in C2 and C3. C5.2 is also presented at this level and only the “other” item is offered in this customisation unit, implying that the client must provide the bespoke design of the apartment. Conversely, if the client does not want C5.1 at the second level, the client is presented with C2 and C3 without the “other” item and must select one item in each of these customisation units. This alternative configuration sequence creates a more coherent sequence than the one adopted by Company 2 because the properties of the customisation units based on the decision for C5.1 are more clearly presented.

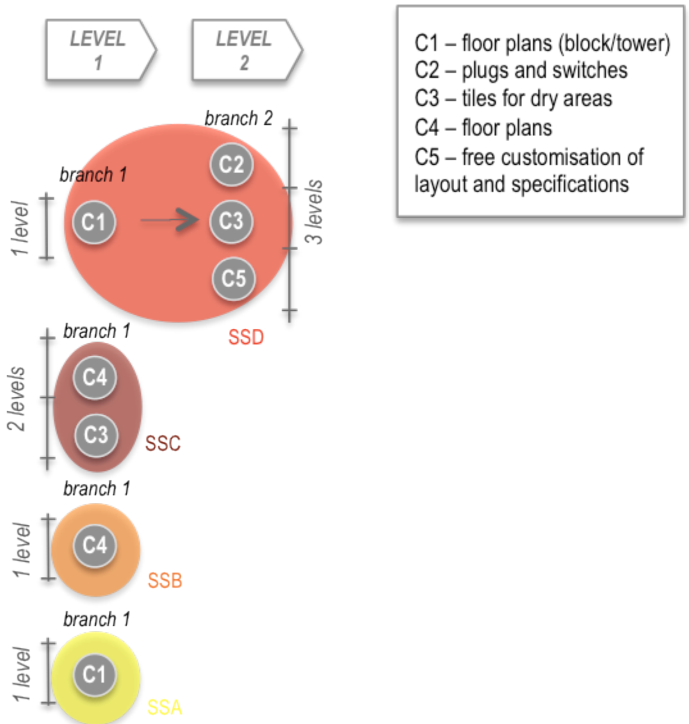

Figure 86: Configuration sequences (case study 2)

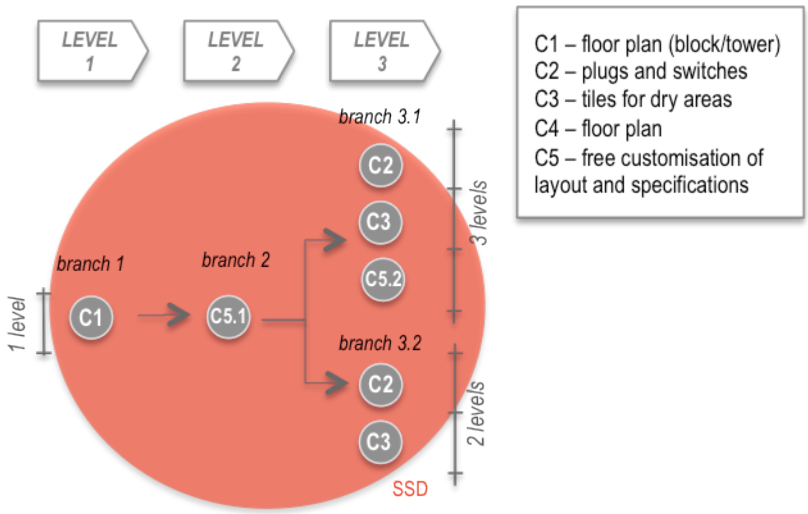

Figure 87: Alternative configuration sequence (case study 2)

The upper part of Figure 88 shows the production sequence adopted by Company 2, involving sixteen work packages according to the line-of-balance of Project J. Although additional work packages are needed for producing the building, only the work packages related to the production of the apartments, which is the customised product under consideration, are included in this analysis. Also, each building developed by Company 2 has a slightly different production sequence. The sequence depicted in Figure 88a was developed for project J and will be used for analysing the four solutions spaces.

The bottom part of Figure 88 (b, c, d, and e) shows the work packages impacted by customisation in solution spaces A (SSA), B (SSB), C (SSC), and D (SSD). The order penetration point (OPP) of SSA is not located in any of these activities since this solution space entails only a segmented standardisation[57]. SSB, SSC, and SSD have the order penetration point in the same position. This finding was drawn when examining case study 2 using the order penetration point category as defined in the first version of the framework[58]. By analysing the activities developed by the organisation to provide the customised products and identifying the ones that were affected, which was proposed in the second version of the framework, the OPPs can be more clearly located. Also, they can be specifically located within the set of activities undertaken by an organisation, which makes such category less generic and more useful in analysing or locating OPPs.

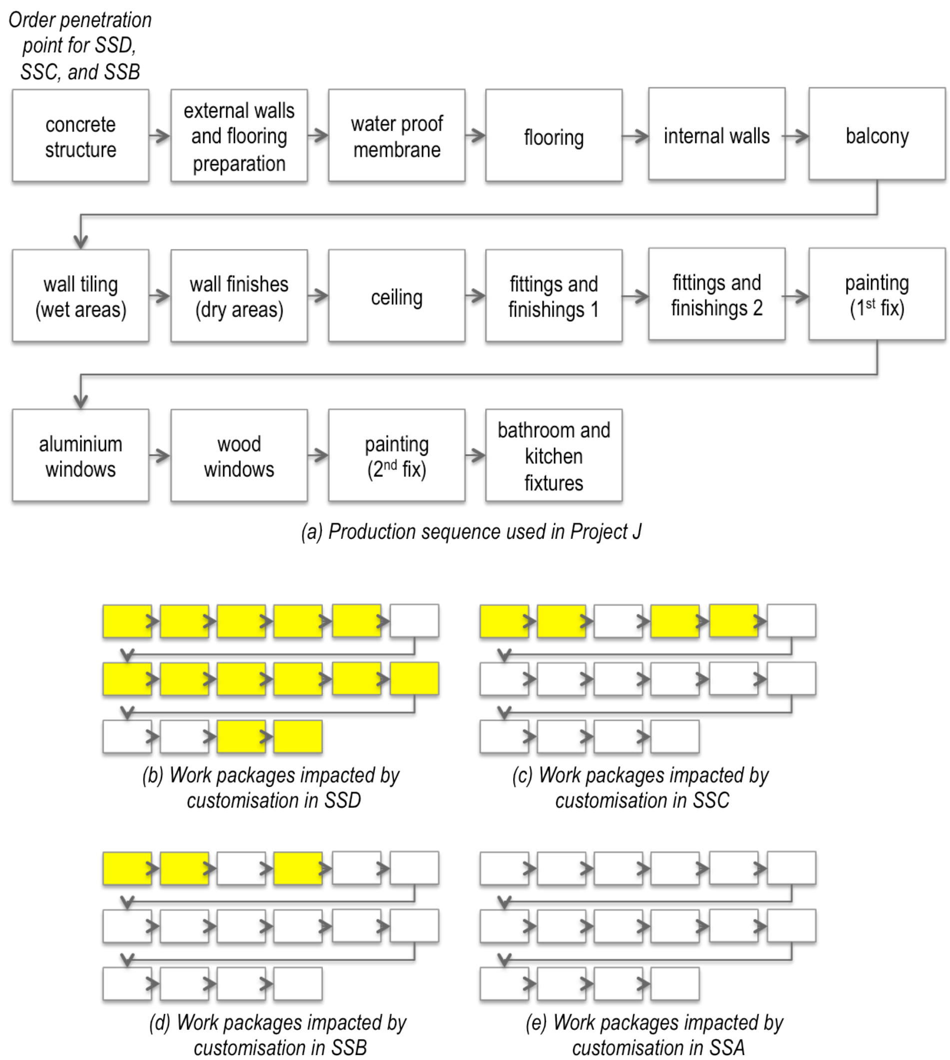

Figure 88: Production sequence in case study 2 and the work packages impacted by customisation in this sequence considering SSA, SSB, SSC and SSD

57 In a segmented standardisation, a mix of products is offered in response to client requirements but such products are not produced in response to order of each particular client. Further information on this type of customisation can be found in section 5.3.2.

58 More details on the analysis of case study 2 using the order penetration point category as devised in the first version of the framework can be found in section 5.4.2.

SSD has a PAC of approximately eighty percent (Figure 89), since one of the customisation units, *C5 – free customisation of layout and specifications*, impacts all work packages, except for the balcony, aluminium windows, and wood windows. This is because the client can customise the interior layout of the dwelling unit but not the windows and balcony because these are also parts of the building facade, which cannot be changed. In SSC, only four work packages are impacted by customisation (Figure 88): concrete structure, external walls and floor preparation, floor tilling, and internal walls. The concrete structure and the floor preparation work packages are also impacted because the position of the holes in the slab for the services systems may change depending on the floor plan selected in C4. The different floor plans also impact the internal walls work package because each apartment plan has a different internal layout. *C3 – floor tiles options* impacts only the flooring work package. As depicted in Figure 89, SSB has a PAC slightly inferior to SSC (Figure 88) because it does not have C3. Since SSB does not include C3, the floor and wall tiling work package is not impacted in this solution space. SSA has only *C1 – floor plans options (per tower or block),* which is a segmented standardisation. No information in terms of the client order is required for performing the production activities in this type of customisation, and hence no work packages are impacted.

	SSD	**SSC**	**SSB**	**SSA**
Activities affected / total number of activities	13 /16	4/16	3/16	0/16
Percentage of activities affected by customisation (PAC)	81,25%	25%	18,75%	0%

Figure 89: Percentage of activities affected (directly or indirectly) by customisation units in the four solution spaces (Case study 2)

It could be argued that other work packages are also affected by the customisation in SSC (Figure 88b). Alike the internal walls work package, it seems that the waterproof membrane or the gypsum ceiling work packages, for instance, would also be affected by customisation. Nonetheless, those and the other work packages are indeed not affected by the customisation in this solution space. In the case of the gypsum ceiling work package, once the internal walls are built, the crew knows that they should install the ceilings within the walls configuring each of the rooms. Likewise, once the holes in the slabs are perforated, the crew knows that the waterproof membrane should wrap them, regardless of the number and the position of holes required for the different floor plans. Although the activities within those work packages are different because they produce different apartment plans, the crews do not need to look at the client order for undertaking those activities.

6.5.2.2 Modules, module combinations, and module interfaces

In case study 2, each building is personalised in terms of the theme adopted, its overall aesthetic, and the apartment plans employed. Hence, Company 2 adopts an overall approach in terms of the product architecture, but that is translated differently in each particular residential building developed. Their overall approach is to use a few rooms of the apartment as modules in order to create different apartment plans and to maintain a substantial part of the apartment unchanged, configuring a platform. Hence, the modules are organised around primary functions[59]. This approach is adopted for *C1 – floor plans (per block or tower)* and *C4 – floor plans*. In order to illustrate this overall approach, the architecture devised in Project J[60] will be analysed (Figure 90a). Three product variants are offered: (i) 3b5p apartment (Figure 90b); (ii) 3b6p apartment (Figure 90c); and (iii) 4b7p apartment (Figure 90d). As displayed on that figure, they are created by using nine different modules for rooms A, B, C, and D.

Figure 90: Schematic floor plans of the three product variants in Project J

Figure 91 shows the module combinations used in the three product variants. Modules 4, 7, and 9 are used two times each and the total number of modules reuse is nine. The module reuse index (MRI) of this product architecture is 0,66 (Formula 5). Other module combinations could be created from a technical perspective since the modules for each room (A, B, C, and D) have the same dimensions. Yet, they would result in unsuitable

[59] Primary functions are the functions carried out by people in the spaces of buildings. Further information on this construct can be found in section 6.4.4.

[60] This project was selected because Company 2 was developing it when this investigation was carried out.

combinations from a functional perspective. An example of such combination is to have *module 7 – bedroom 3* and *module 8 – toilet*, because it would create a bedroom with an en-suite toilet (without a shower), instead of an en-suite bathroom. The analysis of the modules combination for creating the three product variants suggests that the modules have been designed to create these variants and not to enable the creation of other combinations. This is aligned with the approach adopted by Company 2 in which the client only chooses a product variant (3b5p apartment, 3b6p apartment, and 4b7p apartment) and does define the combination of modules. If the clients were suppose to create the module combinations, then the configuration rules would need to be explicit in order to enable to them to create suitable combinations.

	Product variants		
Module	**3b5p**	**3b6p**	**4b7p**
1	X		
2		X	
3			X
4	X		X
5		X	
6	X		
7		X	X
8	X		
9		X	X

Figure 91: The modules combination in the three product variants

$$\text{MRI} = \frac{2\text{ (module 4)} + 2\text{ (module 7)} + 2\text{ (module 9)}}{9} = \frac{6}{9} = 0{,}66$$

Formula 5: Modules reuse index (MRI) in case study 2

The module interfaces are tightly coupled since changes in the platform are required to fit the different modules within rooms A, B, C, and D. Although the modules used for each of those rooms have the same shape and dimension in terms of footprints and floor-to-ceilings height, these are not sufficient parameters for creating loosely coupled modules. For instance, in order to built *module 2 – bathroom* in room A, the platform should have a layout for the service systems that is different from the layout needed for *module 3 – toilet*. Likewise, there is *module 5 – TV lounge* and *module 4 – bedroom 2* that can be used in room B. Yet, they have different electrical layouts and the platform is not prepared to interchangeably cope with them. As a result, the modules used for each of the rooms (A, B, C, and D) are not interchangeable. Another problem is the overlap between the physical limits of the modules and the platform: the internal walls that enclose the modules are also the walls enclosing the rooms that are part of the platform. Because of that, those parts of the platform can only be built once the modules combination has been defined. This suggests that the organisation of the functional elements followed a spatial perspective in this product architecture. Yet, such perspective was not considered in allocating these elements into physical components. This results in an ambiguous correspondence (not a one-to-one) between the components and the spatial hierarchies in which one physical part is associated to two or more modules.

The fact that Company 2 builds each apartment at once and does not rely on a delayed product differentiation approach reduces the negative implications of the tightly coupled interfaces. In spite of this, having a platform and a limited number of modules, regardless of the module interfaces, can increase the learning effect in building the apartments. This is because all apartments in the building have a large portion that is standardised and the variations are circumscribed to specific parts of the product: the modules. Another reason for having this particular product architecture, with modules with standard shapes and dimensions, is to keep standardised the area and footprint of the apartments. Having each apartment of a building with different footprints in terms of shapes and areas would require the structural system to be designed for coping with expansions and the retractions of the areas of the apartments. Such structural system is likely to be more expensive than the one required for a building whose apartments areas and shapes are standardised. In order to have all apartments in a building, standardised in terms of areas and footprints, all modules used in each family should have standard dimensions and shapes. Yet, it is not necessary for the module interfaces to be loosely coupled.

6.5.3 Case study 3

6.5.3.1 Classes of customisation units, configuration sequences, and order penetration point

In case study 3, there is only one solution space and all customisation units are used in it. *C6 – types of dwellings units* has discrete items with the "other" and the "none" items. This is because the registered provider can decide the mix of dwellings and also the amount of each type of dwelling. For instance, it is possible to have four 3b5p houses, one 2b3p bungalow, and none of the other dwelling types in a residential scheme. In fact, this customisation unit could be broken down in five sub-customisation units, one for each type of dwelling unit. Each dwelling unit can be conceived as a sub-customisation unit with only the "other" and the "none" items. Such sub-customisation units would have only the "other" item because Company 3 does not offer a pre-defined range such as 1, 2, 3, 4 dwellings and so on. *C5 – bathroom fit-outs, C4 – kitchen fit-outs,* and *C1 – external cladding* have categorical items with the "other" item. The "other" item happens when the client decides to have a bespoke fit-out and commissions his own supplier.

Due to the lack of definition concerning *C2 – roofing* and *C3 – windows and doors*, it is not possible to organise those customisation units according to the classes of items. This indicates that Company 3 did not define the scope of the customisation involved in those customisation units, which can explain part of the problems identified in the production process and the development process of a project[61]. The only implicit decision concerning those customisation units is that the "none" item would not be available because the product offered by Company 3 is a turn-key approach. If the "none" item is offered it means that the registered provider would need to do some work to complete the dwelling unit, prior to its handover to the householders. Based on this assumption, C2 and C3 should be located in the first or third column of Figure 92. Yet, the line in the table that they would be placed hinges on the nature of the change involved in these customisation units.

[61] More details can be found in section 6.1.

	Without the "other" item (closed)		With the "other" item (opened)	
	Without the "none" item	With the "none" item	Without the "none" item	With the "none" item
Binary				
Categorical			C4, C5	
Ordinal				
Discrete				C6
Continuous				

Figure 92: Classification of the customisation units in case study 3

In terms of the configuration sequence, there is only one tree with one branch because the decisions concerning the six customisation units are made in parallel at a single horizontal level (Figure 93). It must be emphasised that the configuration sequence presented in Figure 93 is tentative and almost hypothetical due to the fact that the customisation process of Company 3 was not clearly established when this investigation was undertaken. This configuration sequence has several vertical levels and only one horizontal level. This implies that the client has to consider simultaneously several customisation units, which may increase the perceived burden of choice, since there are several customisation units that need to be considered at the same time and the client might go back and forth in selecting the items for each of these. Yet, having all customisation units in a single branch provides the client with an overview of all the customisable items of a product.

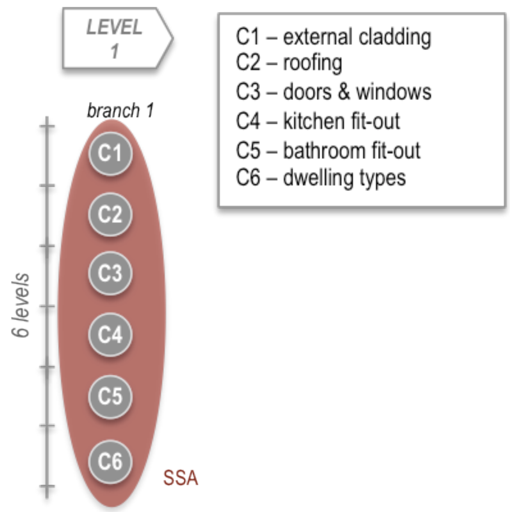

Figure 93: Configuration sequence (case study 3)

It seems that the product configuration sequence in case study 3 works if the client selects the same items in each of the customisation units for all of the dwelling units. For instance, if the client selects thirty dwelling units and all of these have the same specification in terms of the roofing, windows and doors, external cladding, and kitchen and bathroom fit-outs. Yet, in some cases the client might want to have different specifications for sub-sets of dwellings in order to create different streetscapes, for instance. The configuration sequence used by Company 3 does not support these customisations per sub-set. The main problem is that *C6 – types of dwelling*, which has discrete items and involves the "none" and "other" items, is mixed up with the other customisation units in a single branch.

