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Application of industrial production methodologies in the development of stationary furniture for the building industry.

The case of the company CASAIS - EC.

Cláudia de Lima Brito

Dissertation for Master's Degree in Product and Industrial Design

Dissertation Advised by
Doctor Bárbara Rangel

Dissertation Co-Advised by
Eng.º Miguel Pires and Prof. Dr. Jorge Lino

Porto, 2nd July 2018

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Cláudia de Lima

"Why can’t we mass-produce houses – standard, well-designed, at low cost – in the same way Ford mass-produces cars?”

Gilbert Herbert, in *The Dream of the Factory-made house* (1984)

Resumo

A eficácia do desenvolvimento de produto é encarada como um ponto inerente ao sucesso de uma empreitada. Tipicamente o mobiliário fixo é desenhado e desenvolvido individualmente e exclusivamente para um determinado projeto – feito à medida – de acordo com as especificações do cliente e os requisitos deste projeto. Este estudo tem como objetivo propor e avaliar uma estratégia para desenhar e desenvolver mobiliário fixo numa empresa de construção, de acordo com os princípios de produção industrial.

Dada as exigências no sector da construção é pertinente propor alternativas para as estratégias atuais, que visem a sustentabilidade dos recursos e dos processos. A relevância deste estudo é justificada pela necessidade de alcançar a industrialização e a normalização dos produtos integrados na arquitetura e ao mesmo tempo conseguir dar resposta às solicitações variadas do cliente e as especificações do projeto.

Um caso de estudo, realizado na Casais – Engenharia e Construção, comprova que ao integrar métodos de modularização e gestão de produtos, é possível proporcionar uma ampla variedade de produtos, normalizados na empresa, sem comprometer a complexidade interna. Propõe-se uma estratégia para o desenho e desenvolvimento de mobiliário fixo normalizado, baseado numa plataforma de produto, apropriada para uma empresa de construção.

A aplicação desta estratégia alternativa resulta numa redução considerável do tempo do ciclo de desenvolvimento de mobiliário fixo e melhora a apresentação dos produtos, reduzindo, porém, a liberdade de design.

Os resultados mostram que esta estratégia, quando usada corretamente, pode contribuir positivamente e num panorama geral acrescentar valor para o projeto de construção. A estratégia alternativa proposta é um exemplo de como com um número limitado de componentes normalizados pode gerar uma grande quantidade de opções/variantes.

Palavras-chave: Desenvolvimento de produto, mobiliário fixo, design industrial, construção civil

Abstract

The effectiveness of product development influences a construction project success. Currently stationary furniture is designed and developed individually and exclusively for a project – made to measure - in compliance with the customer requirements and project specifications. This study aims to propose and evaluate a strategy to design and develop stationary furniture in the specific setting of a building construction company, in accordance with the main industrial production principles.

Given the actual construction sector demands, it is relevant to propose alternatives for the current strategies, that might address the sustainability of resources and processes. The relevance of this study is justified by the need of achieving standardization of developed product and at the same time to be able to respond to customer requirements and project specifications.

A case study, performed at a construction group, CASAIS, proved that by integrating industrial production methodologies, the company can achieve optimum balance between standardization and product variety, providing economical, technical and time advantages. A platform-based strategy resulted in a substantial reduction of the product development cycle time, improvements of the product presentation, however design freedom is reduced.

Results shown that this alternative strategy, when properly used, can contribute positively and add value to the construction project. This strategy is an example of how an abundance of configuration options can be realized with a limited set of standardized components.

Keywords: Product development, stationary furniture, industrial design, construction industry

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This research was supported by the company CASAIS, Engineering and Construction that I would also like to express my gratitude for giving me the opportunity to provide me an "hands-on" experience that made possible to acquire a depth understanding of my research, providing me an additional learning experience and for the reliance. I would like to thank the technical office team, namely my co-supervisor and chief department engineer Miguel Pires, for the guidance, not only in this research with his immense expertise, but also for leading me in my first labour market experience. I would like to thank architect Mário Fernandes for his trust and for sharing his wisdom and vision. To those with whom I worked the most, a special highlight to my colleague designer Ana Simões for her assistance, encouragement and support. I would also like to give a special acknowledgement for those who showed support in Carpin - Casais, Wood & Metal.

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List of Acronyms

BIM – Building Information Management

BOM– Bill of Materials

CE – Concurrent Engineering

DFA – Design for Adaptability

DFMA – Design for Manufacturing and Assembly

DFV – Design for Variety

DFO – Design for Operability

DFX – Design for Excellence

DSM – Design Structure Matrix

FBAUP – Faculdade de Belas Artes da Universidade do Porto

FEUP – Faculdade de Engenharia da Universidade do Porto

FF&E – Fixture, Fittings and Equipment

GDP – Gross Domestic Product

IBS – Industrialise Building System

IPD – Integrated Project Delivery

KPI – Key Performance Indicator

LPD – Lean Product Development

MDIP - Master's Degree of Product and Industrial Design

PDP – Product Development Process

QFD – Quality Function Deployment

RTA – ready-to-assemble

VSM – Value Stream Mapping

Chapter 1 **Introduction**

The present thesis was developed under the scope of the Master in Product and Industrial Design, from the Faculty of Engineering (FEUP) and the Faculty of Fine-Arts (FBAUP) of the University of Porto. The research described was developed while performing an internship at Casais, Engineering and Construction S.A, in Braga – Portugal, within a period of approximately six months.

Product development process performance of stationary furniture influences the building construction project. Given its importance and current demands in the construction sector, such as the increasing complexity of modern buildings and client demands, the declined number of skilled workers, increasing operation costs and quality standards and the competitive market, there is a need of standardise and industrialise construction. In this way it is relevant to approach the way how products are designed and developed in the construction sector.

Typically, stationary furniture is designed and developed individually and exclusively for a construction project – made to measure - in compliance with the customer requirements and project specifications. This piece of furniture is unique and highly adapted to this project, in the way that the model cannot longer be reused for another project. The process is repeated every time a project arrives, and it is necessary to design and implement any kind of stationary furniture.

Recent guidelines for construction products encourage rethinking design processes and increasing standardization and industrialization in the design process and outcomes. However, a building construction is considered a unique 'product' and thus, it demands the development of single unique furniture as well. The question is: 'How can we balance furniture standardization and variation in the design of stationary furniture?'

This study aims to propose and evaluate a strategy to design and develop stationary furniture in the specific setting of a building construction company based on industrial production principles.