Figure 94 illustrates how the configuration sequence could be changed to address these problems. In the first level, the client would select the types of dwellings. In the second level the client would create sub-sets of dwelling units that would have the same features in terms of finishing, fixtures, roofing, and windows and doors. In other words, the items selected in C1, C2, C3, C4, and C5 would apply to all dwelling units forming the sub-set under consideration. Ultimately, if clients would like each dwelling unit to be different from the others in terms of specifications, they could assign each of these as a sub-set.

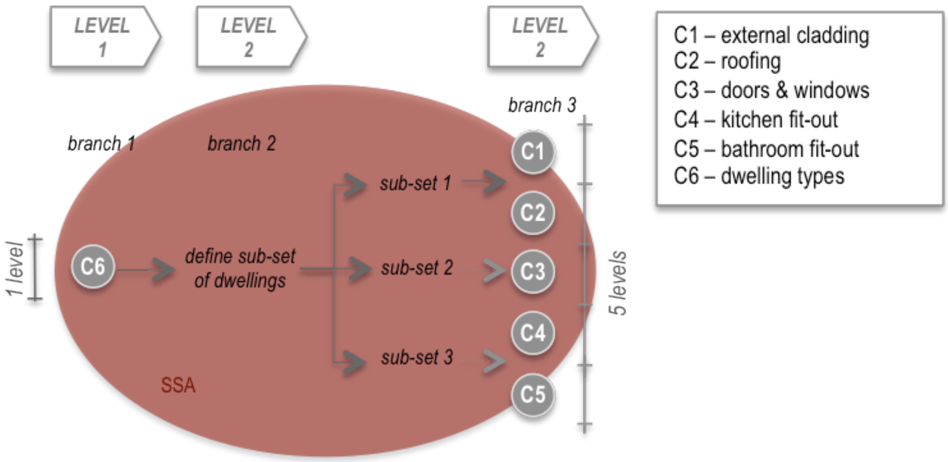

Figure 94: Alternative configuration sequence proposed for case study 3

Figure 95 displays the production sequence used in case study 3 based on the five areas of the factory identified in the study description: cutting shop, panel framing, panel assembly, box assembly, and box fit-out. The most appropriate unit for analysing the production sequence in this case study would be the workstations. Yet, they are not used because Company 3 did not have the workstations and the activities within them clearly defined when this investigation was carried out.

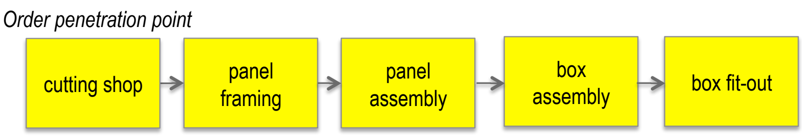

Figure 95: Production sequence in case study 3

As depicted in Figure 95, all areas of the factory are impacted by the customisation since the scope of *C3 – windows and doors* is not clearly defined and the items offered in *C6 – types of dwellings* are not strictly followed. Because Company 3 is accepting clients' requests for layout alterations, the crews need to look at the clients' orders prior performing all production activities. If only the items available in the *C6 – dwellings types* were used and *C3 – windows and doors* had a limited number of items without the "other" item, only the cutting shop and some workstations in the box fit out areas would be impacted by the customisation. Once the mix of timber components for a dwelling type are cut, wrapped as a kit, and tagged by the crew at the cutting shop, the other areas can perform their production activities without the need of any information concerning the clients' orders. In order words, the crews are able to perform their production activities by looking at the kits of elements and their tags (for instance, a 2b4p house). Some workstations at the boxes fit-out area, involved in the windows installations and bathroom and kitchen fit-outs, would also be impacted by customisation, since the crews would need to check the clients' orders before installing those elements.

6.5.3.2 Modules, modules combination, and module interfaces

In case study 3, each of the ten boxes is a module. Each box entails a set of rooms, as described in section 6.1, suggesting that the modules were organised around primary functions[62]. Conversely to case study 2, there is only one product architecture that is used in all residential schemes produced. Company 3 is allowing customisations outside the scope of *C6 – dwellings types* and has no clear definitions concerning some customisation units. Yet, product was designed assuming that the modules layout would not change from one client's order to another. Figure 96 shows the module combinations used for creating the five product variants (2b3p bungalow, 2b4p flat, 2b4p house, 3b5p house, and 4b6p house). Module 2 is used three times and module 10 is used two times, whereas the other modules are used only once in any combination. Hence, the modules reuse index (MRI) is 0,5 (Formula 6). Due to technical constraints such as the position and size of the staircases and the overall dimensions of the modules it is difficult to create other module combinations beyond the five combinations used for the product variants. This suggests that the modules have been designed to create these five product variants, but not to support the devising of other combinations. This is aligned with the approach adopted in which Company 3 creates the module combinations and only offers the product variants to the registered providers.

$$\text{MRI} = \frac{\text{3 (module 2) + 2 (module 10)}}{10} = \frac{1}{2} = 0{,}5$$

Formula 6: Modules reuse index (MRI) in case study 3

The fact that there are limited commonalities across the modules hinders the adoption of a delayed product differentiation approach. In order for Company 3 to adopt this approach they would need to have twelve modules in stock, ready to be assembled according to the product variant selected by the client. These twelve modules would include two modules 2 and two modules 10 and one of every other module. These duplications are necessary should the client select the 2b4p flat, which uses two modules 2, or the 4b6p house, which uses two modules 10. Yet, because Company 3 is not considering such approach and is developing all production activities based on actual orders, these implications do not apply.

[62] Primary functions are the functions carried out by people in the spaces of buildings. Further information on this construct can be found in section 6.4.4.

	Product variants				
Module	2b3p bungalow	2b4p flat	2b4p house	3b5p house	4b6p house
1	X				
2	X	XX			
3		X			
4		X			
5			X		
6			X		
7				X	
8				X	
9					X
10					XX

Figure 96: The modules combination used in the five product variants

The module interfaces are defined as loosely coupled; the modules can be produced independently and do not require any alteration or adjustment to be assembled in the five combinations. Because each module entails a set of rooms, it can be argued that a spatial perspective was followed in devising this product architecture. The loose coupling of the module interfaces indicates that such perspective was followed not only in the organisation of the functional elements but also in their allocation into physical components. In this case study, there is an unambiguous (one-to-one) correspondence between the components and the spatial hierarchy. Because of that there are no problems such as one physical part pertaining to two or more spatial modules. Nonetheless, a drawback in this architecture is that there is a redundancy in the physical elements after the modules are assembled, creating double walls and double floor/ceiling.

The product architecture developed in this study is bound to have this level in the spatial hierarchy (a set of rooms) and loosely coupled interfaces because of the business model adopted by Company 3. If they adopted a more aggregated level of the hierarchy[63] of the product architecture, namely having each module as an entire dwelling unit, it would create complications from a transportation perspective in delivering the modules to the site. If they adopted a less aggregated level, having each module a single room, as in case study 2, the redundancies that already exist in terms of physical components would increase, jeopardizing the competitive criteria of cost. It could be argued that the redundancies could be actually reduced, for instance by removing the ceiling of the module used on the ground floor, and using the floor of the module used in the first floor as the ceiling. Yet, this creates negative implications that are likely to exceed the potential benefits. The watertighness of the modules as they are transported to the construction site would also be compromised. The structural stability when craning the modules is also diminished if one of the external plans (ceiling, wall, or floor) forming a module is removed. Finally, such changes would compromise a main asset of the system: having the modules delivered to the construction site fully fitted internally, contributing to the competitive criteria of reduced delivery time. As external plans of the modules are removed to avoid redundancies, the extent that the module can actually be fitted in the factory is reduced since final finishing can only be executed once the modules are assembled.

[63] More details on the hierarchical levels of a product architecture can be found in section 6.4.4.

6.5.4 Case study 4

6.5.4.1 Classes of units and configuration sequences

In case study 4, there are two solution spaces and each customisation unit is used in only one of these. *C1 – dwelling types for a specific location* and *C2 – dwelling types for elsewhere* have discrete items with the "none" item. They have discrete items because the client can decide the amount of dwellings of a particular type (Figure 97). They also have the "none" item because the client can decide not to use a particular type of dwelling. C1 and C2 have the "other" item because bespoke dwellings can also be designed and combined with the existing range of items in each of these customisation units in developing a residential scheme.

	Without the "other" item (closed)		**With the "other" item (opened)**	
	Without the "none" item	**With the "none" item**	**Without the "none" item**	**With the "none" item**
Binary				
Categorical				
Ordinal				
Discrete				C1 and C2
Continuous				

Figure 97: Classification of the customisation units in case study 4

In terms of the configuration sequence, there is one tree with one branch in the first level and two branches in the second level (Figure 98). The branch in the first horizontal level is related to the location of the plot, which is not under the control of the consortium members, but that defines which branch at the second level will be used. Depending on the location of the plot, one customisation unit or the other will be used. Case study 1 has a similar configuration sequence in terms of the number of levels. Case studies 1 and 4 demonstrate how sequences, similar in terms of levels, can be actually different depending on who makes the decisions at each level. As previously discussed, in case study 1 it is Company 1 that makes the decision at the first level. In that study, the clients make the decision at the second level. Hence, from the clients' perspective, it is a simple configuration process because it entails a single horizontal level, involving only one or two customisation units. Alternatively, in case study 4, the decision in the first level is not made by the registered providers but hinges on the scheme location. Only the decision at the second level concerning the mix and amount of dwellings to be used in the scheme is made by the registered provider.

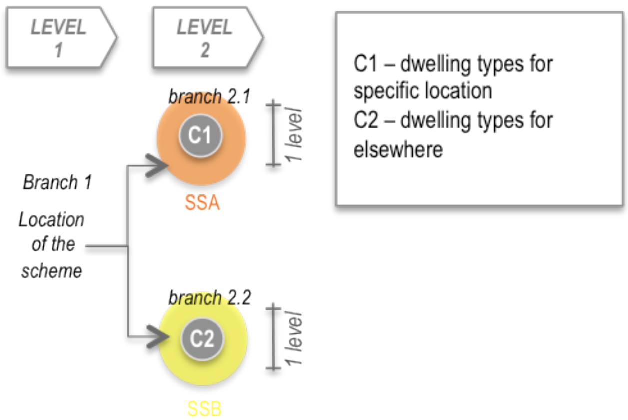

Figure 98: Configuration sequence (case study 4)

6.5.4.2 Modules, modules combination, and module interfaces

In this case study, each module is a set of floor plans used for one dwelling unit. A module defines the size, position, and relationship between the rooms forming the dwelling, but not the construction methods and specifications to be used. All dwellings have a standard floor-to-floor height and front-to-back depth in order to facilitate their combinations. Figure 99 depicts module 6 to illustrate the type of information available concerning each of the modules. There are some suggestions of position for doors and windows and indications of the furniture arrangement. Alike case studies 2 and 3, it seems that the modules are organised around primary functions[64].

The product architecture in this study involves mainly the organisation of the functional elements (the rooms) from a spatial perspective, but not the allocation of those elements into physical parts. For that reason, this product architecture differs from the ones encountered in case studies 2 and 3. The main reason for having a product architecture that entails only the organisation of the functional elements and not their allocation into physical parts is the fact that the consortium does not have production assets such as a factory for producing the dwellings units. Furthermore, they commission different contractors, which use different construction methods for building the residential schemes. The facades of the dwellings are not defined in order to enable them to assume different features according to the identity and aesthetic desired for the scheme at hand.

[64] Primary functions are the functions carried out by people in the spaces of buildings. Further information on this construct can be found in section 6.4.4.

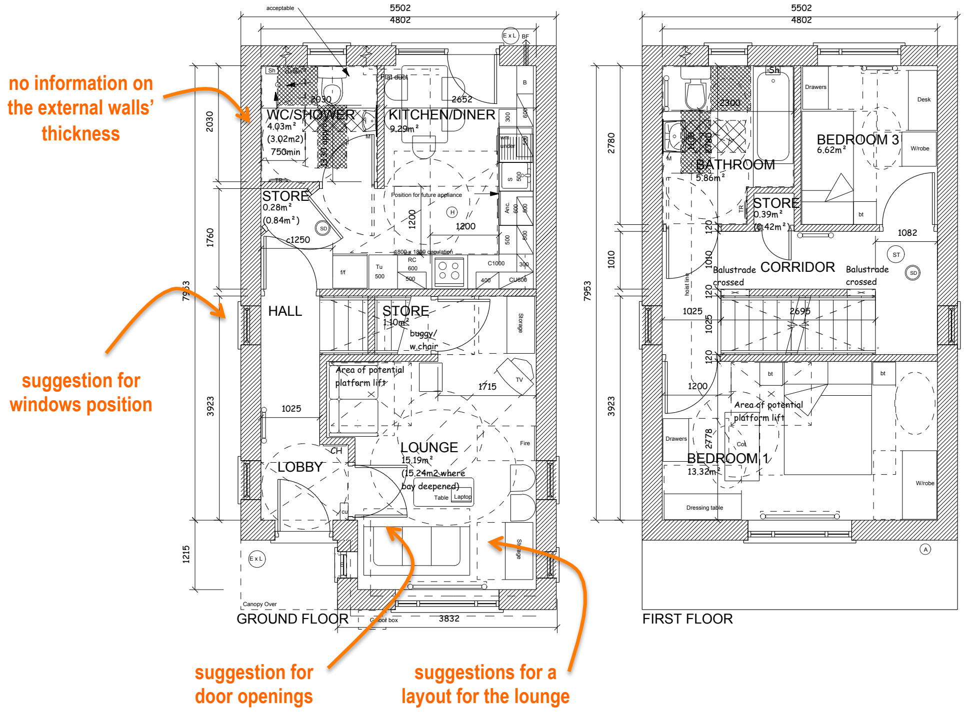

Figure 99: Module 6 (3b5p house in customisation unit 1)

As illustrated in Figure 100, a limitless number of product variants can be created in this product architecture and there are no pre-defined combinations of modules. Conversely to case studies 2 and 3, each registered provider creates a modules combination when designing a residential scheme. Each combination can have a specific mix in terms of the type and the amount of modules. Hence, it is not possible to calculate the modules reuse index (MRI) for this product architecture. The only configuration rule that needs to be followed in creating a product variant is to use only modules from one customisation unit or the other, depending on the location of the scheme under consideration. It is not possible to define the coupling of between the modules once there is only an organisation of the primary functions but not their allocation into physical parts. It can be argued that there was some consideration in how the modules would be combined: all modules have a standard floor-to-floor height in order to ease their combination and the thickness of the external walls were left undefined since they depend on the construction method to be adopted. Although the modules are coordinated in terms of dimensions and connections, this is not sufficient for defining the module interfaces as loosely coupled.

		Product variants				
Customisation units	**Module**	**Scheme A**	**Scheme B**	**….**	**….**	**Scheme n**
Dwelling types for specific location	1	X				
	2	X		X	X	
	3				XXXX	
	4			XXXXX		
	5	XXXXX		X	X	
	6	X		X	XX	
	7			XX		
	8	XX				
Dwelling types for elsewhere	9		XXXXX			X
	10					
	11					
	12					X
	13		XX			XX
	14		X			
	15		X			
	16		XX			
	17					XXXX

Figure 100: The modules combination in each product variant (case study 4)

6.6 EVALUATION THE UTILITY OF THE SECOND VERSION OF THE SOLUTION

As discussed in chapter 4, although the case studies were incrementally added for creating the instantiations. Yet, not all studies could be used at all stages of the research for testing the utility of the solution. Hence, although case studies 1 and 2 were used for producing instantiations using the second version of the framework, only case studies 3 and 4 were used to assess its utility.

6.5.1 Case study 3

The instantiation of the second version of the framework using case study 3 enabled the identification of opportunities for improvement, especially in terms of product architecture. Hence, prior to the presentation of the instantiation to Company 3, in order to assess the framework utility, the researcher carried out a design exercise to illustrate how the modules combinations could be improved by increasing the modules combination index (MRI). This exercise and also the instantiation were presented in a meeting with representatives of Company 3.

6.5.1.1 The design exercise for improving the modules combination

The analysis of case study 3 using the decision categories related to product architecture indicated that ten modules are needed for creating the five product variants. The examination of the module combinations indicated that there are some commonalities in terms of the primary functions (kitchen, bedroom, bathroom, among others) embedded in the modules combinations. Nonetheless, even when a primary function is used across different modules, it is translated differently in terms of the layout used in each of them. This indicated an opportunity to investigate alternative allocations of the primary functions into the physical parts. This would increase the commonalities across the modules, which may have a positive impact in the efficiency of the production process.

It could also reduce the total number of modules needed for creating the product variants, increasing the modules reuse index (MRI) and supporting the adoption of a delayed product differentiation approach.

It was observed, when analysing the module combinations for the 2b4p dwellings, available as a flat or as a house, that they use five different modules: modules 2, 3, 4, 5, and 6 (upper part of Figure 101). Yet, the flat and the house actually have the same requirements in terms of rooms' dimensions because they lodge the same number of householders. Thus, these two types of dwellings represent an opportunity to increase the modules reuse index (MRI) by devising modules that can be used in those two modules combinations. The five modules used for creating the 2b4p flat and 2b4p house were assembled into several combinations and assessed. It was found that modules 5 and 6, originally used only for the 2b4p house, could also be used to create a flat. Furthermore, module 6 could also be used for creating the 2b3p bungalow, replacing module 2.

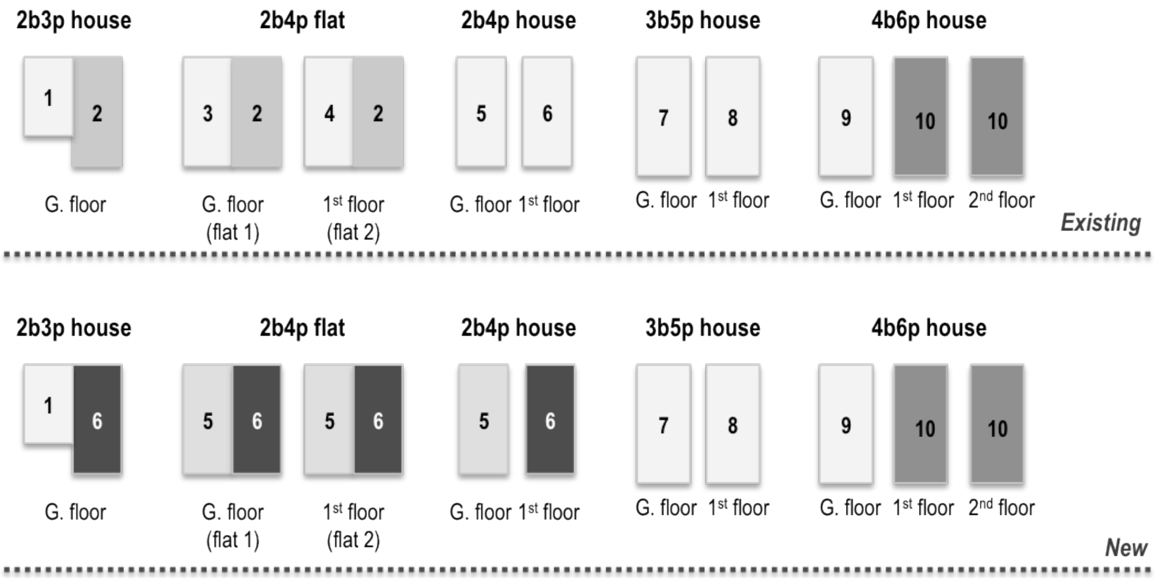

Figure 101: The existing and the new module combinations for creating the five product variants

The bottom part of Figure 101 shows the new configurations of the dwelling types based on the above-mentioned changes. Modules 2, 3, and 4 could be eliminated and only seven modules would be needed for creating the five dwelling types. Although this reduction in the number of modules can be achieved, minor changes in the design of modules 5 and 6 are necessary. Figure 102 and Figure 103 show the modifications required:

a) 2b4p flat: in the adapted version, the staircase in module 6 is converted into two wardrobes. A corridor is also created (Figure 102 and Figure 104). It is proposed in module 5 that the staircase and the hall have a double-height, enabling this module to be used for the ground and first floors of the flat with minor changes;

b) 2b3p bungalow: in the adapted version, the staircase in module 6 is eliminated and integrated into the hall. Bedroom 2 is converted into the lounge (Figure 103). The hall, in module 1 can be reduced, and the area of the bedroom increased.

A key idea in creating the adapted versions of modules 5 and 6 is that a circulation area is always needed for connecting each two modules. It is usually a corridor or a hall, for horizontal connections, and a staircase or elevator, for vertical connections. In the case of the 2b4p flat, that has the two connection approaches it seemed reasonable to use the same vertical connection used for the 2b4p house, which is a linear staircase (Figure 104). Yet, this was not adopted on the current 2b4p flat. In fact, in the current version a L-shape staircase, located on the corner of the floor plan is used for accessing the second story flat. Thus, flipping module 5 and putting it side by side with module 6, as depicted in Figure 104, creates a 2b4p flat in terms of number of rooms and their functions. Yet, there is an excess of staircases and a lack of corridor connecting the two boxes (Figure 104). This was solved by increasing the area of the bedrooms, by adding a cabinet and creating a corridor (Figure 104).

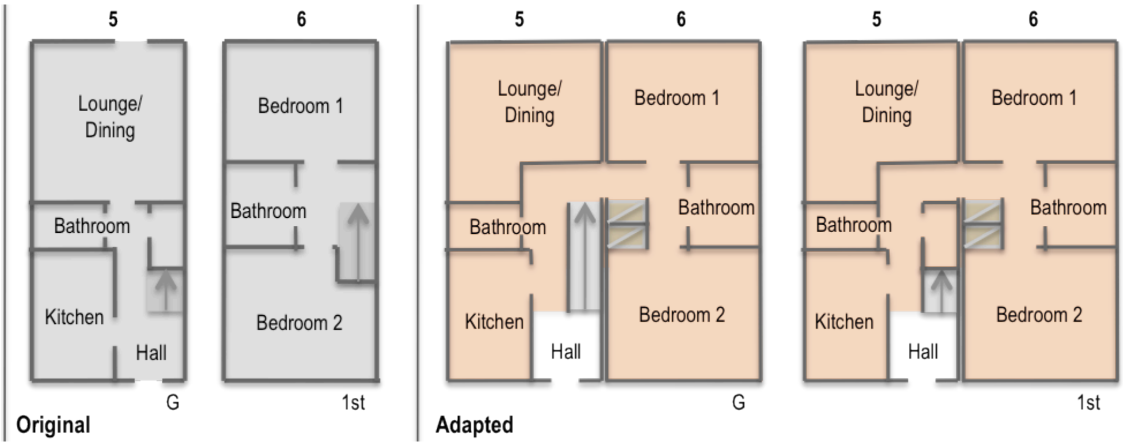

Figure 102: The adapted versions of module 5 and 6 for creating a 2b4p flat

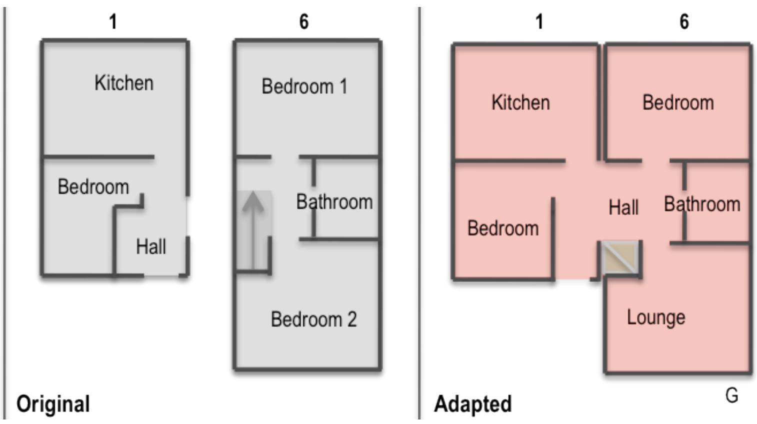

Figure 103: The adapted versions of module 1 and 6 for creating the 2b3p bungalow

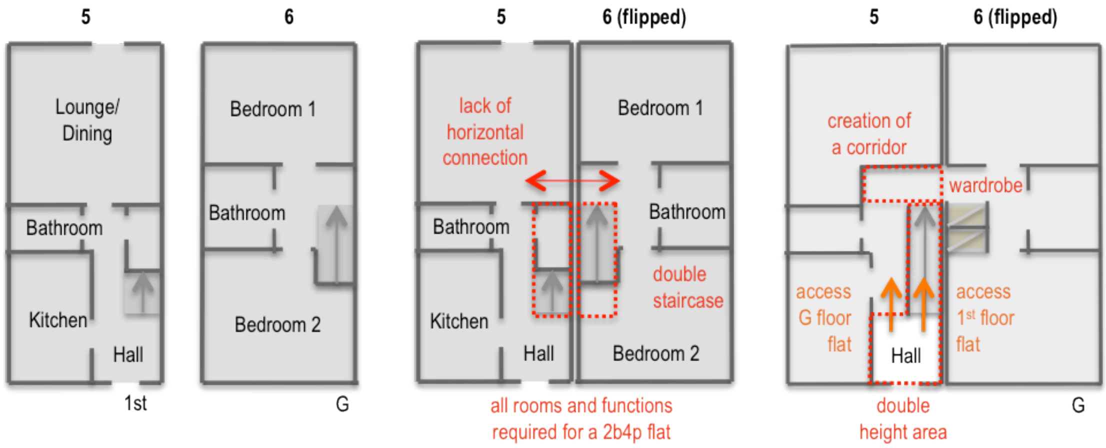

Figure 104: Development process of the new version of the 2b4p flat

Nonetheless, it must be pointed out that the adapted version of the modules 1, 5, and 6 were developed by the researcher and were only presented to Company 3. They were not discussed with the off-site manufacturing consultant and the architectural practice that designed the product. Thus, unforeseen constraints and limitations might arise, preventing the adoption of the adapted version of the modules. Nonetheless, even if the proposed alterations in the modules are unfeasible, they illustrate how a design exercise aiming at narrowing down the number of modules could be undertaken. The module combinations index (MRI) for the suggested module combinations is 0,9 (Formula 7), which is larger than the MRI (0,5) for the module combinations used by Company 3. Nonetheless, slight changes are required for using the adapted version of the modules in the different combinations. The ideal scenario would be to interchangeably use modules 5 and 6 throughout the modules combinations used for the 2b3p bungalow, 2b4p flat, and 2b4p house. Nonetheless, the adaptations required in order to use them in the additional dwellings are considered to be better than the module combinations used by Company 3.

$$\text{MRI} = \frac{4\ (\text{module } 6) + 3\ (\text{module } 5) + 2\ (\text{module } 10)}{10} = \frac{9}{10} = 0{,}9$$

Formula 7: Modules reuse index (MRI) based on the suggestions proposed

6.5.1.3 Evaluation of the solution utility

The assessment of the solution utility was based on the results of a meeting with Company 3 in which the new module combinations and the instantiation using case study 3 were presented. Figure 105 summarises the key statements made by the representatives of Company 3 that attended that meeting. In terms of the customisation strategy, they recognised that they did not have a clear and common understanding of the product and the customisation offered in terms of what could and could not be customised. The lack of a common understanding was also recognised as a main cause of the problems in communicating the product and the scope of customisation to clients. This lack of understanding was also considered to reinforce the clients' requests for customisations outside the scope of the solution space. The recognition of those issues led to the decision to rethink the marketing strategy and how the product was presented to clients (Figure 105).

Further understanding of the customisation strategy	**Decision and future actions**
"We have unlimited options; the client is getting what he/she wants and not what the system has to offer."	"We need to look at our marketing strategy, we are not doing it right."
"We are not able to clearly communicate the product to the clients."	
"We (as a company) do not have a clear understanding of the product."	
Existence of a large number of modules	"We need to standardise the box and look at ways to reduce the number of modules"
Alignment between the customisation strategy, the strategic goals, and the processes	**Decision and future actions**
"There are problems in the production process. There is knowledge missing."	"We need to implement visual management in the medium term."

Figure 105: Decisions and future actions that unfolded from the instantiation (case study 3)

The findings related to product architecture categories made Company 3 realise that they had ten modules instead of three modules, as perceived by some of the interviewees. Based on that, Company 3 decided to investigate alternatives to increase the commonalties across the modules and reduce the overall number of modules (Figure 105). This was driven on the results of the modules combinations proposed by the researcher and the increase of the module combinations index (MRI) achieved in it. In terms of the alignment between the customisation strategy and the processes, Company 3 realised that there were problems in the production process and that improvements were necessary in order for it to adequately cope with solution space offered. The researcher suggested the adoption of visual management[65] as a starting point for tackling those problems, which was embraced by Company 3 as a future action.

6.5.2 Case study 4

Case study 4 provided a different assessment of the solution usefulness compared to case studies 2 and 3. Because the instantiation was presented early in the study (on December 2010), it was possible to monitor and collect evidence on the actions and decisions that unfolded until the conclusion of the study on July 2011. Differently from the previous studies, the assessment of the solution utility in case study 4 relies primarily on actions, rather than plans and perceptions of the registered providers. Figure 106 summarizes the keys results of the assessment of the solution utility.

[65] Visual management is concerned with the development of visual workplaces. A visual workplace provides information to help people to carry out the required activities in the most efficient and effective way (GALSWORTH, 2005).

<table>
<tr><th>Understanding of the customisation strategy</th><th>Decisions in terms of future actions</th><th>Actions that were monitored</th></tr>
<tr><td>There is a redundancy of dwelling types.</td><td rowspan="5">Need to develop a new customisation strategy that is able to meet the consortium strategic goals.

Look into alternatives to standardise the kitchen, bathroom, and utilities rooms to be produced as pods and used in residential schemes to be developed under the framework agreement.</td><td rowspan="5">(i) Analysis of the dwelling units in existing schemes for providing basis for the pods design

(ii) Visit to a pod manufacturer

(iii) Survey with pod manufacturers

(iv) Appraisal of the cost of responsive repairs related to kitchens and bathrooms

(v) Development of the design of the pods</td></tr>
<tr><td>There is not a rationale for the specific mix of dwelling used in the customisation units.</td></tr>
<tr><td>There are no commonalities across the dwelling types.</td></tr>
<tr><td>Alignment between the customisation strategy, the strategic goals, and the processes</td></tr>
<tr><td>The customisation units and solution spaces will not be able to meet the new strategic goals.</td></tr>
</table>

Figure 106: Decisions and future actions that unfolded from the instantiation (case study 4)

The instantiations made the consortium realise that there was a redundancy in terms of the dwellings units, because of the specific requirements for a particular location of England. It also revealed that there was not a rationale for having the specific mix and amount of dwellings used in each customisation unit. This indicated that the dwellings types had not been strategically conceived. Additionally to the large number of dwelling types, there were no commonalities across them except for the front-to-back depth. The dwelling types were not likely to meet the new goals[66] set for by the consortium such as the reduction of costs without reductions in the dwelling floor areas. Based on the recognition of those points, the consortium decided to develop a new customisation strategy, looking into alternatives to standardise the kitchen, bathroom, and utilities rooms to be produced as pods and used in residential schemes to be developed under the framework agreement (Figure 106). The consortium selected those rooms because it considered that they account for a large portion of the cost of a dwelling.

As depicted in Figure 106, several actions unfolded from the decision to devise a new customisation strategy. One of the first actions carried out was to analyse the dwellings units used in previous schemes developed by the consortium members in order to provide a basis for designing the pods. Figure 107 illustrates one of the analyses carried out by the architectural technologist. It aimed to identify the most frequent types of dwelling used in residential schemes previously developed. Based on this analysis, it was decided that the pods developed should be able to meet the requirements of 2b4p, 3b4p, and 3b5p houses since they were the bulk of dwellings used in previous schemes.

A visit to a pod manufacturer was also carried out, followed by an effort to identify potential companies that could supply kitchen and bathroom pods in the northwest region of England. The investigation entailed questions related to the types of pod provided, the cost (including transportation to the construction site), the materials used, if the pod supplied would work with timber framed and brick and block structures, among others. Around

[66] Goals were driven by the cuts in the funding for social housing and changes in the regulations.

fifteen manufacturers were identified, which provided different types of pods at different costs. Overall, the analysis of the pod suppliers and the visit indicated that there were some manufacturers in the market capable of supplying pods that met the requirements in terms of design, construction methods, and cost defined by the consortium.

Throughout the analysis of the dwelling unit used in previous schemes and the realisation of the survey, the design of the pods was carried out. Figure 108 shows the latest designs developed by the three architectural practices. Figure 109 depicts a design exercise also developed by the three architectural practices aiming to explore how those pods (kitchen, bathroom, and utilities rooms) would fit in different dwelling types.

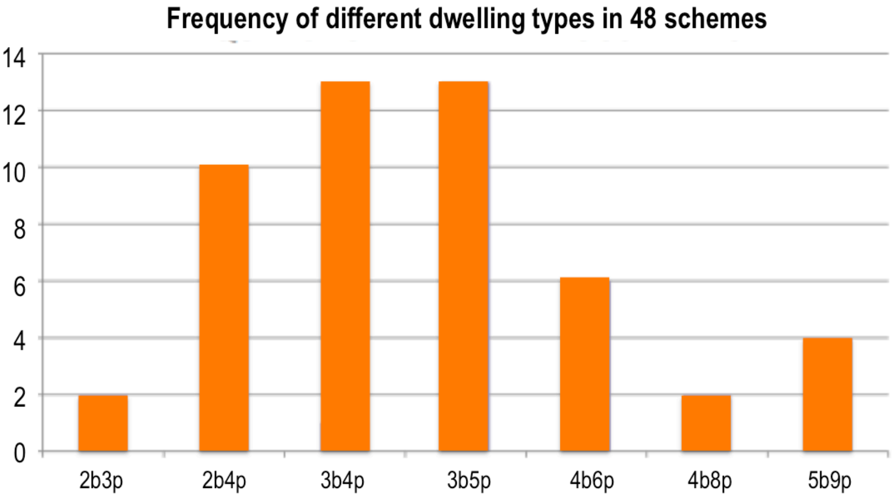

Figure 107: Example of analysis concerning the dwellings units

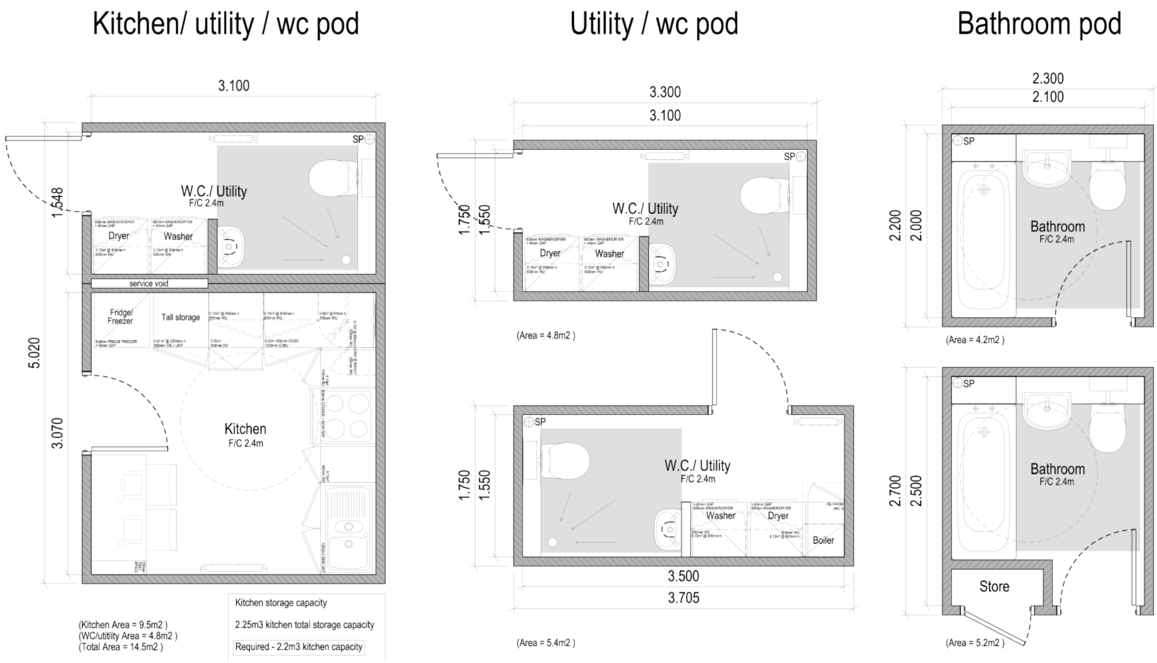

Figure 108: Design of the kitchen, bathroom, and utilities room pods

Another action that unfolded from the decision to look into alternatives to standardise the kitchen, the bathroom, and the utilities room to be produced as pods was to assess the cost involved in the maintenance and repairs of those rooms. Such assessment was important in order to evaluate the potential cost savings since it was expected that the pods would cost more at the out-set but would create cost savings in the life cycle of the dwelling. It was assumed that the pods would have more quality than a bathroom or kitchen built using bricks and blocks or timber frame because they would be manufactured in a controlled environment. The analysis of the responsive repairs[67] performed in the stock of properties managed by one of the registered providers during one year was carried out. Such analysis identified the most frequent types of repair undertaken in bathroom and kitchen and quantified the associated costs. Although it was not possible to estimate the cost savings yielded by the adoption of pods, this analysis provided some figures on the costs that could be eliminated or reduced.