A case study, performed at Group Casais, proved that by integrating industrial production methodologies - modular design - the company can achieve optimum balance between standardization and product variety, providing economical, technical and time advantages. A platform-based strategy resulted in a substantial reduction of the product development cycle time and improvement in the product presentation. Although the design choice becomes limited and consequently design freedom is reduced.

1.1 **Motivation**

The motivation for this research stems from a case provided by the construction company CASAIS, Engineering and Construction, S.A. Currently stationary furniture included in their projects is being made to measured. This means every time a new project starts, new furniture must be designed and developed from scratch. This strategy has been resulting in several negative aspects such as the overtime spent in this activity, the number of errors found in late stages of development and the lack of quality that leaves a great deal to be desired.

This research embraces the idea that by better understanding the specifications of building construction relative to the manufacturing industry it is possible to contribute – with industrial production principles and methodologies - for the industrialization of construction.

1.2 **Goals of the study**

Given the characteristic of the challenge provided by the company, the objective of this research starts by analysing existing methodologies and strategies, that are typically used in the manufacturing industry to design standard products. Through the understanding of these methodologies, strategies, the ideas were to lump up several methods and approaches to design and propose an appropriate strategy for a construction company

As said, furniture is being designed specified and developed only and exclusively for the on-going project, and not being used for any other future project. This happens due the fact that there is no type of prerequisites for furniture dimensions or any kind of standardisation in these company. Several industrial production strategies have proved to be a successful approach for achieving this balance between product variation – to fulfil customer requirements – and standardisation – to proposed solutions in a more effective and efficient way for the manufacturers. In this way the goal of this study case is to prove that by integrating an alternative strategy to design and developed built-in furniture employing industrial production methodologies, the company can achieve economical, technical and time advantages.

Figure 1 maps the goals of the study and provide some orientation towards the task list followed to achieve the goals.

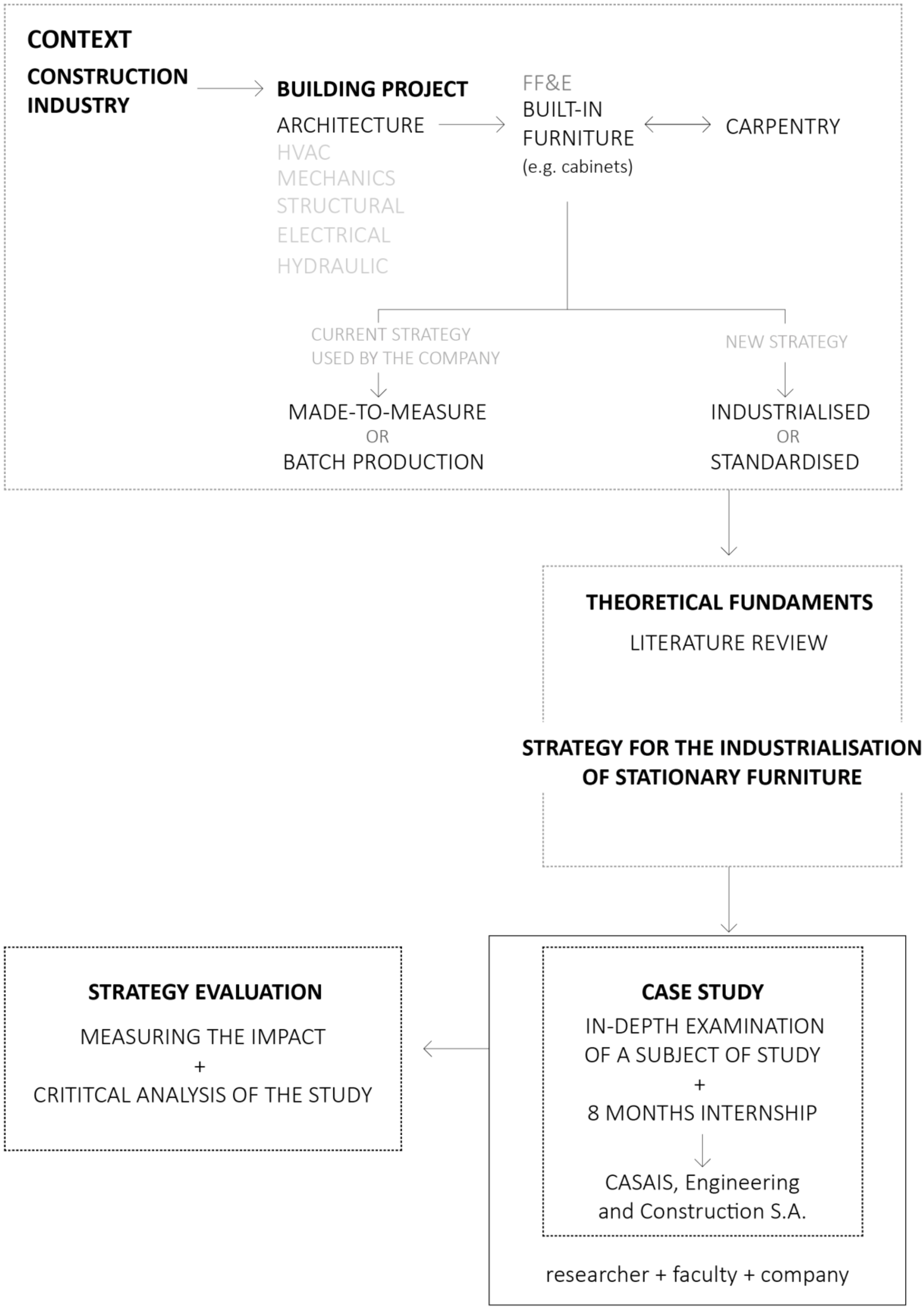

Figure 1 *- Graphical explanation of the goals of the study.*

1.3 Methodology

In this thesis, both primary and secondary data are collected. The term primary data refers to the data originated for the first time by the researcher with the purpose of addressing the research problem at first hand. Secondary data is the already existing data, collected by other researchers earlier.

The literature review focused on secondary data, namely articles from scientific journals, conference papers, books, report and master, doctoral dissertations, as well as websites and databases related to the goals of this research.

The research project started with an internship in an engineering and construction company with a duration of 8 months. This method provided an "hands-on" opportunity to acquire an unparalleled depth understanding of the problem and it provided an additional learning experience as well as access to other documents from the organization. A study case approach is adopted to enable implementation and result analysis from a real-world case and context.

To collect primary qualitative data within the company concerned, four interviews were performed. The aim of using an unstructured interview was to provide freedom in terms of content and structure, leading the interview to new findings.

1.4 Structure of the document

This thesis is organized around four chapters, which are summarized as follows.