[67] This analysis was carried out by Sonia C. Romero as part of her master thesis supervised by Dr. Patrícia Tzortzopoulos Fazenda under the MSc Project Management in Construction at the University of Salford.

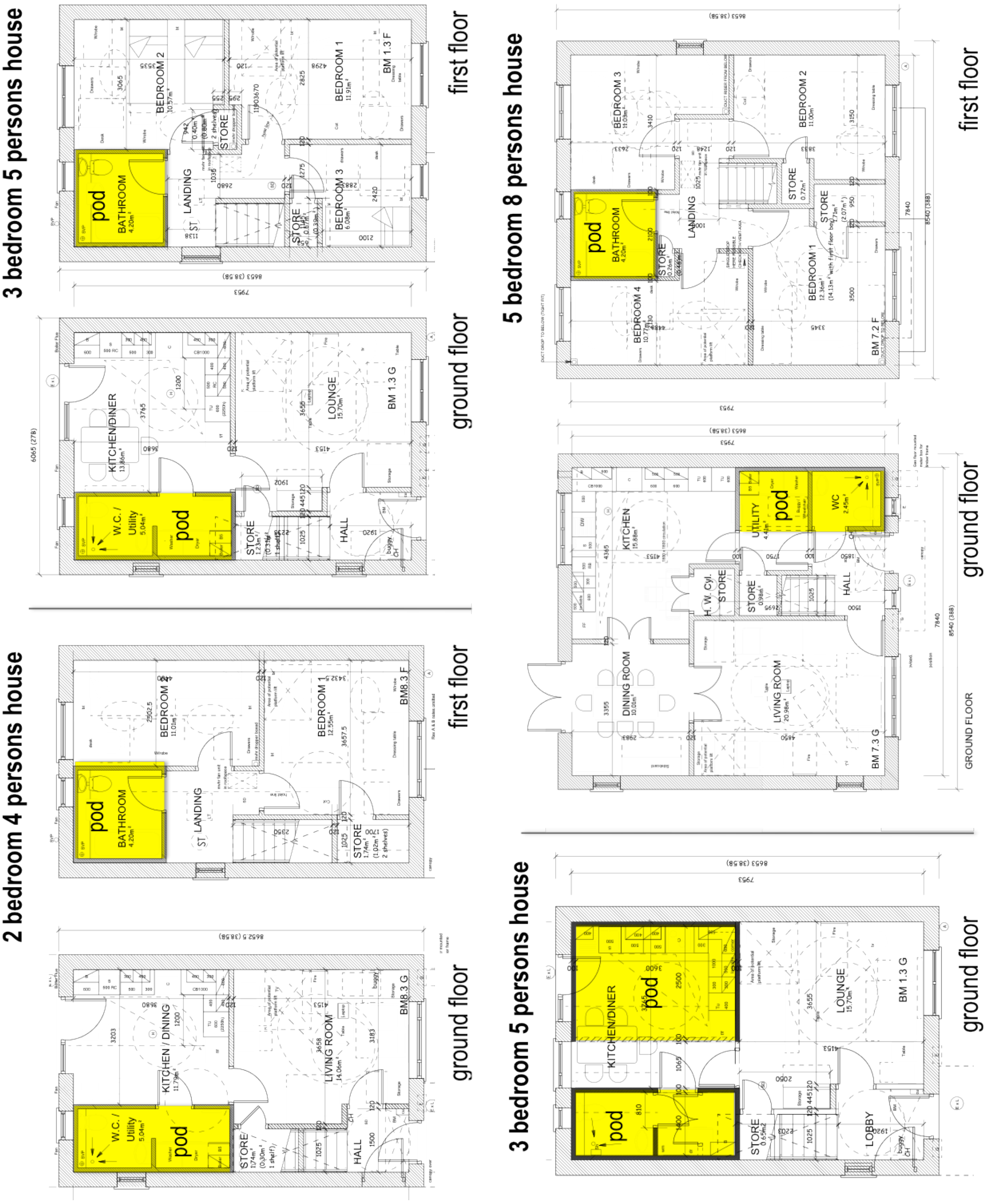

Figure 109: Design exercise showing how the standard pods would fit in different dwelling types

7. DISCUSSION

This chapter is divided into three sections. In the first section, an overview the conceptual framework, the decision categories proposed, and the relationship among them is presented. In the second section, the scope of applicability of the framework is discussed, based on its application in the four empirical studies. In the third section, the theoretical contribution of the framework is pointed out.

7.1 THE CONCEPTUAL FRAMEWORK

7.1.1 Overview of the framework

Figure 110 depicts the ten decision categories[68] for devising customisation strategies in the house-building sector. Customisation units, solution spaces, and classes of items are core categories that need to be initially considered, since they provide the basis for defining the others. Customisation units and classes of items outline the scope of the customisation strategy, whereas solution spaces define the different ways in which the customisation units can be combined. Additionally to the consideration of the classes of items that will be used in the customisation units, it is also important to consider if the "none" and the "other" items will be offered. By deciding those three core categories, it is possible to define the product variants[69] that will be offered in each of the solution spaces that form a customisation strategy. The instantiations also provided empirical evidence that the core categories should be defined prior defining the other categories. For instance, it was difficult to analyse the production sequence in case study 3 due to the lack of definitions concerning the customisation units and the classes of items categories.

In terms of the sequence of decisions, once the core categories have been outlined, the other categories related to product architecture, clients' interface, and operations can be defined. Those definitions can lead to a revision of the decisions concerning the core categories as illustrated by the double arrows in Figure 110. In fact, devising a customisation strategy is likely to entail several cycles: define the core categories, use those decisions to define the other categories, and revise the decisions initially assumed in the core categories.

[68] The detailed conceptualisation proposed for each of those categories can be found in sections 5.3.1, 5.3.2, 5.3.3, 5.3.4, 5.3.6, 6.4.1, 6.4.2, 6.4.3, 6.4.4, 6.4.5, and 6.4.6.

[69] A product variant is generated when the items in all customisation units forming a solution space are defined.

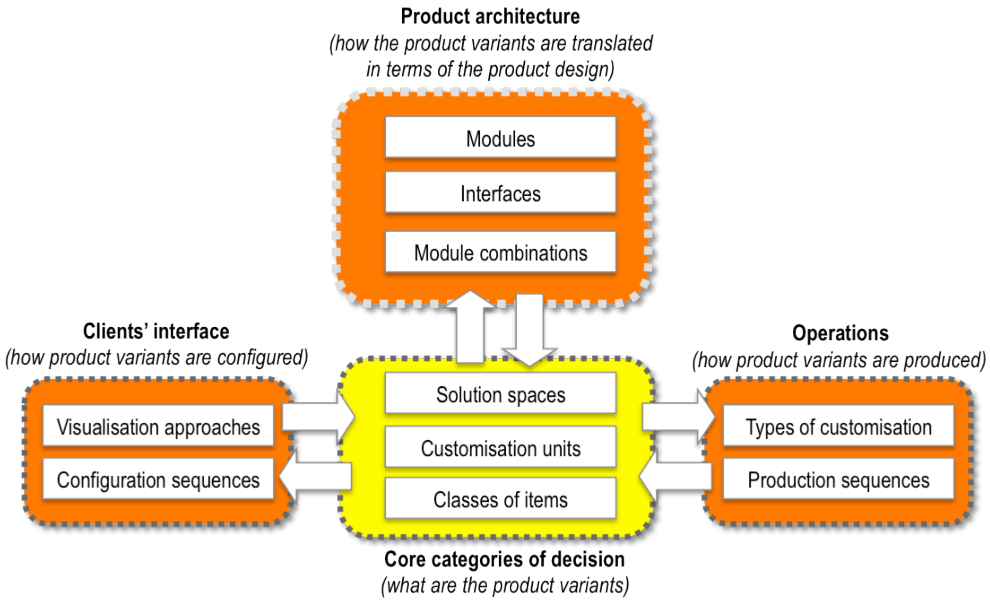

Figure 110: A framework for defining customisation strategies in the house-building sector

The two categories related to the clients' interface are concerned with how the customisation units are presented to clients and how such clients engage in creating a product variant (Figure 110). They also define how the product variants are configured and the degree of participation of the client in this process. Different decisions concerning those two categories can have different implications in problems such as the perception of burden of choice faced by the clients. The visualisation approaches category defines if a customisation unit is perceived by the client, by the company, or by both of them. Yet, it does not address the implications in selecting a particular item have over the product cost and delivery time. The configuration sequence category is concerned with the sequences in selecting the items within the customisation units to create a product variant. There are three key elements to be considered in devising a configuration sequence: trees, branches, and levels (horizontal and vertical). As presented in the discussion of the four hypothetical types of sequences[70], distinct decisions concerning these elements can facilitate or complicate the configuration process depending on the number of customisation units that need to be considered in the vertical and horizontal levels.

The categories related to the product architecture are concerned with how the product variants available in the solution spaces are translated in terms of the product design (Figure 110). The modules category is concerned with the definition of the scale of the modules within the several hierarchical levels that comprise a product architecture, and whether the modules will embody functions that are inherently associated to solid mass or spatial void. It also defines the organisation of the functional elements and their allocations into physical components. The modules combinations category focuses on the mix of modules used for creating the product variants, and whether they support the adoption of a delayed product differentiation approach from a design perspective. This can be assessed by the modules reuse index (MRI), which measures the reuses of modules

[70] Further information on the hypothetical types of configuration sequences can be found in section 6.4.2.

across the module combinations used in a product architecture. The modules interfaces category defines the physical connection between interacting components and whether they can be interchangeably used across the module combinations.

The decisions related to operations are concerned with how the product variants are produced. The types of customisation define the stage in the value chain in which each of the customisation units is produced. They may involve activities that shape the physical parts of the product, its surrounding services, or not involve any alteration of the product itself, as in a segmented standardisation. In general, the type of customisation assigned to a customisation unit does not change, when it is used across different solution spaces. The order penetration point category proposes that each solution space may have a different order penetration point, depending on the customisation units forming each of them. By analysing the solution spaces used in a customisation strategy, it is possible to compare the order penetration points in terms of their proximity to the product inception or delivery. The order penetration point category is also concerned with the activities undertaken by an organisation to provide a customised product, which are impacted by customisation. An activity is impacted when it is necessary to have a decision on the item selected in a customisation unit in order to carry out such an activity. The percentage of activities affected (PAC) by customisation is an indicator that can be used for comparing the impacts that solution spaces have on a company's process.

7.1.2 The scope of applicability of the framework

Figure 111, Figure 114, Figure 112, and Figure 113 present a summary of the decision categories from each of the case studies. The core categories of decision (solution space, customisation units, and classes of items) were used in the four studies, carried out in distinct organisational contexts, in terms of scale of products, years in the market, and stages in the product development process (Figure 111). This suggests that those categories should have a broader scope of applicability than the other categories. Other categories could not be used in every case study. For instance, the product architecture categories could not be used in case study 1 because Company 1 was at an early product development stage. Also, constructs related to some categories such as the percentage of activities affected by customisation (PAC) do not seem to be applicable in every organisational context. Such indicator was not applied in case study 4, since the consortium is not in charge of the development and production of residential projects.

The examination of the categories related to product architecture, clients' interface, and operations in the empirical studies indicates that they have a narrower scope of applicability than the core categories. For defining the categories related to the product architecture, it is necessary to have an outline of the product design. The results of case study 1 (Figure 112) suggest that those categories cannot be used by organisations at an early stage of product development process, since in the conceptual level there is limited information on the product design. Also, those categories are more successfully applied if the product architecture entails not only the organisation of functional elements but also their allocation into physical components (Figure 112). For instance, the product architecture investigated in case study 4, which entailed only the organisation of functional elements, hindered the analysis of the modules interface categories since there are no physical parts defined in order to assess the interaction among modules. The fact that the consortium does not undertake the production process, which may vary depending on the construction methods used by the contractor, may explain the lack of definition in terms of the allocation of the functions into physical components.

The categories related to the clients' interface perspective also require some definition regarding the marketing strategy in order to be used in the definition of a customisation strategy. It seems that rough plans in terms of the promotion and retailing of a product are sufficient for enabling this category to be used. In case study 1, it was possible to analyse the configuration sequence and visualisation approaches categories (Figure 114), but not the module, module combinations, and module interfaces categories (Figure 112). A possible explanation is that the retail and promotion modes are usually outlined when defining a business model, whereas the detailed design of the product is a technical activity that happens at later stages in the product development process.

Likewise, the categories related to operations require some definition in terms of the sets of activities used for producing different product variants. The extent that this set of activities is structured and consolidated has a positive influence on the richness of the findings generated by the instantiations. For instance, Company 2 had a fairly standardised process, which enabled the PAC to be generated for each of the four solution spaces. Such indicator could not be precisely calculated in case study 3 because Company 3 was still organising the workstations and the production sequence at the manufacturing plant (Figure 113). Likewise, the types of customisation category could be more easily defined in case study 2 than in case study 3 (Figure 113). For instance, it was not possible to define the types of customisation involved in C1, C2, and C3 in case study 3 or the properties of the items contained on them (Figure 113). It was difficult to define those categories because there was limited information available in terms of the production process and the classes of item category. Such findings also corroborate the proposition that the core categories need to be defined before the categories related to the product architecture, clients' interface, and operations.

	Case study 1	Case study 2	Case study 3	Case study 4
Customisa- tion units	C1 – off-the-shelf mixes C2 – promotion mode C3 – packages C4 – colours C5 – shapes	C1 – floor plans per (tower or block) C2 – plugs and switches C3 – floor tiles C4 – floor plans C5 – free customisation of layout and specifications	C1 – external cladding C2 – roofing C3 – doors and windows C4 – kitchen fit-outs C5 – bathroom fit-outs C6 – dwelling types	C1 – floor plans for specific location C2 – floor plans for elsewhere
Classes of items	C1 – categorical C2 – categorical C3 – ordinal C4 – categorical C5 – categorical	C1 – ordinal C2 – categorical with the “other” item[1] C3 – categorical with the “other” item[1] C4 – ordinal C5 – only “other” item or “none” item	C1, C2, and C3 – not possible to define C4– categorical with the “other” item C5 – categorical with the “other” item C6 – discrete with the “other” and “none” items	C1 – discrete with the “other” and “none” items C2 – discrete with the “other” and “none” items
Solution spaces	2 solution spaces (SSA and SSB)	4 solution spaces (SSA, SSB, SSC, and SSD)	1 solution space (SSA)	2 solutions spaces (SSA and SSB)

[1]the “other” items are available only in SSD and only if C5 is selected

Figure 111: Instantiations of the core decision categories

	Case study 1	Case study 2	Case study 3	Case study 4
Modules		Each module is a room Platform Modules are organised around primary functions Ambiguous (not one-to-one) allocation of functional elements into physical components	Each module is half of a dwelling unit No platform Modules are organised around primary functions One-to-one allocation of functional elements into physical components	Each module is a dwelling unit No platform Modules are organised around primary functions No allocation of the functional elements into physical components
Modules combina- tions		Number of modules: 9 MRI[1]: 0,66 Client only selects the product variant	Number of modules: 10 MRI[1]: 0,5 Client only selects the product variant	Number of modules: 17 MRI[1]: not defined Client creates the modules combination
Modules interfaces		Tightly-coupled	Loosely-coupled	(Not possible to define)

[1]Modules reuse index (MRI)

Figure 112: Instantiations of the decision categories related to the product architecture

	Case study 1	Case study 2	Case study 3	Case study 4
Types of customisa- tion	C1 – Segmented standardisation C2 – Retailing C3 – Packaging C4 – Fabrication C5 – Fabrication	C1 – Segmented standardisation C2 – Installation C3 – Fabrication C4 – Fabrication C5 – Design	C1, C2, and C3 – not possible to define C4 – Fabrication C5 – Fabrication C6 – Design	C1 – Design C2 – Design
Order penetration point	The OPP of SSB is closer to the inception of floor tiles than the OPP of SSA	SSB, SSC, and SSD have the same OPP which is located closer to a project inception than SSA	SSA has an OPP that is located closer to the project inception than its delivery	SSA and SSB have the OPPs in a similar position, which is closer to the project inception than its delivery
		PAC[1] (SSA) = 0% PAC[1] (SSB) = 18.75% PAC[1] (SSC) = 25% PAC[1] (SSD) = 81.25%	PAC[1] (SSA)= 100%	

[1] Percentage of activities affected by customisation (PAC)

Figure 113: Instantiations of the decision categories related to operations

	Case study 1	Case study 2	Case study 3	Case study 4
Visualisation approaches	C1, C4, and C5: collaborative C2 and C3: transparent	All units have a collaborative approach	All units have a collaborative approach	All units have a collaborative approach
Configura-tion sequences	Tree 1 – One branch with (two vertical levels) at the first horizontal level and two branches (one with two vertical levels and one with one vertical level) at the second horizontal level	Tree 1 – One branch (with one vertical level) at the first horizontal level and one branch (with three vertical levels) at the second horizontal level Trees 2 – one branch at the first horizontal level and two vertical levels Trees 3 and 4 – one branch at the first horizontal level with one vertical level	Tree 1 – one branch with six vertical levels at the first horizontal level	Tree 1 – One branch at the first level and two branches (each one with one vertical levels) at the second horizontal level

Figure 114: Instantiations of the decision categories related to clients' interface

7.2 THE THEORETICAL CONTRIBUTION OF THE FRAMEWORK

Figure 115 presents an overview of the theoretical contributions of the framework, which are mainly related to (i) the proposed categories, which are based on constructs that have been proposed or refined in this study, and (ii) the connections established among those categories.

The solution spaces, visualisation approaches, types of customisation, modules, module interfaces, and order penetration point categories were build upon existing underpinnings of the MC approach (Figure 115). Their main contribution is to adapt those constructs to the context of the house-building sector, enabling them to be more readily used in defining customisation strategies. Differently, the customisation units, configuration sequence, classes of items, and modules combinations categories were conceptualised by the researcher in order to address the problems encountered in the empirical studies. They do not rely as much as the other categories on the existing literature.

The solution space category is grounded on the notion presented by Von Hippel (2001), Salvador *et al.* (2009), Piller (2007), and Kumar (2005). The solution space is a given set of choice options that the client can define, configure, or modify to suit his individual needs (PILLER, 2007). It should define a scope of customisation that falls within the pre-existing capability and degrees of freedom built into an organisation processes (VON HIPPEL, 2001). The innovation brought by this category is to propose that a solution space is made of building blocks, namely, customisation units. The conceptualisation of the customisation unit as a set of items that offer different performance within a particular parameter, eliciting the nature of change embedded in it, is another theoretical contribution. It is important because it enables to clearly define the scope of a customisation strategy. For example, such conceptualisation was essential for identifying the differences between C1 and C4 in case study 2 and the different implications that they have in terms of the production process. The examination of the empirical studies using the customisation unit and solution space conceptualisation reflected what was occurring in the real world: customisation strategies can assume different states, and not all customisation units need to be offered all the time. Such categories formalise what was being observed in the real world, which was not done by prior models, underpinnings, and taxonomies related to the MC approach.

Decision categories	The nature of the conceptualisation proposed	Key connections among the categories
Customisation units	A new conceptualisation	**Customisation units** are the building blocks of a **customisation strategy**. Each **customisation unit** entails an attribute (for example, colour) of the product that is customisable and the range of **items** offered for it (for example, blue, red, and green).
Solution spaces	Adaptation and operationalisation of an existing concept	A **solution space** is formed by one ore more **customisation units**. A **product variant** is created when the items in each of the **customisation unit** forming the **solution space** are defined.
Classes of items	A new conceptualisation	A **customisation unit** has different properties depending on the **items** contained in it. (The properties of each **item** are defined by the **classes of items** category.)
Visualisation approaches	Adaptation and operationalisation of an existing concept	Each **customisation unit** can be displayed differently to clients and to the company. (How a customisation is displayed is defined by the visualisation approaches category.)
Types of customisation	Adaptation and operationalisation of an existing concept	Each **customisation unit** entails one **type of customisation**, depending on the process, which is used for providing such customisation.
Order penetration point	Adaptation and operationalisation of an existing concept	Each **solution space** has an **order penetration point.**
Configuration sequences	A new conceptualisation	The **customisation units** used in a **customisation strategy** can be organised in different **configuration sequences**, which are defined in terms of three elements: trees, branches, and levels (horizontal and vertical).
Modules	Adaptation and operationalisation of an existing concept	**Modules** are the product parts that are combined for creating the different **product variants.**
Module combinations	New conceptualisation	Each **product variant** has a particular **module combination.**
Module interfaces	Adaptation and operationalisation of an existing concept	**Module interfaces** defines the interaction among the modules forming a **modules combination**.

Figure 115: Overview of the theoretical contribution of the framework

It should be pointed out that the definition of the scope of the customisation offered in a strategy was initially conceptualised as the choice menu. Indeed, the choice menu or other interface used for configuring a customised product contains the attributes that are customisable and also the range of options available for them. Yet, when the term choice menu and other similar terms such as configuration toolkits, choiceboards, configurators are used in the literature, they usually address a particular type of interface rather than the scope of the customisation. For that reason, the term solution was considered to be more suitable, since it did not imply that a particular interface was used for configuring a product. Adopting this term is particularly important since this investigation holds that a customisation strategy can happen without the active participation of the client (for instance, if all customisations units are presented using a transparent approach) and hence, no interfaces are required.

Besides proposing that a solution space is made of customisation units, another contribution of the framework is the proposition that a customisation strategy can have more than one solution spaces (Figure 115). In fact, such conceptualisation was driven by what was observed in the case studies: three of the four customisation strategies entailed two or more solution spaces. By outlining the solution spaces that can be adopted, its customisation units and the properties of the items contained in them, the scope of the customisation offered is defined.

The particular features of the *C5 – free customisation of layout and specifications* in case study 2 and *C6 – types of dwellings* in case study 3 led to the development of the classes of items category. Besides the customisation units and the solution spaces, such category plays a key role in defining the scope of the customisation offered in a strategy. The classes of items category was devised to translate what was observed in the real world as a conceptualisation, which had not been addressed in previous studies. In particular, the "none" and the "other" items, which were observed in practical contexts (case studies 2 and 3), seem to introduce several implications in terms of the customisation strategies and the process required for supporting them. For instance, most of the customisation practices developed by Company 2 focus primarily on reducing the negative implications of *C5 – free customisation of layout and specifications*, which is a customisation that entail the "other" item, since clients can have the internal layout of their apartment designed by interior designers. The other customisation units, which did not entail the "other" item, do not require the support of so many practices and seem to be more easily managed by Company 2.

The "none" item is grounded on the notion that removing features from a product may increase the perceived value. Removing options can increase the perceived value because, in some cases, clients may not want an item of a customisation unit, or might not want to pay the premium associated to it. Gilmore and Pine (2000) define this as the client sacrifice The main contribution of the "none" item is to operationalise the notion of client sacrifice (GILMORE, PINE, 2000): for each of the customisation units forming a customisation strategy, the organisation may decide to offer the "none" item (or not). By conceptualising the client sacrifice in terms of an item that can be offered in the customisation unit, such notion can be more readily used in defining a customisation strategy. Furthermore, the "none" item also highlights the fact that allowing clients to dismiss items offered is also a form of customisation, in spite of the fact that customisation is usually associated to an increase in the items available for a product.

The "other" item increases degree of the customisation offered in a customisation unit, providing a truly bespoke product variant since the client is not constrained by a defined range of items. The *C5 – free customisation of layout and specifications* in case study 2 illustrates that such approach can be adopted in customisation strategies. The challenge in adopting the "other" item lies in creating a customisation strategy that is still within the boundaries of the mass customisation approach. If the "other" item is indiscriminately adopted it might have a strong negative impact on cost and delivery time. Three guidelines can be drawn from case study 2, which provides an example of a customisation strategy that successfully embodied the "other" item. First, there should be a clear definition of the nature of change that can be embedded in the "other" item. Company 2 had strict guidelines in terms of what could and could not be changed in the bespoke dwelling unit developed by the interior designer. Second, there should be a clear definition on how the item or information about it is delivered. Company 2 defined the types of design document, the drawings notation that should be followed, and also the types of design documents that should be delivered. Third, the organisation should have process in place that enables it to efficiently and effectively cope with the "other" item. In fact, Company 2 had developed several practices to support *C5 – free customisation of layout and specifications.*

Based on the conceptualisation of customisation strategies in terms of customisation units and solution spaces, the other decision categories were devised. The types of customisation and visualisation approaches categories provide further details on the features of the customisation units. The types of customisation category expands and clarifies the generic levels of customisation proposed by Da Silveira *et al.* (2001), creating a more coherent taxonomy by explaining in detail each type of customisation. Some generic levels were divided into more specific types of customisation and new types of customisation are added. A contribution of this category is that it incorporates several types of customisation described in the literature, creating a broader taxonomy. In addition to that, this category makes such knowledge more readily applicable for defining a customisation strategy. As proposed in the framework, each customisation unit entails one type of customisation (Figure 115), depending on the process used for providing such customisation, and a customisation strategy can involve one or more customisation units. This implies that a customisation strategy can incorporate one or more types of customisation, which has not been suggest by previous studies that proposed taxonomies of customisation, such as Gilmore and Pine (1993), Pine (1995), Da Silveira *et al.* (2001), Lampel and Mintzberg (1997). Besides introducing this proposition, this investigation was able to provide empirical evidence that distinct types of customisation can be pursued in a single customisation strategy, as exemplified by case studies 1, 2, and 3.

The visualisation approaches category adapts and operationalises the transparent, the collaborative, and the adaptive approaches proposed by Gilmore and Pine (1993), enabling them to be more readily used by organisations in devising customisation strategies. Alike the previous categories, those approaches were also conceptualised considering the customisation units as building blocks: for each customisation unit, the organisation can define the visualisation approach that will be used. This enables a customisation strategy to be partially transparent and partially collaborative, for instance. This was not suggested by Gilmore and Pine (1993) and, in fact, the description of the approaches, as proposed by them, suggest that collaborative and transparent are opposing strategies. In spite of that, the proposition that a customisation strategy can entail different visualisation approaches was corroborated by case study 1, in which some customisation units have a transparent approach while other have a collaborative approach. A limitation is that this category does not address how the cost and the delivery time are affected by the client choices. It is mainly concerned with how the customisation units and their items are displayed to clients.

The order penetration point category operationalises the underlying notion that some activities are demand driven and need information concerning the customisation required by the client to be carried out, whereas others are forecast driven and can be realised without any input of the client. A major innovation introduced by this category is to assume that the decoupling point does not happen in a single stage of the value chain. In fact, it is proposed that each solution has an order penetration (Figure 115). Such understanding is aligned with what has been proposed in recent studies, such as Verdouw *et al.* (2008) and Wong (2011): there is not a single order penetration point. Nonetheless, the order penetration point is still defined as previously proposed in the literature (YANG, BURNS, 2003): the point in which the client order first enters the value chain. The order penetration category also seeks to identify the production activities that require inputs in terms of the items selected in the customisation units in order for those activities to be carried out. The percentage of activities affected (PAC) indicator has been proposed in this study for assessing such impact. This category combines the analysis of the activities affected by the customisation in addition to location of the order penetration point. Hence, it is able to provide a more meaningful structure than the generic order penetration point positions discussed by Olhager (2003), Mason-Jones and Towill (1999), Naim *et al.* (1999), and Christopher (2000) for devising a customisation strategy.

The advancements brought by the analysis of the specific activities undertaken by an organisation which are impacted by customisation are clear when analysing the SSD and SSC in case study 2. If only the position of the order penetration point was considered, the two solution spaces would have similar implications in the production process. Yet, calculating the PAC provided a different perspective: in SSD approximately 80% of the activities are impacted by customisation, whereas in SSC only 25% are impacted. Another contribution of this category, compared to previous studies, is that the particular process of the organisation under consideration is used for the analysis. This provides a more meaningful conceptualisation since it reflects real world settings, rather than generic types of supply chain such as the ones proposed by Barlow *et al.* (2003), Naim *et al.* (1999), Yang and Burns (2003), Pagh and Cooper (1998), Olhager (2003), and Lampel and Mintzberg (1996).

Clearly, the order penetration point and types of customisation categories do not address all decisions that should be considered by an organisation in terms of operations in devising a customisation strategy. Decisions related to the supply chain management, for instance, remain untapped. Nonetheless, an important contribution of those categories is to use constructs that enable an organisation to shape a customisation strategy while also addressing the implications of this strategy from an operations viewpoint. The customisation unit and solution space, which are core categories that define the scope of a customisation strategy, are also basic constructs that are needed for defining the order penetration point and types of customisation categories (Figure 115). Hence, the implications that different decisions concerning the core categories have over operations, which is addressed by the order penetration points and types of customisation categories, can be more easily defined.

The configuration sequence category addresses problems such as burden of choice and matching needs with product specifications, discussed by Huffman and Kahn (1998), Piller (2005), and Salvador *et al.* (2009). The main innovation brought by this category is to conceptualise the configuration sequence in terms of three fundamental elements (tree, branches, and levels) that can be manipulated for addressing problems related to the configuration process. The perception of burden of choice can be addressed by leveraging the customisation units that will be presented in each of the levels forming a configuration sequence. The uncertainty faced by client in matching needs and the specifications of the product can be addressed by manipulating the trees and the sequencing of the customisation units in the different horizontal levels. For instance, in the configuration sequence suggested for the SSD in case study 2, the customisation units are hierarchically organised: the properties of *C2 – plugs and switches* and *C3 – floor tiles* change depending on the decision regarding C5.1. If the client does not opt for C5.1, C2 and C3 will be presented without the "other" item, avoiding the configuration of a product variant that is not provided by Company 2.

The modules category builds upon the dimensions of the product architecture proposed by Ulrich (1995) and refined by Fixson (2009): (i) the organisation of functional elements; and (ii) their allocation into physical components. It also incorporates the notion proposed by Salvador *et al.* (2002), Fixson (2005), and Salvador (2007) that there are several hierarchical levels in a product architecture. Also, a product can be usually described using several different hierarchies rather than a single one. The main contribution introduced by this category is to incorporate the concepts of physical mass and spatial voids that configure the built environments and discuss their implications in terms of the dimensions of the product architecture and its hierarchical levels. Based on this, it is also proposed that a module can be organised around: (i) primary functions (functions performed by people in the spatial voids) or (ii) secondary functions (functions performed by the physical mass in order to create the spatial voids or to support the primary functions to be adequately performed). A spatial perspective is usually adopted if the product architecture is organised around primary functions. Complementary, a components perspective is usually adopted if the product architecture is organised around secondary functions.

In this category, the notion that a modular product has a one to one correspondence between functional elements and physical components proposed by Ulrich (1995) is also discussed considering those perspectives. This sheds some light in the problems encountered in devising a modular architecture around primary functions: although such functions are performed by people in the space, they still need to be supported into physical parts and, more often than not, a bundle of interconnected components are needed for creating a space. Another contribution of this decision category is to identify that problems are created when the perspective chosen is not consistently used in organising the functional elements and allocating them into physical components. This happened in case study 2, in which a spatial perspective was followed in the organisation of the functional elements, but not in their allocation into physical components. Differently, case study 3 has a consistent product architecture since the spatial perspective was considered in the organisation of functional elements and their allocation into physical components.

The modules interfaces category also builds upon the notion of loosely and tightly coupling, proposed by Ulrich (1995). Yet, it is limited to the consideration of the physical connection among interacting modules and does not involve the analysis of other kinds of interaction discussed by Fixson (2005) and Pimmler and Ulrich (1994). The literature provides generic descriptions for defining the coupling between modules. For instance, Ulrich (1995) states that they in modular architecture, the modules should be loosely coupled. Proposing that the coupling among modules is defined by the extent that they can be interchangeably used across the modules combinations without any physical alterations provides a more operational and prescriptive conceptualisation. Such definition also addresses the singularities of the construction industry.

In some cases, the coupling among modules is associated to the extent that the modules can be produced as an independent sub-assembly and be later assembled into a product, regardless of the other modules used. Yet, the construction industry is not in the same level of industrialisation compared to most manufacturing industries. If such conceptualisation was adopted, only in the case of some construction methods, such as prefabricated timber frame or steel frame, modules can be considered as loosely coupled because they are first produced and later only assembled. Hence, adopting the conceptualisation proposed in the framework for the module interfaces category makes the coupling among modules more dependent upon the decision in terms of product architecture than the construction method adopted. For instance, the product architecture in case study 2 is defined as tightly coupled because there is not a one-to-one correspondence between functions and physical components and because changes are necessary for combining the modules. The design decisions, and not the construction method adopted, were the contributing factor for having this particular product architecture.

The modules combinations category establishes a connection between the customisation strategy and the product architecture by defining how the modules are used for creating the product variants (Figure 115). By analysing the modules combinations, opportunities for improvement can be identified. In case study 3, improvements in the design of some modules were suggested based on the analysis of the module combinations. Another contribution brought by this category is the modules reuse index (MRI), which can be used for comparing different modules combinations and improving a modular architecture as exemplified by case study 3. This index can be used for improving the product architecture as exemplified by the design exercise carried out in case study 3: the MRI increased from 0,5 to 0,9. Such index can also provide an indication of the most adequate product architecture for adopting a delayed product differentiation, from a product design perspective. Considering different product architectures, the one with the highest index would be the most suitable one, since it has a limited number of modules that are used several times across the product variants. Another contribution introduced by the module combinations category is to elicit the notion that the modules combination can be created by the organisation or by the client as observed in the empirical studies. If the organisation creates the modules combinations, the client is usually presented only with product variants to select from. Conversely, the client can create his own product variant by mix and matching the different modules. In that case, the configuration rules should be clearly presented in order to avoid the creation of inadequate combinations.

8. CONCLUSIONS

The problems related to the provision of standardised homes and the need to provide customised dwellings that fulfils clients' specific requirements provides the background of this investigation. The MC approach and related concepts were chosen as the theoretical background for addressing such problems. The MC approach provides the basis for developing customisation strategies that are able to meet householders' requirements without substantial increases in cost and delivery time. Yet, there are two fundamentals problems in the literature addressing such approach: the fragmented body of knowledge on the MC approach and the shortage of prescriptive research to support the devising of customisation strategies in real-world contexts. Based on such a research problem, four objectives were defined for this investigation, which correspond to outputs of the design science approach (Figure 116).