The first chapter presents a general introduction, which in turn is divided into four sub-chapters. This chapter describes the motivation that lead this research, the goals of the study intended to be achieved, the methodologies adopted along the research and the structure of the document.

Chapter two presents a literature review in which it is made a description and comparison between the manufacturing industry and the construction industry. Fundamental notions are defined and exemplified. In the end, a summary on the most relevant practices and methodologies used for product development strategic improvement is presented.

Chapter three concentrates on the case study in which a platform-based strategy is designed and implemented in a construction company. This alternative strategy is compared with the current one.

This chapter also is dedicated to the comparison of performance indicators and measurement of results.

Finally, chapter four examines the achievement of the aim and objectives of the research, presenting conclusions about the research hypothesis and recommendations for improvements of the presented strategy.

Appendices provide additional detailed information related to the research, which is presented separately. The information attached provides further information on interviews and an article submitted for a conference relevant for this research.

Chapter 2 **Literature Review**

The literature review chapter presents the review and synthesis of the relevant literature from the research areas being investigated such as product design and development, design project management, manufacturing and construction industries, products in building construction, methodologies for product development and management, among other related with the research topic. In this way the literature review required the research of relevant information and as much as possible information on the subject being study before proceeding further.

This chapter is organized around four main groups:

– *2.1 Manufacturing Industry vs Construction Industry*, which includes a broad description, comparison and analysis of the characteristics and specificities of the manufacturing and the construction industry; includes insights about the current situation and future perspectives for product development in both industries;

– *2.2 Fundamental notions + examples*, which describes a list of cross-cutting concepts, from both industries under study, for a holistic understanding; the relevance of these concepts is supported with real-world case examples and references;

– *2.3 Product Development Process in the specific setting of building construction*, includes a brief analysis of a typical process followed for developing products for construction projects. It is included a construction product categorisation, giving emphasis on fixed furniture products

– *2.4 Product Design and Development: methods and strategies*, were there are classified and described relevant methodologies, typically used in the industrial production industries. It is included a review on different methods to measure the performance of these methodologies.

2.1 **Manufacturing Industry vs Construction Industry**

Manufacturing industry refers to those industries which involve in the manufacturing and processing of items either the creation of new commodities or in value addition (Economywatch 2010). Manufacturing is defined as "high production; i.e. high-volume production on an assembly line of relatively simple, standardized, self-contained products" (Crowley 1998). According to Chryssolouris (1992), manufacturing is "the process of transforming materials and information into goods for the satisfaction of human needs" (as cited in Crowley 1998). Manufacturing is essential for the economic well-being and quality of life of a nations' citizens because manufacturing creates lasting wealth while also distributes wealth through jobs (Hu 2013). The Manufacturing industry accounts for a significant share of the industrial sector, it generates about 16% of GDP – Gross Domestic Product – and it is one of the largest contributors to employment (Eurostat 2017). Figure 2 visualises how the Manufacturing sector is organised.

Manufacturing Subsectors

(1) food products
(2) beverages
(3) tobacco products
(4) textiles
(5) wearing apparel
(6) leather and related products
(7) wood and product of wood and cork except furniture; articles of straw and plaiting materials
(8) paper and paper products
(9) reproduction of recorded media
(10) coke and refined petroleum products
(11) chemicals and chemical products
(12) basic pharmaceutical products and pharmaceutical preparations
(13) rubber and plastic products
(14) other non-metallic mineral products
(15) basic metals
(16) fabricated metal products, except machinery and equipment
(17) computer, electronic and optical products
(18) electrical equipment
(19) machinery and equipment n. e. c.
(20) motor vehicles, trailers and semi-trailers
(21) other transport equipment
(22) furniture
(23) others
(24) repair and installation of machinery and equipment

Figure 2 - *List of the 24 Manufacturing Subsectors combining the most diverse activities (Eurostat 2017).*

This sector is sensitive to the price of raw material, but increasing labour and land costs in the development process became a prime concern (Vogler 2016). Throughout the different subsectors, it is required the participation of a number of specialists and functions (Cooper et al. 1998), that typically work inside a factory or in a manufacturing plant in a controlled environment (University 2018).

According to Cooper et al. (1998) the manufacturing and the construction industry are closely related to the fact that both involve the design and development of a product. Either a building or a car, both concentrates phases such as the development of an idea, try to answer clients' needs and requirements to the final commercialisation of a 'product'. Since the goal of this research focuses on industrial production methodologies currently used in the manufacturing industry for developing products, the approach on the manufacturing industry along this chapter is closely related to the part of the industry that includes new product development activities.

Construction industry is one of the world economy's largest sector and a huge driver of global growth (McKinsey 2017). It generates about 10% of GDP and positively influences the growth of employment (Averjanoviene et al. 2008). In terms of production output, this industry proves to be one of the largest industries. This industry is very sensitive to the price of raw materials. A large number of specialized personnel is implicated (Formoso, Tzortzopoulos, and Liedtke 2002). The level of professional skills required for this sector differs according to the type of work: in the professional area or construction management, requires high degree education in construction sciences, construction management or engineering, business and management and appropriate professional experience in the sector. Skilled workers, which are mostly men, are usually trained crafts (Averjanoviene et al. 2008). Work on site is considered to be one of the most dangerous with the highest number of fatal accidents compare to any other European economic sector (Eurostat 2014). Figure 3 lists the four construction industry subsectors.

Construction Subsectors

(1) Building construction: Construction of residential and non-residential structures, including commercial and social buildings.

(2) Civil construction: Construction of all types of civil works, including transportation, utilities, and telecommunications.

(3) Industrial construction: Construction of light and heavy industrial facilities, including warehouses, manufacturing, oil and gas installations, and mining installations.

(4) Specialty construction: Specialized trade construction of elements common across all types of construction (for instance, framing, roofing, glass and glazing, masonry, drywall, and insulation).

Figure 3 *- Construction Subsectors List (McKinsey 2017).*

Construction industry is the biggest product-based industry, when compared with the serviced based industries (University 2018), and have an impact in many other economic sectors since is a major consumer of service and intermediate products such as raw materials, chemicals or electrical equipment. Construction products – buildings, houses, hospitals - are large and usually immobile, demands a higher degree of complexity in the number and range of component parts; its production on site introduces varying degrees of uniqueness; and building products must be more durable (Gann 1996). Excluding specific standard projects or modular houses, a construction product is unique, it is not mass produced and it has a permanent location (Gann 1996; Nobre, Santos, and Neto 2004). Construction projects demand a lot of work teams and information flows are huge (Crowley 1998). Construction company's clients can be either private individuals, businesses or some public clients, such as government agencies. The general contractors, usually, the one heading up the construction process of the project, bring subcontractors to subcontract certain elements of the project to a more specialized firm or company to reduce costs or to mitigate project risks (University 2018). According to Nobre, Santos, and Neto (2004), in the construction industry building subsector, the value of the product is obtained exclusively from the projects that reflect the needs of the clients, thus the production does not add any value to the product. This means that the project guidelines provides the specifications and details of the product and the production is in charge of executing them as described, generating the risk of decrease value of its execution if it not in accordance with the project (Nobre, Santos, and Neto 2004).