Outputs of the design science	Objectives of the investigation
Solution (Conceptual model)	Devise a conceptual framework for defining customisation strategies in the house-building sector
Constructs	Refine a set of concepts related to MC, in order to adapt them to the specific context of house building
Method	Propose a sequence of steps for defining a customisation strategy
Instantiations	Implement the proposed framework in real cases, aiming to assess its utility

Figure 116: The outputs of the design science approach and the objectives of the investigation

The final version of the framework, which emerged in the course of the research process is the proposed solution (Figure 116). As discussed in chapter 4, the solution embodies three other outputs of the design science approach proposed by March and Smith (1993): constructs, a model, and a method (Figure 116). Each decision category proposed in the framework entails one ore more constructs. There are also constructs such as product variants, that are not parts of decision categories but that result from the decisions taken in these. The relationships established among the decision categories proposed, summarized in Figure 115, makes this framework a model. The order that these categories should be considered by an organisation in devising a customisation strategy makes this framework also a method. Details on the sequence of decisions that should followed in defining a customisation strategy are presented in section 7.1.

In spite of the fact that the solution contains these three outputs (constructs, a model, and method), they have distinct emphasis, in terms of the contribution provided by each of them. The primary contribution of this investigation is the constructs and the relationship established among them (the model). The order that should be followed in defining the decision categories (the method) is a secondary contribution, since the order could be completely defined only at the end of the research process, when the decision categories were completely developed. Additionally to the final version of the framework, discussed in chapter 6 and summarized in chapter 7, a preliminary version of the framework was presented in chapter 5. The goal in presenting an initial version was to illustrate the process undertaken in conducing this investigation and how an early version of the framework has evolved until reaching the final one.

Instantiations is the output of the design science approach related to the fourth objective of this investigation (Figure 116). They were generated throughout the solution development cycles in three stages (A, B, and C) by examining the empirical studies according to the decision categories proposed. The instantiations provided the basis for refining the framework throughout those cycles and also for presenting the studies' findings to the organisations in order to assess the utility of the solution. Furthermore, they provide evidence that the proposed framework works, namely, that it can be used for analysing customisation strategies (Figure 116). The instantiations were also included as sections of this document because they assist in understanding the decision categories and how the conceptualisations proposed for each of them apply in real world contexts.

In terms of the evaluation of the utility of the solution (Figure 116), it was necessary define criteria to clarify how the utility of the solution was going to be assessed. Three criteria were outlined: (i) usefulness in assisting the organisations in understanding their customisation strategies; (ii) usefulness in supporting decision-making and future actions; and (iii) usefulness in identifying conflicts between the customisation strategy and the business strategy and the customisation strategy and the organisation's processes. As presented in sections 5.5 and 6.6, the utility of the framework in each of the three case studies was assessed against those three criteria. The empirical evidence used for such assessment entails mainly the perceptions of the organisation involved in case studies 2, 3, and 4 and plans in terms of decisions and actions to be undertaken based on the study findings. In case studies 2 and 4, it was also possible to monitor actions and decisions that unfolded, providing additional evidence of the solution utility.

Concerning the assessment of the theoretical contribution of the solution, the framework was discussed in relation to the existing literature on the MC approach as presented in section 7.2. As depicted in Figure 115, the decision categories entail different kind of theoretical contribution. Some categories (configuration sequence, customisation units, modules combinations, and classes of items) are more heavily grounded on the empirical data of the studies. Hence, their main contribution is to conceptualise and abstract such data, creating new knowledge to be added to literature on the MC approach. Other categories (visualisation approaches, order penetration points, solution spaces, modules, and module interfaces) rely on existing underpinnings of the MC approach. The main contributions of those categories is to operationalise and adapt concepts, creating a knowledge that is applicable to real-world situations within the house-building sector.

This investigation does not propose technological rules, which is also a possible output for design science research (VAN AKEN, 2004). It seems that further empirical studies need to be carried out using the proposed framework prior deriving technological rules. In spite of that, it is possible to identify three types of technological rules that could be developed in future studies. First, it seems that some technological rules could address the implications of the different decisions within a category. They could be derived by examining the decision categories in different organisational contexts. For instance, the practical implications in assuming distinct decisions in the configurations sequence category are encapsulated in the four hypothetical types of sequence. Other hypothetical decisions, focusing on illustrating the implications of contrasting decisions, should also be developed for the other categories. It seems that a second type of technological rules would be related to the sequence of decisions to be followed in defining a customisation strategy. The method proposed in the framework (start by defining the core categories, define the other categories, and then revise the decisions taken in the core categories) is embryonic and should be further developed.

A third kind of technological rules could investigate the patterns of decisions assumed by an organisation, concerning the categories proposed, and whether these were aligned with the strategic goals and processes of a particular organisation. Such investigation could create technological rules that provide prescriptions such as “if competitive criteria X and Y are followed, the decision in the categories related to the product architecture should be A and B”. Clearly, this is a simplified rule and eventually it will not be possible to formulate rules in those terms. Nonetheless, the application of the framework in different contexts can reveal patterns of decision that work well in particular contexts, which can be useful for organisations that are developing strategies. In fact, some findings of this investigation provide initial contributions that could be used in developing such type of technological rules. In case study 1, the customisation strategy entails customisation units without the “other” and the “none” items which seems to be aligned with the strategic goals and the stage in the product development process that Company 1 was at. Hence, it could be suggested that the usage of the “none” and the “other” items in customisation units should be carefully considered by organisations that are starting a customisation strategy.

8.1 SUGGESTIONS FOR FUTURE RESEARCH

The development of this investigation also raised topics to be addressed in future studies. These are organised around six points:

a) This investigation proposes a framework with a set of categories that should be considered by organisations of the house-building sector in devising customisation strategies. Although an initial sequence for defining those categories is proposed, future studies should implement the framework to refine such sequence, in order to produce an empirically grounded method.

b) Studies should also be conduced with organisations that are starting the development of a customisation strategy in order to identify technological rules on the usage of the framework and the cycles involved in the strategy formation process.

c) Another theme for future investigation is to further explore the relationships among the decision categories and the implications that a decision in one category may have on the others. This investigation aimed to describe the range of decisions that can be assumed in each of the categories and their implications. For instance, it is proposed that all types of customisation (except for the one at the use stage) can be presented using any of the three visualisation approaches. Yet, empirical data is required for corroborating, refining, or refuting those propositions.

d) The patterns of decisions that are suitable for particular processes or strategic goals should be further explored in upcoming research initiatives aiming to create technological rules. A critical analysis of the patterns of decisions and the organisations contexts was carried out based on four empirical studies and some lessons could be drawn. Yet, studies looking at other organisational contexts should be conduced to broaden the glossary of patterns of decisions versus particular goals and processes.

e) The decision categories proposed have different levels of maturity. The core categories appear to be more consolidated than the others and seem to be applicable to a wider range of contexts. The decision categories concerning the product architecture should be further refined and expanded, in particular, the module interfaces category. The types of interface that apply to the product architecture of buildings and also operational prescriptions in defining these should be the focus of future studies.

f) Although the decision categories proposed address aspects of the product design, clients' interface, and operations that should be considered within these areas in defining a customisation strategy, they do not intend to address all decisions. Area-specific frameworks could be developed as subsequent research endeavours.

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APPENDIX A – DATA COLLECTION PROTOCOL

A.1. Key questions used in the semi-structured interviews in case study 1

Level of the hierarchical structure: identification of the business model, competitive criteria, and clients

- What are the competitive criteria pursued in the floor tiles business?
- What are the market segments that your company plans to target?
- Who are your rivals?
- How will be the retail approach for each of those segments?
- How will be promotion approach for each of those segments?
- How often do you plan to introduce new tiles models?
- Do you intend to offer only a catalogue of choice for the tiles or also produce bespoke tiles?

Level of the hierarchical structure: description of the product and the customisation options

- How much customisation do you plan to offer for the floor tiles?
- Will it vary depending on the market segment?
- Do you intend to initially only produce some models of tile and based on the demand introduce new ones?
- Do you plan to offer colour options for the tiles?
- Do you plan to offer shape options for the tiles?

APPENDIX B[71] – DATA COLLECTION PROTOCOL

B.1. Key questions used in the semi-structured interviews with employees of Company 2

Level of the hierarchical structure: 1. Identification of the business model, competitive criteria, and clients

- What is the business explored by Company 2?
- Could you tell me a little about the history of the Company?
- How do you advertise and retail your products?
- What are the competitive criteria pursued by Company 2?
- Who are the clients?
- Who are your competitors? How do you see Company 2 in relationship to them?

Levels of the hierarchical structure: 3.1 Mapping of the product development process

- Could you please describe the main stages and activities involved from a project inception until the handover of the apartments to clients?
- Can you also describe the duration and relationship in terms of time among these activities?
- How the customisation of the apartments fits within this process?
- What are the main activities involved?
- Could you describe each of them?
- Who is involved in each of those activities?

Level of the hierarchical structure: 3.2. Identification of practices

- What tools and practices do you use for supporting the product development process, and the activities related to the customisation of the apartment?
- Could you describe them and explain how each of them works?
- Could you show me documents related to those practices and tools?

Level of the hierarchical structure: 3.3. Description of the product and the customisation options

- What is your product?
- Do you have different lines of product?
- What can the client customise in the product?

[71] This protocol aims to illustrate the core questions that were used in case study 2, although not all sub-sets of questions were used in every interview. The sub-sets of questions were combined in order to encompass only questions that were relevant or suitable for the interview at hand. Also, additional questions were added depending on the interview.

- What are the options for each of the product parts that can be customised?
- Does it vary depending on the line of product?

APPENDIX C[72] – DATA COLLECTION PROTOCOL

C.1. Key questions used in the semi-structured interviews with employees of Company 3

Level of the hierarchical structure: 1. Identification of the business model, competitive criteria, and clients

- What is the business opportunity explored by Company 3?
- How does the Product[73] fit into the structure of Company 3 and the Corporation structure?
- What are the competitive criteria pursued by Corporation in the business unit related to the Product?
- How many product lines does Company 3 have? Please describe them.
- Could you please describe the key stage and activities since the initial toughs on the idea for the Product until its full development?
- What are the competitive criteria pursued in the Product and in the other lines of product?
- Who are the key clients for the Product and other lines of product?
- Do you see the Product as a new business model (a turn keys approach)?
- How do you advertise and retail your product?

Level of the hierarchical structure: 3.1 Mapping of the product development process

- Could you please describe the main stages of the process from the moment you offer the Product a client until the units are handover to clients?
- At which point does the client define the desired customisation options?
- How do you present the customisation options available to clients?
- Could you briefly describe the main stations and the activities performed in each of these?
- What where the criteria for dividing the activities into the stations the way it is? Have you done any studies on this?
- What are the more and less critical stations in the production line? Why?
- Do you only buy the customised parts after an order has been placed?

Level of the hierarchical structure: 3.3 Description of the product and the customisation options

- Could you please describe all the options available to clients in the Product?

[72] This protocol aims to illustrate the core questions that were used in case study 3, although not all sub-sets of questions were used in every interview. The sub-sets of questions were combined in order to encompass only questions that were relevant or suitable for the interview at hand. Also, additional questions were added depending on the interview.

[73] The name of the product was used when conducing the interviews but is removed in this document for disclosure purposes.

- How many different modules are needed for providing the five dwelling types?
- What are the commonalties among these modules?
- Why have you defined that the module would be a floor?
- How was the design of the dwellings types developed?
- Who was involved in this process?
- What were the goals to be achieved by the dwelling units in terms of design?
- What were the criteria for developing those designs?
- How many different modules are needed for providing the five dwelling types?
- Have you tried to establish other types of modules (such as modules per room)?

C.2. Key questions used in the semi-structured interview with the Architectural practice that developed the design of the boxes

<u>Level of the hierarchical structure: 1. Identification of the business model, competitive criteria, and clients</u>

- Could you tell me a little bit about your organisation and how did you become involved in the development of the Product?
- How was the design of the house types developed?
- Who was involved?
- What were the goals to be achieved by the dwelling units in terms of design?
- What were the criteria for developing those designs?
- Did you use any information from clients such as satisfaction survey or other sort of data for developing this?
- The five dwellings types were defined from the outset or they evolved throughout the design process?
- Have you done studies to see how the units could be combined for creating interesting landscape?

<u>Level of the hierarchical structure: 3.3 Description of the product and the customisation options</u>

- Could you please describe all the options available to clients in the Product?
- How many different modules are needed for providing the five dwelling types?
- What are the commonalties among these modules?
- Why have you defined that the module would be a floor?
- How was the design of the dwellings types developed?
- Who was involved in this process?
- What were the goals to be achieved by the dwelling units in terms of design?
- What were the criteria for developing those designs?
- How many different modules are needed for providing the five dwelling types?
- Have you tried to establish other types of modules (such as modules per room)?

C.3. Key questions used in the semi-structured with the consultants in case study 3

<u>General information</u>

- Could you tell me a little bit about your organisation and how did you become involved in the development of the Product?

Levels of the hierarchical structures: 1.Identification of the business model, competitive criteria, and clients and 3.1 mapping of the product development process

- How was the dynamics of the development process of the Product? Who was involved?
- What was your input in developing the Product?
- What concepts did you propose to be used in the Product? Where did they come from?
- What were the goals to be achieved by the Product units in terms of design?
- What were the criteria for developing these?
- Did you use any information from clients such as satisfaction survey or other sort of data for developing this?
- The five dwellings types were defined from the outset or they evolved throughout the design process?

Level of the hierarchical structure: 3.3 Description of the product and customisation options

- Could you please describe all the options available to clients in the Product?
- How many different modules are needed for providing the five dwelling types?
- What are the commonalties among these modules?
- Why have you defined that the module would be a floor?
- How was the design of the dwellings types developed?
- Who was involved in this process?
- What were the goals to be achieved by the dwelling units in terms of design?
- What were the criteria for developing those designs?
- How many different modules are needed for providing the five dwelling types?
- Have you tried to establish other types of modules (such as modules per room)?

C.5. Key questions used in the semi-structured with the two architectural practices that develop schemes using the boxes

General information

- Can you tell me a about the type of work your organisation does?
- What is your understanding of the Product?
- What are the pro and cons of the Product?

Level of the hierarchical structure: 3.2 Mapping of the product development process

- What is your role in delivering the Product?
- Could you please describe the process, once you have received a scheme from Company 3 until the final stages of such process? In fact, when does your involvement start?
- For how many schemes have you develop site plans using the Product? For whom?
- Could you show me schemes you have designed using the Product?
- Are any of these already built? Are you involved in any definitions of the internal layout and specifications of the house types?

- Do you define the external finishings to be used and roofing? At which stage of the process are these defined and by who?
- Are there guidelines for putting the different unit types together in a scheme? All the different house types can be combined or are there some limitations?
- Do you have key drivers for drawing master plans (for example, maximise number of residents)? If so, are these general or scheme specific?
- What kind of information does Company 3 pass on to you when they send you a plot?
- They mentioned that 15-20 units per scheme would be ideal. Why is that?
- Is there an ideal mix or combinations of units (in terms of volume)?

Level of the hierarchical structure: 3.3 Description of the product and customisation options

- What can be and cannot be customised on the Product?
- What are the options for each of the parts that can be customised?

C.6. Key questions used in the semi-structured with the structural engineers in case study 3

General information

- Can you tell me a about the type of work your organisation does?
- How long have you been working with Company 3?
- Do you work with Company 3 for providing traditional houses?
- Have you been involved in the development of the structure for the Product?

Level of the hierarchical structure: 3.1 Mapping of the product development process

- Could you please describe the process, once you have received a scheme from Company 3 until the final stages of such process? In fact, when does your involvement start after the agreement?
- For how many schemes have you develop site plans using the Product? For who and where?
- How many units do they have?
- Are any of these already built?
- In average, how many units on a scheme do you have to do structural modifications of the units?
- Do you see any the benefits in using the Product, from a structural perspective, for developing master plans compared to traditional master plan development? If yes, what are these?
- Do you see any negative aspects in developing master plans using the Product compared to traditional master plan development? If yes, what are these?

Level of the hierarchical structure: 3.3 Description of the product and customisation options

- Could you explain little how is the Product structure system (is it a posts and beams system)?
- Is there a standardisation of the structure across the different unit types for the Product? Like all floors have the same structure? All the structures are similar and there are just small changes?
- What is the reason for doing these alterations?
- Do these changes have implications in terms of the dimensions of the units?
- What is your understanding of the Product?
- What can be and cannot be customised on the Product? What are the options?

C.7. Key questions used in the semi-structured with the registered providers in case study 3

General information

- What is the type of product your company provides?
- Which types of schemes do you work with?
- What type of information do you have about the residents for a scheme at the moment you are procuring contractors?
- Where does this information come from? Do you collect it?
- How is this information used in developing a master plan and the house units design?
- Ideally, what would be your degree of involvement in developing the master plan and the housing types?

Level of the hierarchical structure: 3.3 Description of the product and customisation options

- How did you become aware of the Product?
- What is your understanding of the Product?
- Have you decided to use the Product in any scheme? Why? At which stage are you?
- Do you perceive any benefits in such product (against a traditional product brick-and-block)? If yes, what are these?
- Do you see any negative aspects in such product (against a traditional product brick-and-block)? If yes, what are these?
- What do you think could be improved in the Product?
- What do you think of the new business model proposed for this Product?
- What pars of a housing do you think is OK to standardise and which parts is essential for you to be able to choose?
- What do you can and cannot change (customise) in the Product?
- What do you think about having to decide (a) finishing, (b) fixtures, (c) windows and doors (d) roofing, (e) external cladding, and (f) dwelling types from a set of options defined by the contractor?

APPENDIX D – DATA COLLECTION PROTOCOL

D.1. Key questions used in the semi-structured with the Architectural practice 1

Level of the hierarchical structure: 3.3 Description of the product and customisation options

- How many dwellings types do you have?
- What were the criteria and guidelines used in developing these particular designs for the dwellings?
- What are the goals they are suppose to meet?
- Why are there two different sub-sets of dwelling types?
- Why (in each of this sub-set) are there some dwellings that differ from the other in terms of their overall design aesthetics?
- Could you please describe me how the design of these dwellings was developed?
- Who was involved in this process?
- Can you design bespoke dwellings to be used with the dwellings of the set?
- Are there any commonalities across these dwellings?
- How these dwellings are combined for creating a scheme?
- Are there any specifications in terms of materials or construction methods to be used in building these dwellings?