Due to the different industries characteristics, construction and manufacturing have distinct development process (Tzortzopoulos, Betts, and Cooper 2002). It is considered that the final product of a manufacturing process is a common artefact – such as a piece of furniture - and the final product of a construction process is a building – such as a residential building. The design and construction process can be analysed as a product development process (PDP), since it describes the flow of activities needed to develop a product (Tzortzopoulos, Betts, and Cooper 2002). In this way, the following section focuses on describe the process followed to develop a final product in the two industries under study.

A. **Manufacturing - Product Development Process**

Which processes are needed and followed to develop a product in the manufacturing industry?

Product development process (PDP) is defined as the sequence of steps or ativities that an organization employs to conceive, design, and comercialise a product (Ulrich and Eppinger 2012). In the manufaturing industry, this process is usually oriented to mass production - to produce a number of units of the same product (Tzortzopoulos, Betts, and Cooper 2002). The transformation of raw material – input – into transformed finished goods on large scale – output – requires to follow a sequence of steps - process. The main goal of defining a development processes is to maintain and support the key-activities under control, efficiently, effectively and flexible enough to changes (Silva 2001). Developent processes are represented mostly under a sequence of steps and decisions need to perform a certain process. Flowcharts, diagrams and map processes are the commonly used to process management (Silva 2001).

Ulrich and Eppinger (2012) presented a generic PDP, based on a six phase approach, as illustrated in **Figure 4**. The process starts with a planning, linked to activities related to research, technology and business, followed by the concept deveopment, design activities, testing, and refinement and production. The conclusion of the process is the product launch in which the product becomes available to purchase in the marketplace.

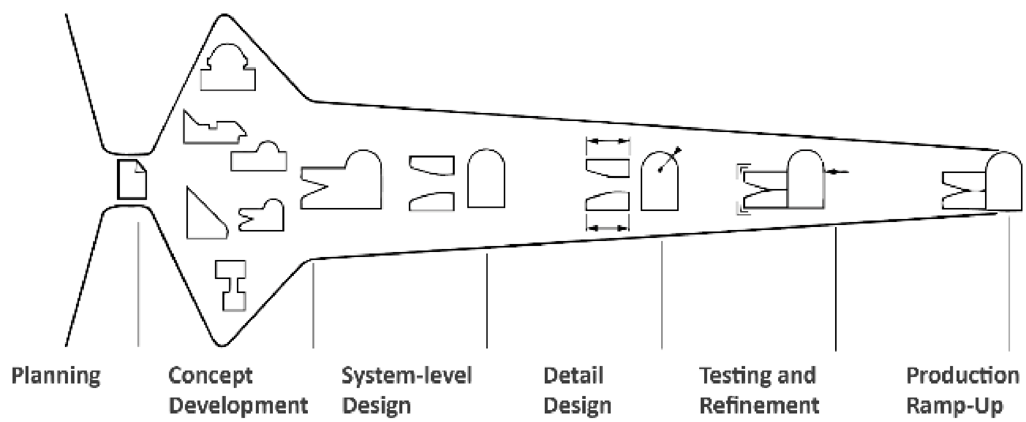

Figure 4 *- The six-phase generic product development process. Adapted from "Product Design and Development" (Ulrich and Eppinger 2012).*

Product development is a interdisciplinary activity requiring contribution from different disciplines at a firm; however beyond the customer or the end user, three funtions are central to a product development project: Marketing, Design and Manufacturing (Ulrich and Eppinger 2012).

- Marketing mediates interactions between the organization and the customers, facilitates the identifcation of product opportunities, defines market segments, and identifies customer needs. Marketing funtions also includes setting prices and overseing the launch and promotion of the products.

- Design plays an important fucntion in the role of defining the physical form of the product to best meet customer needs. Design funtion includes engineering design (mechanical, electrical, software) and industruial design (aesthetics, ergonomics, user interfaces, materials).

- Manufacturing function is mainly responsible for designing, operating and/or coordinating the production system in order to produce a product. Manufacturing function also includes purchasing, distribution and installation – supply chain operations.

In addition to the main participants in the product development process, proposed by Ulrich and Eppinger (2012), literature shows that customers and end users play an important role in the process. **Figure 5** visualises the main participants in a product development process. The authors also refered other functions such as finance, sales and team leaders.

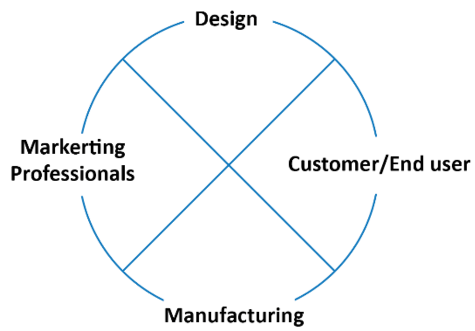

Figure 5 *- Main participants in a product development project in the manufacturing industry. Adapted from "Product Design and Development" (Ulrich and Eppinger 2012).*

Several PDP models are presented in literature. In the manufacturing context, a typical product development process consists of research, marketing, design production, quality control, distribution and recycling (Vogler 2016). Ulrich and Eppinger (2012) defined a generic product development process, as a six phased plan – planning, concept development, system-level design, detail design, testing and refinements and production ramp-up. This PDP is visualised in Figure 6 emphasis on the costs of design changes and ability to impact costs is given on the subchapter 2.3.