APPENDIX E – CAPÍTULO 1: INTRODUÇÃO

Este capítulo apresenta o problema de pesquisa, as questões e objetivos que nortearam esta investigação. A primeira seção apresenta a abordagem da customização em massa (CM) e destaca duas conclusões que resultaram da revisão da literatura: (i) vários estudos adotam apenas uma perspectiva (marketing, design de produto, ou gestão de operações) na investigação da abordagem da CM, resultando em uma fragmentação da literatura, e (ii) há uma escassez de pesquisas focando na operacionalização da abordagem da CM, visando apoiar as organizações do setor habitacional na elaboração de estratégias de customização. A segunda seção discute a importância da customização no setor habitacional e resume as contribuições dos estudos desenvolvidos acerca desta temática. A terceira seção apresenta o problema de pesquisa, que é traduzido em um conjunto de questões de pesquisa e objetivos, apresentados na quarta seção. Na quinta seção, as limitações desta investigação são descritas. A sexta seção resume o conteúdo desta tese.

1.1 A ABORDAGEM DA CUSTOMIZAÇÃO EM MASSA

A idéia central da abordagem da CM é fornecer algum grau de customização, buscando, ao mesmo tempo manter os padrões de eficiência, custo, e qualidade da produção em massa (MACCarthy; BRABAZAN, 2003). A abordagem da CM reflete os avanços na gestão de sistemas de produção e também a sofisticação da demanda dos clientes ao longo dos anos. Antes da Administração Científica, o artesanato foi o modo predominante de produção, que é caracterizado, de acordo com Brown e Bessant (2003), pelo baixo volume de produção e alta variedade. Com o advento da produção em massa como o paradigma dominante, as reduções nos custos, impulsionado pelas economias de escala, tornou-se o critério-chave da competitividade (PAIVA *et al.*, 2004). O progresso no desenvolvimento de sistemas de produção flexível e novas tecnologias da informação apoiaram o desenvolvimento de sistemas de customização em massa, oferecendo maior variedade a um menor custo (DA SILVEIRA *et al.*, 2001). Tal abordagem baseia-se na premissa de que clientes diferem em seus desejos, atitudes e preferências (ENGEL *et al.*, 2000) e que o atendimento dos requisitos específicos de cada indivíduo irá adicionar valor ao produto. A abordagem da CM também altera o *trade-off* entre custo e diferenciação: a customização pode ser alcançada sem um aumento proporcional em termos de custos.

Embora uma estratégia de customização possa criar uma vantagem competitiva, a abordagem da CM não é aplicável a todas as organizações de todos os mercados e setores. Por exemplo, a maioria das necessidades dos clientes em termos de sal pode ser atendidas pelos dois tipos básicos de sal disponíveis no mercado (HART, 1994): sal para a mesa e sal e para a estrada. Da mesma forma, Piller (2007) afirma que os clientes só querem aquilo que querem, independentemente se isto é um produto customizado ou padronizado. Isto destaca a importância de buscar o entendimento do que agrega valor ao cliente e como isto pode ser alcançado, ao invés de simplesmente assumir que um aumento no grau de customização automaticamente agrega valor aos produtos. Além disso, as implicações negativas de uma estratégia de customização não pode ser ignoradas, apesar do fato destas não serem amplamente discutidas na literatura como seus benefícios. Por exemplo, pode-se argumentar que a customização pode, potencialmente, reduzir o consumo de produtos uma vez que os clientes não precisariam comprar vários produtos para satisfazer as suas necessidades, pois teriam as mesmas atendidas por um único produto, customizado. No entanto, o aumento do grau de customização oferecido poderia provocar um aumento no consumo de produtos, uma vez que os clientes passariam a almejar diversas variações de um produto ao invés de um único produto padrão.

Estratégias baseadas na abordagem da CM procuram, simultaneamente, obter os benefícios das estratégias genéricas de custo e diferenciação introduzida por Porter (1980). Por causa da noção implícita da concorrência em duas dimensões (custo e diferenciação), a abordagem da CM é considerado um paradoxo ou uma contradição por Selladurai (2004), Hart (1995), Duray *et al.* (2000), Kumar *et al.* (2007), entre outros. Apesar disso, esta abordagem está alinhada com a mudança nas batalhas competitivas, o que permite a competição em mais de uma dimensão competitiva (PRASAD *et al.* 2001). No entanto, estratégias baseadas nesta abordagem tendem a ser mais complexa do que as estratégias genéricas de custo ou diferenciação, uma vez que dependem de decisões coordenadas em diferentes áreas da organização, a fim de fornecer a customização sem aumento proporcional de custos.

Vários estudos (BARDAKCI, WHITELOCK, 2005; DA SILVEIRA *et al.* 2001;. BARLOW, 1998) defendem a necessidade de uma consideração sistêmica, envolvendo toda a cadeia de valor, a fim de desenvolver e implementar estratégias baseadas na abordagem da CM. Isto deve-se ao fato que a customização tem implicações sobre a aquisição, design de produto, e as áreas de produção (SPRING; DALRYMPLE, 2000). Barlow (1998) reforça a necessidade de integrar as atividades de concepção, produção, e marketing para oferecer produtos customizados. Ahlstrom e Westbrook (1999) apontam que deve haver um diálogo entre a gestão de operações e as áreas de marketing a fim de alinhar a demanda do mercado com a estratégia de operações. Salvador *et al.* (2002) argumentam que as interdependências entre o produto, os processos, e a cadeia de suprimentos devem ser cuidadosamente considerados quando da elaboração de uma estratégia de customização. Com base nesses autores, pode-se argumentar que uma estratégia baseada na abordagem da CM exige decisões coordenadas nas áreas de marketing, design de produto, e operações.

Apesar desses argumentos ressaltando a importância de integrar as diferentes áreas, vários estudos abordam o tema de CM considerando a perspectiva de uma única área. Salvador *et al.* (2009), Piller e Kumar (2006), Duray *et al.* (2000), Ernst e Kamrad (2000) e Fisher (1997) são alguns exemplos de estudos que integram a perspectiva de duas ou mais áreas. Piller e Kumar (2006) propõem um conjunto de práticas que apóia a customização em massa, como o design modular, diferenciação tardia do produto, processo flexível e processo de co-design, envolvendo diferentes áreas, como arquitetura de produto, operações e marketing. Igualmente, Salvador *et al.* (2009) destacam as capacidades de um sistema de customização em massa, o que requer considerações acerca da interface para a criação de produtos customizados, considerando também as perspectivas do design do produto e operações. Fisher (1997) descreve duas cadeias de suprimentos, considerando a natureza do produto (funcional ou inovador) e define parâmetros para o seu funcionamento eficaz. Ele integra as questões relacionadas às características do produto, o tipo de demanda, e o ciclo de vida do produto na definição de uma cadeia de suprimentos. Duray *et al.* (2000) propõem quatro tipos de customização em massa baseadas nos pontos de envolvimento do cliente na configuração do produto e os tipos de modularidade adotados. Ernst e Kamrad (2000) discutem a influência da modularidade e da abordagem da diferenciação tardia produto na configuração da cadeia de suprimentos.

Outra crítica é a ênfase em estudos descritivos ou teóricos, que têm proposto modelos genéricos e taxonomias que não podem ser facilmente utilizados pela indústria na elaboração de estratégias de customização. Apesar da infinidade de estudos sobre a abordagem da CM, pouco é mencionado sobre a aplicação e a influência de variáveis contextuais, tais como características de plantas específicas na elaboração de estratégias de produção (BROWN, BESSANT, 2003). Um número de taxonomias de customização em massa têm sido propostas, tais como Lampel e Mintzberg (1996), Pine (1993), Gilmore e Pine (1997), e Da Silveira *et al.* (2001). Hart (1995) propõe fatores internos e externos que devem ser considerados por uma organização previamente a elaboração de uma estratégia de customização. Apesar de Hart (1995) discutir as implicações dos diferentes fatores na adoção de uma estratégia de customização, ele afirma que as questões de como definir a implementação de uma estratégia de customização, quando começar, em que áreas focar, e quão rápido prosseguir, permanecem ainda sem resposta. De acordo com MacCarthy *et al.* (2003), a literatura é limitada na compreensão do conteúdo das estratégias baseadas na abordagem da CM que são mais adequadas para ambientes específicos. Isto sugere que a base conceitual relacionada a CM que permite a provisão produtos customizadas com eficiência similar a produção em massa já está delineada. No entanto, parece que esta é predominantemente descritiva ou fornece prescrições em um nível genérico, dificultando sua adoção pela indústria. Desta forma, a elaboração de ferramentas que abordam os fundamentos da abordagem da CM, mas que também sejam capazes de integrar características específicas do contexto da organização, poderia permitir uma maior adoção de tal abordagem pela indústria.

1.2 IMPORTÂNCIA DA CUSTOMIZAÇÃO NO CONTEXTO HABITACIONAL

Várias tendências têm contribuído para a crescente diversidade das necessidades das famílias acerca de sua moradia. Estas incluem as mudanças no perfil demográfico das famílias, os novos papéis assumidos pelas mulheres (HASELL, PEATROSS, 1990; BRANDÃO, HEINECK, 2003), a co-existência do morar e trabalhar (FRIDMAN *et al*., 1997; BRANDÃO, HEINECK, 2003), e a proliferação de equipamentos e novas mídias, adicionando novas funções para as habitações (BRANDÃO, HEINECK, 2003; FRIDMAN et al, 1997). Tramontano (2002) destaca cinco tendências recentes em termos de arranjos domésticos: (i) um aumento de famílias monoparentais, (ii) um aumento de pessoas morando sozinhas, (iii) um aumento em casais com relação estável, mas que não são legalmente casados, (iv) um aumento de pessoas que vivem juntas, com base em interesses comuns ou preferências ao invés de vínculos sanguíneos, e (v) uma diminuição no número de crianças na família nuclear tradicional. Além destas tendências, que surgiram nas últimas décadas, há uma pluralidade de significados e dimensões associadas a habitações (SIXSMITH, 1986; EDELSTEIN, 1986; LAWRENCE, 1987; SMITH, 1994). Por exemplo, Smith (1994) identificou seis qualidades essenciais de uma casa (continuidade, privacidade, auto-expressão e identificação pessoal, relações sociais, calor, e uma estrutura física adequada) e que estavam ausentes em habitações não considerados pelos moradores como casas. Em termos de identificação pessoal, a customização das habitações é um meio para expressão da identidade do indivíduo (SMITH, 1994). Da mesma forma, Lawrence (1987) aponta vários fatores, psicológicos, culturais e demográficos que influenciam o design, significado, e uso das habitações e argumenta que as pessoas percebem a habitação de formas distintas.

Claramente, empreendimentos habitacionais devem atender às novas exigências introduzidas pelas tendências que surgiram nas ultimas décadas. Noguchi (2003) observa que os clientes não estão mais satisfeitos com os produtos repetitivos e que habitações devem ser capazes de atender a necessidades individuais. Da mesma forma, Barlow (1999), na avaliação da indústria da construção residencial no Reino Unido argumenta que aumentar a atratividade das novas habitações, o que exigirá o desenvolvimento de abordagens para atender aos requisitos atuais e futuros dos clientes, é um grande desafio a ser vencido. O significado idiossincrático que a habitação tem para cada família fornece um argumento adicional para o desenvolvimento de estratégias de customização que permitem o atendimento de necessidades específicas.

No Brasil, o tema de customização tem sido abordada por Cirico (2001), Oliveira e Moschen (2001), Brandão e Heineck (2003, 2007), Frutos e Borenstein (2003, 2004), Carvalho (2004), e Payeras (2005). No geral, esses estudos têm uma natureza descritiva e exploram estratégias ou abordagens para customizar unidades habitacionais (OLIVEIRA, MOSCHEN, 2001; BRANDÃO, HEINECK, 2007; ROSSI, 1998; EBERT, 2006), mapeiam as mudanças no ambiente domiciliar planejado ou realizado pelas família (SZUCS, 1998; CIRICO, 2001; REIS, 1998; REIS, 2000), calculam os custos associados à customização de habitações (CARVALHO, 2004), e quantificam os resíduos de construção e demolição gerados por customizações (PAYERAS, 2005). No geral, tais estudos focam no projeto das habitações e sugerem algumas abordagens para aumentar a adaptabilidade ou flexibilidade as mesmas. O tópico de customização também é marginalmente abordado por outros estudos (CARVALHO, FENSTERSEIFER, 1996; BARROS NETO *et al.*, 2002) centrado na estratégia de produção e na flexibilidade como um critério competitivo. Tais estudos exploram os diferentes tipos de flexibilidade e como estes podem ser utilizados por empresas do setor da construção civil. No entanto, eles abordam a customização considerando apenas a perspectiva de gestão da produção.

No contexto internacional, há estudos sobre a customização no setor habitacional no Reino Unido (NAIM, BARLOW, 2003; BARLOW, OZAKI, 2003; BARLOW, 1998; BARLOW, 1999), Japão (PATCHELL, 2002; GANN, 1996; BARLOW *et al.,* 2003; Noguchi, 2003) e México (NOGUCHI, HERNANDEZ-VELASCO, 2005). Tais estudos discutem a abordagem da CM, que foi concebida considerando as características do setor manufatureiro, e os princípios relacionados do marketing, design de produtos, e operações. Noguchi e Hernandez-Velasco (2005) identificaram a demanda por customização de projetos residenciais baixa renda no México. Eles concluíram que as habitações foram modificados logo após a ocupação e atribuíram isso à falta de oportunidades para customização nas etapas de projeto e vendas.

No contexto do Reino Unido, Barlow (1998, 1999) discute as barreiras para a adoção de customização em massa e práticas inovadoras no setor da habitação, tais como a falta de estratégias claras, o medo de mudanças, e o baixo grau de competição. Barlow e Ozaki (2003) analisam a receptividade e demanda do clientes por customização através de um estudo com uma organização do setor residencial, que começou a oferecer opções de layout e especificações. A investigação indicou que havia uma grande demanda pelo lado dos clientes, mas que mudanças estruturais, tais como pré-fabricação e uma gestão eficaz da cadeia de suprimentos seriam necessárias para oferecer esta customização de forma eficaz. Em geral, os estudos com foco no contexto britânico adotam uma perspectiva em nível de indústria, focando em identificar obstáculos e oportunidades para a adoção da abordagem da CM.

Em termos de contexto japonês, Barlow *et al.* (2003) analisam o *decoupling point*[74] *n*as cadeias de suprimentos de organizações que atuam no setor residencial. Eles concluem que as estratégias de customização podem ser apoiadas por diferentes modelos de cadeia de suprimentos. Gann (1996) explora as semelhanças e diferenças da industrialização no setor automobilístico e habitacional no Japão. Ele também destaca as características particulares do Japão, que permitiu a adoção da abordagem da CM de forma mais eficaz do que na Europa e EUA. Patchell (2002) também se concentra na indústria da construção japonesa e examina como a interação entre os construtores locais e nacionais moldaram o setor da construção naquele país. Os estudos sobre o contexto japonês têm uma abordagem mais prática do que os outros, principalmente em termos do que deve ser considerado por uma organização do setor habitacional para o desenvolvimento de uma estratégia de

[74] *Decoupling point* é o ponto em que os requisitos do cliente entram pela primeira vez da cadeia de valor. Ele divide a cadeia de valor em duas partes: a parte a montante, em que a produção é orientada por previsão, e a parte a jusante, em que a produção é orientada à demanda. Este conceito será discutido mais detalhadamente na seção 3.4.

customização. No entanto, as características específicas da indústria da construção e sua influência na adoção de estratégias de customização ainda são um ponto focal destes estudos.

Além da ênfase no entendimento da customização em massa em nível das características indústria, os estudos descritos acima também abordam tal conceito de forma fragmentada. Por exemplo, Barlow *et al.* (2003) considera principalmente a perspectiva de gestão de operações, descrevendo as cadeias de suprimentos observada nas diferentes empresas. Noguchi e Hernandes-Velasco (2002) aborda questões relacionadas a perspectiva de marketing, tais como a demanda por customização, mas não conecta tais questões com a gestão de operações e o design de produto. Por isso, há oportunidades para investigar a abordagem da CM de forma mais holística, integrando os fundamentos teóricos das diferentes áreas envolvidas na implementação de uma estratégia de customização. A abordagem da CM pode parecer superficialmente atraente, mas na verdade exige a consideração de questões complexas como a definição de atributos que os clientes desejam diferenciar, a interação entre o cliente e organização, e se a organização tem a capacidade de oferecer a diferenciação desejada de forma eficiente e rentável (MACCARTHY, BRABAZAN, 2003).

1.3 PROBLEMA DE PESQUISA

Esta investigação envolve um problema com importância prática e relevância teórica, e desta forma prevê contribuições para o mundo real e também para a literatura acadêmica. Habitações devem ser capaz de responder às necessidades específicas das famílias, aumentando o valor de tais produtos, sem um aumento proporcional nos custos e prazos de entrega. Além disso, se uma estratégia de customização não é desenvolvidas pela empresa e apenas habitações padronizadas são oferecidas, possivelmente personalizações serão realizadas pelos moradores conforme indicado por Miron (2008), Payeras (2005), Noguchi e Hernandes-Velasquez (2005), e Reis e Lays (2002). Em muitos casos, estas personalização não serão realizadas de forma eficaz e eficiente, podendo inclusive comprometer a qualidade e segurança da habitação. Para ilustrar a relevância prática do problema de pesquisa abordado nesta investigação, a Figura 117 mostra fotos antes e depois, que mostram as personalizações realizadas informalmente pelas famílias após a ocupação de moradias em um assentamento residencial de baixa renda estudado por Miron (2008). A construção de garagens, instalação de cercas, e outras modificações informais trouxeram prejuízos a qualidade das habitações e do loteamento. Assim, argumenta-se que o desenvolvimento de ferramentas que apoiem as organizações do setor habitacional na elaboração de estratégias de customização pode evitar ou mitigar tais problemas.