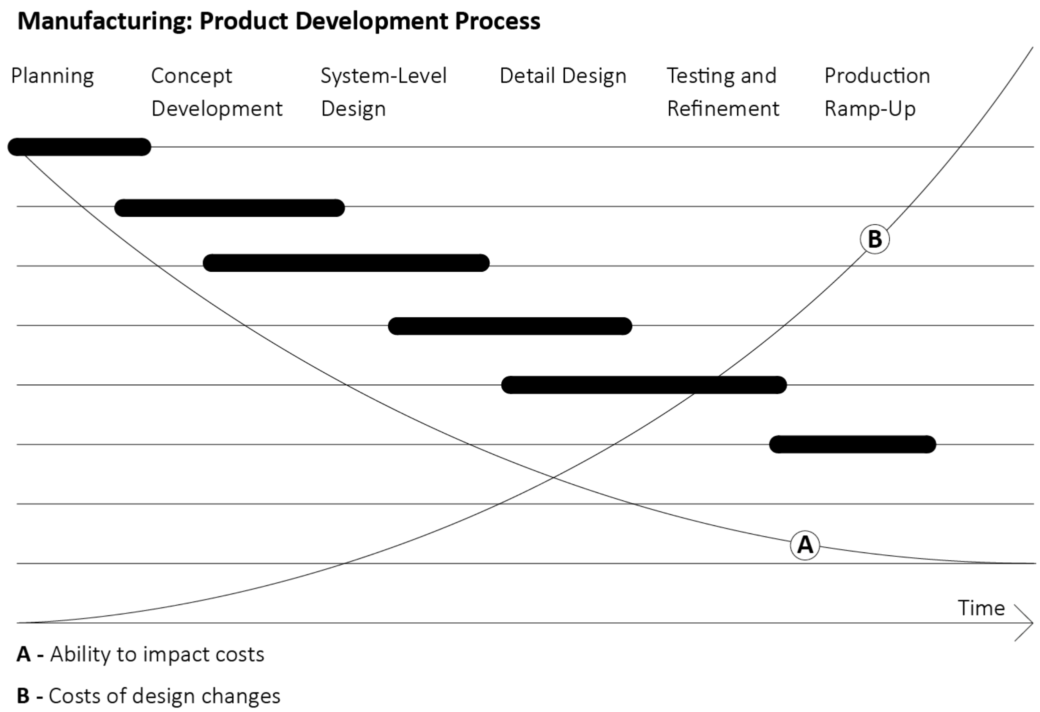

***Figure 6** - Six phase generic product development process presented by Ulrich and Eppinger. Adapted from "Product Design and Development" (Ulrich and Eppinger 2012).*

Understanding and defining a development process is relevant for: assuring quality – through checkpoints along the PDP phases, ensure coordination – through the definiton of roles of each player, contributions and information and materials exchange, organization and planning – schedule of the overall development project, assuring management – proving to the managers the possibility to identify possible problem areas and enable improvements – through documentation and ongoing reviews (Ulrich and Eppinger 2012). Still it is hard to plan the design process as a sequence of well defined steps, as most decisions are effected by some that have been made before and also by others that will be made in future stages of the project (Formoso, Tzortzopoulos, and Liedtke 2002).

B. **Construction - Product Development Process**

Which processes are needed and followed to develop a product in the construction industry?

The process of creating a building is always a complex task with many different participants as well as different aspects and conditions to take into account (Jurse and Wojcik 2015). The process of developing a construction project generally has a long term duration (Fabricio 2002) and includes the constructive process, planning, design project, production project, execution preparation and usage (Romano 2006). Building 'products' are characterized by their uniqueness; the large size, the high value, the long service life, social and economic importance, market variability, urban and cultural impact (Fabricio 2002). In contrast to production industries, businesses and enterprises, products generated by this industry are organized according to a unique cycle of production, non-repetitive, linked to a fix location (Fabricio 2002). According to Silva (1996), product generated by the construction industry are durable consumer goods intended for use and investment (as cited in Fabricio 2002). Practices and methods used are normally developed particularly oriented to each project, since the project presents different peculiarities (Fabricio 2002).

The product development process of a building construction can be defined as a the set of activities needed for a project, from the identification of market opportunities, to specification of the requirements to be delivered to the client (Tzortzopoulos 2004), and project of specialities: architecture, structural, mechanical, electrical, among others. This process consist on a large number of sub processes under the responsibility of various agents – designers from different specialities, developers, managers, executors, suppliers, end users, among others (Romano 2006). For the development of a building project teams are arranged joining different specialities and firms (Fabricio 2009). According to Melhado and Violani (1992), the four main participant in a construction venture are: Clients - as they generate the opportunity; Designers, Engineers and Architects - who give form and shape to the product; Constructor - that operates the product; and the Customer - as end user of the product; **Figure 7** illustrates the main participant in the development process of a construction product.

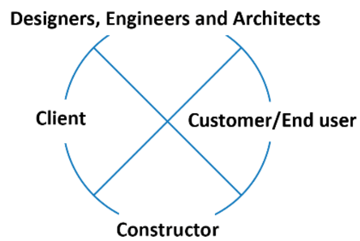

Figure 7 *- Main participants in a construction venture. Adapted from “Projeto Simultâneo na Construção de edifícios” (as cited in Fabricio 2002).*

The development process time of a building construction varies according to the complexity of the final product and the availability of resources from the investors. Fabricio (2009) describes a typical building construction development process starting with: the definition of needs, definition of the architecture project and development of the team (designers, architects and engineers). Another relevant point described by this author, that characterises the construction development process, is that a building, in comparison with manufacturer product, can launched for sale ahead of its completion. A generic construction development model is illustrated in **Figure 8**.

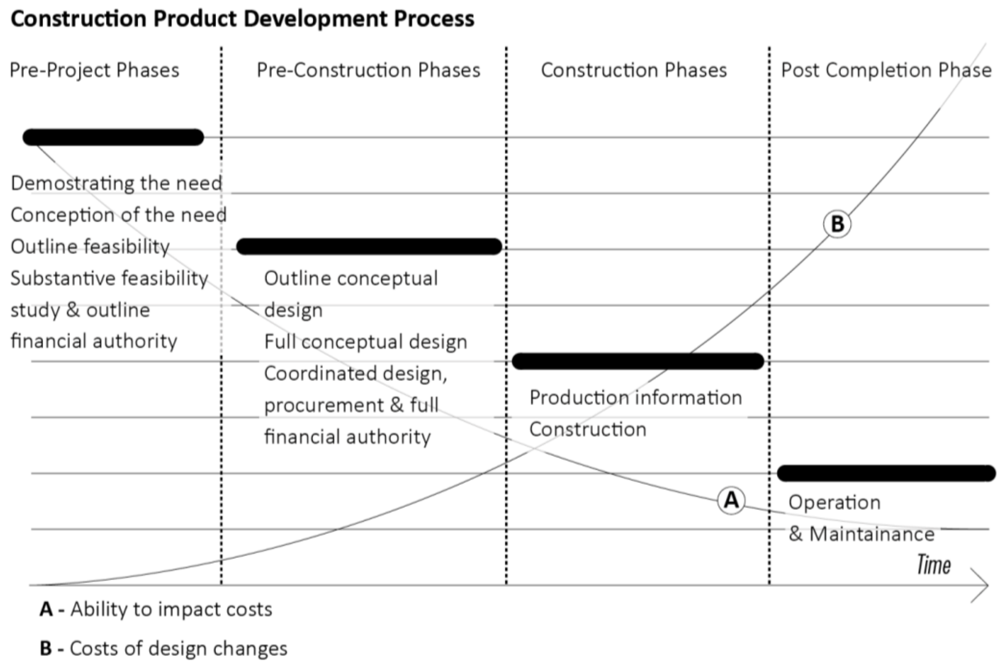

***Figure 8** - Generic design and construction process model. Adapted from "The development of a generic design and construction process" (Cooper et al. 1998).*

Currently there are several methodologies and tools that support the different project phases. Integrated Project Delivery (IPD) is a project methodology that articulates the decisions from the different areas involved in the project. Lean Construction is a methodology, tied to the lean principles and adapted from lean production techniques from the industry, that aims to maximize value to the customer while minimizing waste. Building Information Management (BIM) process tool that integrates the different areas in a common 3D model, supporting decision making and collaboration.

Methodologies and tools have been highlighting the importance in devoting more efforts in early project stages. Authors suggest that by moving design decisions upstream as far as possible, changes are less costly and more effective. Figure 9 shows the Macleamy curve (AIA 2007), illustrating the escalating cost of design changes as a project progresses in the design process.

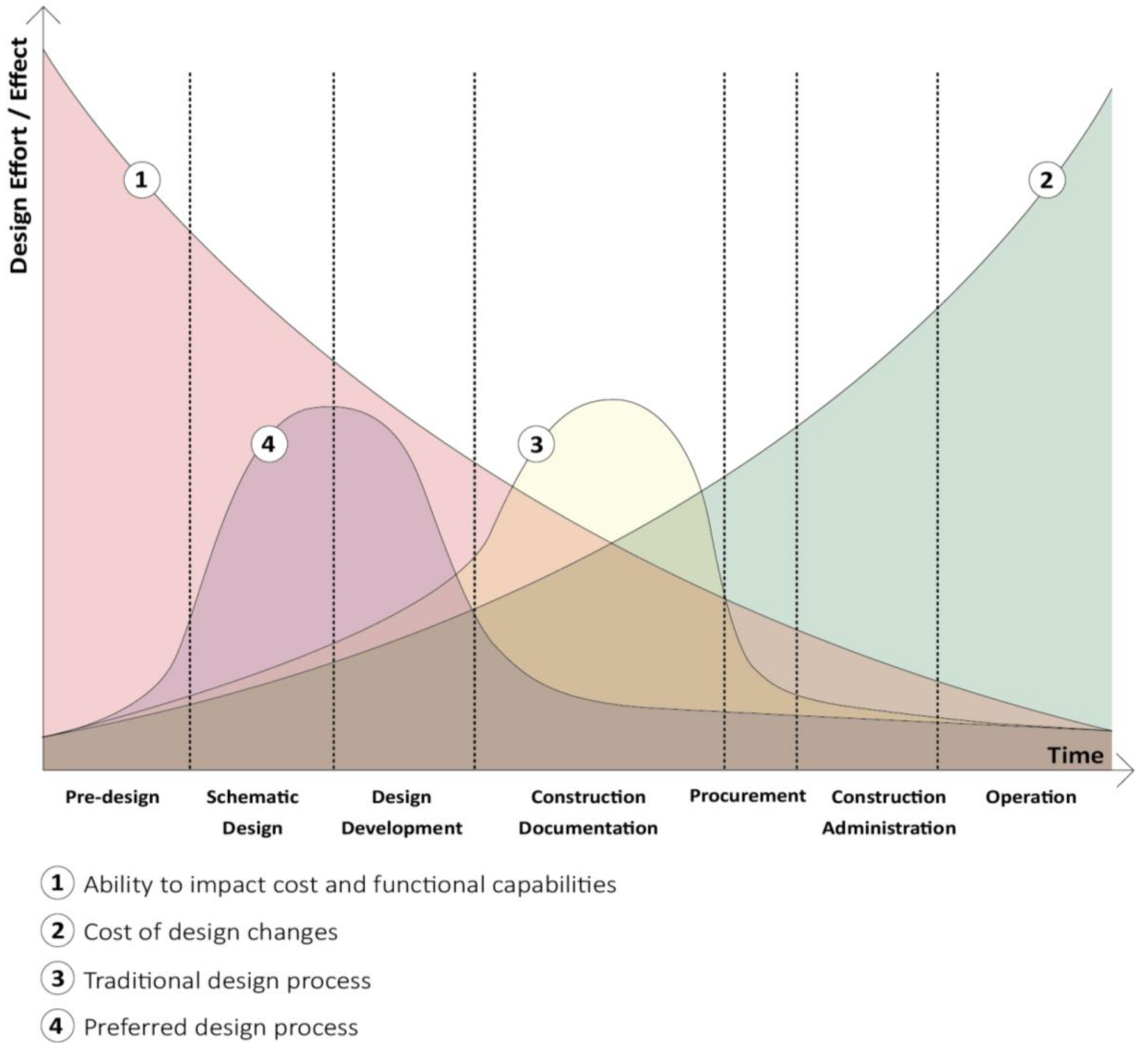

Figure 9 - Macleamy curve visualises a time-effort distribution curve. Adapted from "Integrated Project delivery" (AIA 2007).

C. Comparison between manufacturing and construction

What are the differences of the product development between these industries?

Manufacturing and Construction are two different industries with its similarities and differences, including processes, methodologies, approaches, final product. There are manufactured products in construction and some of the processes, such as those found in airline or in the automobile industry, are translatable to construction (Fernández-Solís 2009). The idea of improving performance in construction by learning from other industries is not new (Crowley 1998; Gann 1996; Sanvido and Medeiros 1989) and a lot of research have been devoted to this topic. Although proving to have similarities, solutions/methodologies/principles from the manufacturing industry cannot be simply applied to the construction industry, without being reshaped or reengineered (Crowley 1998). Trying to force the construction industry and its professionals into a manufacturing mode would be misunderstanding the complex nature of the construction business.

To understand the general characteristics between manufacturing and construction is important to recognise the differences in product size and number of products produced, as shown in **Figure 10**. Mass production usually related to the manufacturing sectors – represented on the upper right corner of the graph – demands more volume and less product size. Artefacts such as cutlery or glass bottles are mass produced. In the opposite way, a construction product (project), e.g. a building or a bridge, is characterised by its large size and uniqueness - represented in the bottom left corner. The middle area – referred as batch – represents a limited number of a product, that is required to meet specific objectives and requirements. Stationary furniture or aircrafts are batch produced.