 

Figura 117: Exemplos de personalizações informais realizadas pelos moradores
(fonte: Miron, 2008)

Considerando uma perspectiva teórica, pode-se dizer que uma parte deste problema de pesquisa está relacionado a base teórica disponível sobre a abordagem da CM. Apesar do fato de haver conhecimento sobre os diferentes aspectos dentro das áreas de design de produtos, operações, e marketing que precisam ser considerados no desenvolvimento de uma estratégia de customização, as pesquisa prescritivas que permitem a aplicação de tal conhecimento para resolver problemas práticos ainda são escassas. A outra parte do problema está relacionada com as características idiossincráticas da indústria da construção, impedindo a aplicação direta de abordagens e conceitos que foram desenvolvidos considerando o setor da manufatura.

Projetos na construção civil são organizados em cadeias de suprimentos temporárias que são configuradas de acordo com o objetivo de projetos específicos (KOSKELA, 2003). Esta natureza temporária tem implicações nas estratégias de customização que podem ser desenvolvidas. Por exemplo, é improvável que uma única estratégia de customização seja utilizada para um grande volume de produtos como acontece no setor manufatureiro. Em muitos casos, as estratégias de customização irão variar de um projeto para outro, dependendo dos objetivos específicos deste projeto e das partes evolvidas. Hofman *et al.* (2009) descrevem as barreiras encontradas na elaboração de uma estratégia de customização e, mais especificamente, em uma arquitetura de produto que poderia ser usado em vários projetos. Tais autores argumentam que a maioria das empresas opera em uma rede descentralizada de fornecedores e clientes, onde não há uma organização líder que controla os padrões de compatibilidade, o que impede a introdução de regras para criação de módulos padronizados.

Na indústria da construção, cada produto é único e geralmente há pouca repetição ao longo de diferentes projetos (VRIJHOEF, KOSKELA, 2000). Uma vez que os fornecedores são passíveis de variar de um projeto para outro, a flexibilidade e a capacidade de lidar eficientemente com a customização pretendida também é passível de flutuação. Como no caso descrito por Hofman *et al.* (2009), algumas partes do edifício não foram modularizadas já que sua reutilização, em projetos futuros, era improvável. Entretanto, algumas das características da indústria da construção não se aplicam plenamente ao setor habitacional. Por exemplo, tipos de casa padrão podem ser usados em vários projetos como sugerido por Barlow (1999), introduzido um certo grau de repetição. Apesar disso, cada prédio tem que responder a um sítio específico e um contexto ambiental particular em termos da orientação solar, ventos, padrões climáticos, topografia, e paisagem. Assim, um edifício é colocado em um sítio e precisa se relacionar com este, não sendo tão independente do seu ambiente como outros produtos.

A escala dos produtos do ambiente construído é diferente da maioria dos produtos do setor manufatureiro, o que também representa um desafio em termos da customização que pode ser oferecida. Este é especialmente o caso se uma arquitetura modular é adotado e um edifício é dividido em módulos, que englobam espaços consideráveis. Na maioria dos casos, é improvável que os grandes módulos de um prédio sejam unidades que possam ser produzidas como partes completamente independentes. Na indústria de construção, as partes de uma edificação são frequentemente fabricados no local, diretamente sobre o prédio. A organização de um edifício em grandes módulos está presente nas idéias de *infill* e suporte proposta pela abordagem do *Open Building*. Alguns dos desafios enfrentados nesta abordagem se relaciona com o entrelaçamento dos sistemas de infra-estrutura e a compatibilidade entre sistemas fornecidos por diferentes fabricantes (KENDALL, 1999). Além disso, a pluralidade de significados e dimensões associadas a habitações introduz um escopo mais amplo de requisitos, que inclui também requisitos simbólicos e semânticos, e que devem ser considerados na elaboração de uma estratégia de customização.

1.4 QUESTÕES DE PESQUISA E OBJETIVOS

Com base no problema de pesquisa apresentado na seção anterior, são propostas três questões de pesquisa para esta investigação:

a) Como definir uma estratégia de customização para empresas de construção que operam no setor habitacional?

b) Como adaptar a abordagem da CM e conceitos relacionados para serem utilizados no setor habitacional?

c) Que decisões devem ser tomadas para a definição de uma estratégia de customização abrangente e coerente?

Com base nessas questões de pesquisa, quatro objetivos são propostos para esta investigação:

a) Propor um modelo conceitual para a definição de estratégias de customização no setor habitacional;

b) Definir um conjunto de conceitos relacionados à CM, a fim de adaptá-las ao contexto específico do setor da construção habitacional;

c) Propor uma sequência passos para a definição de uma estratégia de customização; e

d) Implementar o modelo proposto em casos reais, com o objetivo de avaliar a sua utilidade.

1.5 DELIMITAÇÕES

As categorias de decisão proposta no modelo visam definir o escopo de uma estratégia de customização e suas implicações em termos da interface com o cliente, arquitetura de produto, e operações. Estas áreas foram escolhidas porque, segundo a literatura, são áreas fundamentais que precisam ser consideradas para a definição de uma estratégia de customização de forma holística. No entanto, reconhece-se que outras áreas, como recursos humanos e finanças também precisam apoiar esta estratégia. As categorias propostas também não pretendem abordar todas as decisões que devem ser considerados nas áreas citadas acima, para elaboração de uma estratégia de customização. Além disso, reconhece-se que diferentes perspectivas poderiam ser adotadas na condução desta investigação. A perspectiva escolhida é abordar a customização como uma estratégia relacionada ao estratégia de negócios e se concentrar nas decisões relacionadas ao processo de desenvolvimento de produto que definem uma estratégia de customização. Finalmente, houveram algumas limitações em termos de dados que puderam ser coletadas em cada um dos estudos empíricos devido a suas diferentes etapas no processo de desenvolvimento do produto. Tais limitações serão apresentados em maiores detalhes no capítulo do método de pesquisa.

1.6 CONTEÚDO DA TESE

O restante deste documento está dividido em sete capítulos. O segundo capítulo explora a abordagem da CM e como ela contribui para aumentar o valor dos produtos habitacionais. O processo de desenvolvimento de produtos também é discutido neste capítulo. O terceiro capítulo apresenta os principais conceitos que apoiam a abordagem da CM, considerando as perspectivas de interface com os clientes, design do produto, e operações. No quarto capítulo, a *design science* que foi adotado como estratégia de pesquisa é apresentada. As três etapas que foram seguidas no desenvolvimento desta investigação são descritas, bem como as atividades realizadas dentro de cada uma destas.

O quinto e o sexto capítulos têm uma estrutura similar, conforme ilustrado na Figura 118: a primeira apresenta o desenvolvimento da primeira versão do modelo e o segundo o desenvolvimento da segunda versão. Cada um dos capítulos contém uma descrição dos estudos empíricos, o modelo proposto, as implementação, e uma avaliação da utilidade do modelo, considerando a perspectiva das organizações envolvidas nos estudos. O sétimo capítulo contém um resumo do modelo e das principais relações entre as categorias de decisão propostas. Ele também inclui uma discussão sobre o escopo de aplicação do modelo e sua contribuição teórica. O oitavo capítulo apresenta uma avaliação dos objetivos da pesquisa e as sugestões para trabalhos futuros.

	Capítulo 5 – Desenvolvimento da primeira versão do modelo conceitual	**Capítulo 6 – Desenvolvimento da segunda versão do modelo conceitual**
Descrição dos estudos de caso	Estudos de caso 1 e 2	Estudos de caso 3 e 4
O modelo	Primeira versão do modelo	Segunda versão do modelo
Implementações	Estudos de caso 1 e 2	Estudos de caso 1, 2, 3, e 4
Avaliação da utilidade do modelo	Estudo de caso 2	Estudos de caso 3 e 4

Figura 118: Estrutura do quinto e sexto capítulos

APPENDIX F – CAPÍTULO 8: CONCLUSÕES E RECOMENDAÇÕES PARA TRABALHOS FUTUROS

Os problemas relacionados com provisão de habitações padronizadas e a necessidade de fornecer habitações capazes de atender aos requisitos específicos dos moradores é o pano de fundo dessa investigação. Neste sentido, a customização em massa (CM) e conceitos relacionados foram escolhidos como a base teórica para abordar tais problemas. A abordagem da CM fornece a base para o desenvolvimento de estratégias de customização, capazes de atender aos requisitos específicos de cada família sem um aumento substancial no custo e tempo de entrega. No entanto, há dois problemas fundamentais na literatura que trata desta temática: a fragmentação do corpo de conhecimentos e a escassez de pesquisas prescritiva para apoiar a elaboração de estratégias de customização em casos reais. Com base neste problema de pesquisa, quatro objetivos foram definidos para esta investigação e que correspondem a *outputs* da *design science* (Figure 119).

Outputs* da *design science	**Objetivos da investigação**
Solução (Modelo conceitual)	Propor um modelo conceitual para a definição de estratégias de customização no setor habitacional
Constructos	Definir um conjunto de conceitos relacionados à CM, a fim de adaptá-las ao contexto específico do setor da construção habitacional
Método	Propor uma sequência passos para a definição de uma estratégia de customização
Implementações	Implementar o modelo proposto em casos reais, com o objetivo de avaliar a sua utilidade

Figure 119: Os *outputs* da *design science* e os objetivos desta investigação

A versão final do modelo, que surgiu ao longo do processo de pesquisa é a solução proposta. Conforme discutido no capítulo 4, a solução contem três outros *outputs* da *design science* propostos por March e Smith (1993): constructos, um modelo, e um método. Cada categoria de decisão proposta contém um ou mais constructos. Há também constructos como *variantes do produto*, que não fazem parte de nenhuma das categorias de decisão, mas que resultam de decisões tomadas nestas. As relações estabelecidas entre as categorias propostas, gera por sua vez um modelo. A sequência a ser seguida na definição destas categorias para a definição de uma estratégia de customização torna este modelo também um método. Detalhes sobre a sequência de decisões para definir uma estratégia de customização são apresentados na seção 7.1.

Apesar do fato de que a solução contém estes três *outputs* (constructos, um modelo, e método), eles têm ênfase distintas, em termos da contribuição. A principal contribuição desta investigação são os constructos e as relações estabelecidas entre eles (o modelo). A ordem que deve ser seguida na definição das categorias de decisão (o método) é uma contribuição secundária, uma vez que foi definida principalmente no final do processo de pesquisa, quando as dez categorias de decisão estavam completamente desenvolvida. Além da versão final do modelo, discutida no capítulo 6 e resumida no capítulo 7, uma versão preliminar também foi apresentada no capítulo 5. O objetivo em apresentar esta versão inicial foi de ilustrar o processo de pesquisa e as evoluções que ocorreram ao longo deste processo.

Implementações é o *output* da *design science* relacionado com o quarto objetivo desta investigação (Figure 119). Eles foram gerados ao longo dos ciclos de desenvolvimento da solução que se deu em três etapas (A, B, e C) através da aplicação das categorias de decisão propostas nos estudos empíricos. As implementações auxiliaram no refinamento do modelo e também foram fundamentais para apresentação dos resultados dos estudos para as organizações, a fim de avaliar a utilidade da solução. Além disso, eles fornecem evidências de que o modelo proposto funciona, ou seja, que ele pode ser usado para analisar estratégias de customização (Figura 118). As implementações também foram incluídas como seções deste documento pois auxiliam na compreensão das categorias de decisão e como as conceitualizações propostas se aplicam em contextos reais.

Em termos da avaliação da utilidade da solução (Figura 118), foi necessário definir critérios para esclarecer de que forma a mesma seria avaliada. Três critérios foram delineados: (i) utilidade em ajudar as organizações a compreender as suas estratégias de customização, (ii) utilidade no apoio à tomada de decisões e ações futuras, e (iii) utilidade na identificação de conflitos entre a estratégia de customização e a estratégia de negócios e os processos da organização. Conforme apresentado nas seções 5.5 e 6.6, a utilidade do modelo em cada um dos três estudos de caso foi avaliado utilizando os três critérios. A evidência empírica utilizada para essa avaliação envolveu principalmente as percepções das organizações envolvidas nos estudos (estudos de caso 2, 3, e 4) e os planos em termos de decisões e ações a serem realizadas com base nas conclusões do estudo. Nos estudos de caso 2 e 4, também foi possível monitorar as ações e decisões que foram desenvolvidos a partir das discussões junto às organizações, fornecendo evidências adicionais acerca da utilidade da solução.

Em relação à avaliação da contribuição teórica da solução, o modelo foi discutido em relação à literatura existente sobre a abordagem da CM tal como apresentado na seção 7.2. Algumas categorias de decisão (sequência de configuração, unidades de customização, combinações de módulos, e classes de itens) são baseadas mais fortemente em dados dos estudos empíricos. Assim, sua principal contribuição é conceituar e abstrair tais dados, criando novos conhecimentos que podem ser incorporados à literatura sobre a CM. Outras categorias de decisão (abordagens de visualização, *order penetration point*, espaços de solução, módulos, e interfaces dos módulos) baseiam-se em conceitos existentes na literatura. Neste sentido, a principal contribuição destas categorias refere-se a operacionalização e adaptação de tais conceitos, criando um conhecimento que é aplicável a situações reais no âmbito do setor habitacional.

Esta investigação não propõe regras tecnológicas, que também é um possível *output* para pesquisas que adotam a abordagem da *design science* (VAN AKEN, 2004). Os resultados desta investigação sugere que é necessário utilizar o modelo proposto, em outros estudos empíricos, para que as regras tecnológicas sejam evidenciadas. Apesar disso, foi possível identificar três tipos de regras tecnológicas que poderiam ser desenvolvidas em estudos futuros. Primeiramente, algumas regras tecnológicas podem abordar as implicações das diferente decisões dentro de uma determinada categoria. Estas podem ser obtidas a partir da aplicação destas categorias em diferentes contextos organizacionais. Por exemplo, as implicações práticas em assumir decisões distintas na categoria *seqüência de configurações* são apresentadas quando os quatro tipos hipotéticos de sequências de configuração são discutidas. Outras decisões hipotéticas, com foco em ilustrar as implicações de decisões antagônicas, também podem ser desenvolvidos para as outras categorias. Um segundo tipo de regras tecnológicas poderia estar relacionado com a seqüência de decisões a serem seguidos na definição de uma estratégia de customização. O método proposto no modelo (começar pela definir as categorias principais, definir as outras categorias, e depois rever as decisões as categorias principais) é embrionário e deve ser detalhado.

Um terceiro tipo de regras tecnológicas pode focar nos padrões de decisões assumidas por uma organização, relativos às categorias propostas e o alinhamento destas com os objetivos estratégicos e processos específicos de uma organização. Tal investigação poderia criar regras tecnológicas que criam regras do tipo "se os critérios competitivos de X e Y são seguidas, a decisão nas categorias relacionadas com a arquitetura do produto deve ser A e B". Claramente, esta é uma regra simplificada e, eventualmente, não será possível formular regras nestes termos. No entanto, a aplicação do modelo em diferentes contextos pode revelar padrões de decisão que parecem ser adequados para determinados contextos e que podem ser útil para organizações que estão desenvolvendo estratégias. De fato, alguns resultados desta investigação fornecem contribuições iniciais que poderiam ser usados no desenvolvimento de tal tipo de regra tecnológicas. No estudo de caso 1, a estratégia de customização tem unidades de customização sem o "outro" e o "nenhum" itens. Isto parece estar alinhado com os objetivos estratégicos e do estágio no processo de desenvolvimento de produto que a empresa se encontrava quando o estudo foi realizado. Assim, pode-se sugerir que o uso do "nenhum" e do "outro" itens em unidades de customização devem ser cuidadosamente considerados pelas organizações que estão iniciando uma estratégia de customização.

8.1 SUGESTÕES PARA TRABALHOS FUTUROS

Esta investigação também identificou tópicos a serem desenvolvidos em trabalhos futuros. Estes podem ser resumidos em seis pontos:

a) Esta investigação propõe um modelo com dez categorias de decisão que devem ser considerados por organizações do setor habitacional na elaboração de estratégias de customização. Embora uma seqüência inicial para a definição das categorias é proposta, estudos futuros devem implementar o modelo para refinar tal seqüência, a fim de produzir um método empiricamente fundamentado.

b) Estudos devem ser conduzidos com as organizações que estão iniciando o desenvolvimento de estratégias de customização, a fim de identificar regras tecnológicas sobre o uso do modelo e os ciclos envolvidos no processo de formação da estratégia.

c) Outro tema para investigações futuras é explorar mais as relações entre as categorias de decisão e as implicações que uma decisão em uma determinada categoria pode ter sobre as outras. Esta investigação teve como objetivo descrever a gama de decisões que podem ser assumidas em cada uma das categorias e suas implicações. Por exemplo, propõe-se que todos os tipos de customização (exceto para o uso) podem ser apresentados utilizando qualquer uma das três abordagens de visualização. No entanto, dados empíricos são necessários para corroborar, refinar, ou refutar tal proposição.

d) Os padrões de decisões que são adequados para processos específicos ou objetivos estratégicos devem ser mais explorados em investigações futuras visando a criação de regras tecnológica. Uma análise crítica dos padrões de decisões e os contextos das organizações foi realizado com base nos quatro estudos empíricos e algumas lições foram aprendidas. No entanto, estudos que foquem em outros contextos organizacionais devem ser conduzidos para ampliar o glossário de padrões de decisões versus objetivos e processos particulares.

e) As categorias de decisão propostas têm diferentes níveis de maturidade. As categorias principais parecem ser mais consolidadas do que as outras, sendo aplicável a uma maior gama de contextos. As categorias de decisão sobre a arquitetura do produto devem ser melhoradas e ampliadas, em particular, a categoria de interface dos módulos. Os tipos de interface que se aplicam à arquitetura do produto de edifícios e medidas operacionais para definição destes deve ser o foco de estudos futuros.

f) Embora as categorias de decisão propostas abordem aspectos relacionados ao design do produto, interface dos clientes, e operações, estas categorias não pretendem abordar todas as decisões que devem ser consideradas em cada uma destas áreas. Modelos específicos para cada área poderiam ser desenvolvidos como pesquisas futuras.