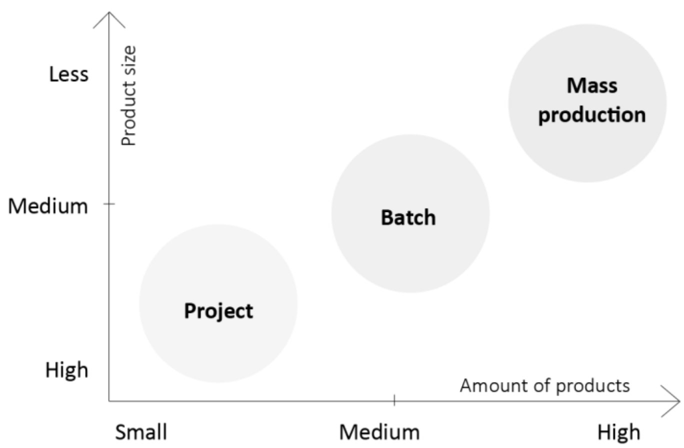

Figure 10 *- Manufacturing vs Construction. Adapted from "Construction Project Management" (University 2018).*

To take advantages of the manufacturing knowledge and methodologies, it is relevant to explore what are the differences between this industry and the construction. **Table 1** organises and summarises the differences of the two industries under study with aspects found in literature.

Variables	Manufacturing Industry	Construction Industry
Work environment	Controlled environment (University 2018). Employs work inside a factory or a manufacturing plant (Kokemuller 2018)	Construction companies typically work outside (Kokemuller 2018) Work on site is considered to be one of the most dangerous (Eurostat 2014).
	Production of a number of units of the same product (Tzortzopoulos,	Large and usually immobile; high degree of component parts varying degrees of

Final Product	Betts, and Cooper 2002; University 2018).	uniqueness; must be more durable; often expensive; (Gann 1996).
Product life cycle	Shorter life cycle (Vogler 2016).	Long cycle of acquisition, use and reacquisition (Gann 1996) involving maintenance and environmental impact.
Quality (implications of poor quality)	If manufacturers produce low quality products, their brand becomes devaluated, they lose customers, and face low sales and poor business conditions (Kokemuller 2018).	If construction quality is poor, buildings are not safe, building inspector may not approve it commercialisation and the company may develop a poor reputations and lose business (Kokemuller 2018).
Errors	When the work is non-conforming the work is discarded (Fernández-Solís 2009).	When the work is non-conforming the work is re-done (Fernández-Solís 2009).
Typical activities	Prototyping and making tools and dies (Tzortzopoulos, Betts, and Cooper 2002).	Production is detached from design; no prototypes due the nature of construction products (Tzortzopoulos, Betts, and Cooper 2002).
Methods and practices	Coordinated, managed and controlled using a common framework – the NPD process (Cooper et al. 1998).	Methods and solutions are developed particularly and oriented to each project (Fabricio 2002).
Labour vs mechanisation	Machines eliminate all skilled operations (Vogler 2016).	It is very labour-intensive (Averjanoviene et al. 2008).

Table 1 *- Summary table: Differences between manufacturing and construction industries: aspects from the literature (Averjanoviene et al. 2008; Cooper et al. 1998; Eurostat 2014; Fabricio 2002; Fernández-Solís 2009; Gann 1996; Kokemuller 2018; Tzortzopoulos, Betts, and Cooper 2002; University 2018; Vogler 2016).*

The product development process in construction differ from other industries due to the peculiarities of its product (Nobre, Santos, and Neto 2004). Oliveira (1997) lists four major characteristics that typifies the construction industry: the complexity of real estate market, the product long cycle of acquisition use and reacquisition, the long product’s life cycle, which involves maintenance and the environmental impact.

In comparison with product outcome from the manufacturing sector, construction products are large and usually immobile, demands a higher degree of complexity in the number and range of component parts; its production on site introduces varying degrees of uniqueness; and building products must be more durable and are often more expensive than other manufactured goods (Gann 1996). When work is non-conforming in the construction, the work is re-done, rather than discarded as in manufacturing (Fernández-Solís 2009). Products from the manufacturing and construction industry vary considerably and it is necessary to compare the PDP to note their physical differences. The process of building and delivering a large product – a construction project, such as a high rise building, a house, a bridge, a tunnel, a power facility – is considered more complex and difficult than the process of making or building a product in the manufacturing process – such as a car, a phone, a piece of furniture (University 2018).

In manufacturing, design is generally oriented to be produced in large quantities of the same products, while in construction, it aims to a unique product (Tzortzopoulos, Betts, and Cooper 2002). Another difference between these two industries relates to the existence of manufacturing activities within design such as prototyping and making tools and dies. Due to the nature of construction products, it is impossible to prototype a building, in the same way a product in manufacturing is prototyped; production tend to be detached from design (Tzortzopoulos, Betts, and Cooper 2002). According to these authors, projects within construction are usually developed by split teams, with poor consideration for customers' needs and generally delivered out of budget and deadline. Whereas in the manufacturing industry these issues have been study for longer, thus improvements achieved translated to the later (Tzortzopoulos, Betts, and Cooper 2002). In the manufacturing industry, all new product development activities are co-ordinated, managed and controlled using a common framework which is the NPD process.

However, not only differences were found when comparing these two industries. Several similarities are organised and summarised in table.

Table 2 *- Summary table: Similarities between manufacturing industry and construction industries: aspects from the literature (Averjanoviene et al. 2008; Cooper et al. 1998; Crowley 1998; Formoso, Tzortzopoulos, and Liedtke 2002; Kokemuller 2018; Tzortzopoulos, Betts, and Cooper 2002; University 2018; Vogler 2016).*

Variables	Manufacturing Industry	Construction Industry

Level of professional skills required	Requires the participation of a number of specialist and functions (Cooper et al. 1998). Involves manual labour to produce something for commercial purposes (Kokemuller 2018)	Large number of specialized personnel (Formoso, Tzortzopoulos, and Liedtke 2002) The level of professional skills required depends on the type of work. Involves manual labour to produce something for commercial purposes (Kokemuller 2018)
Client	Typically sell to distributors, who sell to retailers, who sell to customers (Kokemuller 2018). Importance of client requirements capture and translation into product specifications (Tzortzopoulos, Betts, and Cooper 2002).	Construction owner; Construction company's clients can be either private individuals, businesses or some public clients, such as government agencies (University 2018) Work for private individuals or businesses as well as government employers on projects for hire (Kokemuller 2018)
Information flows	There is a great amount of information, information flows and trade-offs within the process (Tzortzopoulos, Betts, and Cooper 2002).	Construction projects demand a lot of work teams and information flows are huge (Crowley 1998).
Raw material price	The cost of raw material is still a concern, but with increasing labour and land costs the development of the process has become the prime concern (Vogler 2016).	Very sensitive to the price of raw materials (Averjanoviene et al. 2008; University 2018).
Production time	Design and fabrication are the stages that take longer time (University 2018).	Generally, production stages take longer than preliminary stages (University 2018).

Guarantees, Client support Or After-sale service	After it is handled over to the customer/client provisions are made for future support (Cooper et al. 1998).	After it is handled over to the customer/client provisions are made for future support (Cooper et al. 1998).
Project success	Achieved if all external (supplier and consultants) and internal resources are utilised and co-ordinated effectively (Cooper et al. 1998)	Achieved if all external (supplier and consultants) and internal resources are utilised and co-ordinated effectively (Cooper et al. 1998).

In both industries the start of a project can be initiated internally or by indirect and/or direct contact with the customers (Cooper et al. 1998). Furthermore, either in the case of a building or a product, after it is handled over to the customer/client at both cases provisions are made for future support (Cooper et al. 1998). The successful construction of a building or manufacturer of a product can only be achieved if all external (suppliers and consultants) and internal resources are utilised and co-ordinated effectively (Cooper et al. 1998). Both industries seem to exhibit strong hierarchical structure, with skilled and high qualified workers (Averjanoviene et al. 2008).

Tzortzopoulos, Betts, and Cooper (2002) described a relevant list of similarities within the PDP in both industries found in literature. Some common aspects are: the importance of client requirements capture and translation into product specifications; the product development by a multidisciplinary team with different skills and knowledge; the main process stages are similar; there is a big amount of information, information flows and trade-offs within the process; there is a strong unpredictability element; it is a highly uncertain process.

Although there are manufactured products in construction, manufacturing and construction are two different entities. Construction has strong relationships with the manufacturing industry, particularly with the manufacturing of machinery, chemical and wood subsector. It is considered by several authors that construction industry can benefit by learning more about the use of advance manufacturing techniques found in car production as a method to reduce costs and increase standardisation without settling for lower quality or forgoing the demands for customisation (Aitchison 2017; Gann 1996). Taichii Ohno from Toyota came along and demonstrated that the factory-made products, even complex ones, such as cars, did not need to be all identical. The factory could adapt, within their limits, and make what the customer wanted. In this way, customers could participate in the design of their house by choosing from a range of options, as they do when buying a car (Aitchison 2017). At the same time manufacturing industry must take advantage and learn more about the management of customization from the way in which construction companies organize sales, design and final assembly (Crowley 1998; Fernández-Solís 2009; Gann 1996; Kokemuller 2018; McKinsey 2017). Manufacturing principles derived from the car industry have been successfully used to produce attractive, customised and affordable homes (Gann 1996). Influential architects such as Le Corbusier, Walter Gropius, Marcel Breuer and Buckminster Fuller believed fervently in the idea of mechanization and industrialisation of construction (Gann 1996). One of the most influential examples of the application of the manufacturing principles in construction is Le Corbusier's Dom-ino House, produces in 1914, arguing the idea that houses should "go up all of a piece, made by machines tools in a factory, assembled as Ford assembles cars, on moving conveyor belts" (Gann 1996)

D. **Current situation and future perspectives**

The Manufacturing industry is facing several challenges such as shorten innovation lead-times, reduction of time to market, reduction of costs, mass customization demands, more complex products, improving product quality, geographically dispersed design teams and rapid fulfilment needs (Nunes 2004). Today's companies face an increasing speed in the products development, having to offer new products continuously (Vogler 2016). Even though this industry suffered from the paradigm that their offer variety was very limited, in the 90s, customer demands for high product variety led to the development of "mass customization" (Hu 2013). Today many manufacturers must produce not only what the company wishes or is able to produce but also what their clients want. To achieve products according to customers desires in time, with quality and in the most efficient way several authors in literature and the industry have been introducing new strategies and methodologies, such as lean production systems, design for variety, modular platforms, among others.

The trend in manufacturing is going towards much higher integrated modules (subcontracted). The need for design variety - different models and new designs – are leading the industries to a platform design, where more models share the same parts and potentially all non-design critical elements like engines, chassis, gearbox and other are integrate in one platform, onto which different model variation can be built up, saving development time and costs (Vogler 2016) and reducing internal complexity. **Figure 11** schematizes several innovations along the history of manufacturing.

Manufacturing

1970s-80s Lean	**1990s** Outsourcing/Offshoring	**2000s** IT and Automation	**Now - 2020E** Industry 4.0
Innovation from Japan and Europe	Offshoring production	Sophisticated Enterprise Resource Planning (ERP)	Internet of Things (IoT)
6S waste elimination	Vendor developement	Rapid prototyping and simulation	Advanced analytics and machine learning
Total Quality Management (TQM)	First wave of Enterprise Resource Planning (ERP)	Automation and robotics	Virtual Reality (VR) and Augmented Reality (AR)
Just-in-Time (JIT) Quality revolution	Procurement and supply chain revolution		

Figure 11 *- Innovation in manufacturing. Adapted from "Reinventing construction: A route to higher productivity" (McKinsey 2017).*

Construction is becoming increasingly fragmented, with separate organisations taking responsibility for different phases of construction – design, site works and operation - and many suppliers, subcontractors and specialists involved in the design and on site (Averjanoviene et al. 2008). Literature is clear about the four major issues that have been tackling the construction sector. Firstly, there is a lack of construction skilled workforce and the number should decline in the future (McKinsey 2017). Consequently, prices of skilled labour are increasing (Averjanoviene et al. 2008). The following major problem is related with digitalization. According to a McKinsey Global Institute's digitization index, construction is among the least digitized sectors in the world (McKinsey 2017). At the same time, there is an effort to improve this part of the industry. Innovation of digital processes and technologies have been slowly adopted and according to the consulting firm McKinsey & Company, the industry has not embraced existing digital technologies yet, mainly because of the need of high up-front investments. Lastly, the increasing complexity of modern buildings and the growing competition in the market have significantly augmented the pressure for improving the performance of product development in the building industry (Formoso, Tzortzopoulos, and Liedtke 2002). Clients are demanding their facilities to be built quicker, cheaper and higher quality.

An emergent paradigm dictates that the construction should follow industrial trends of increasing efficiency, control, quality, productivity, and overall decrease in cost per unit as see in the automobile, ships and aerospace industries (as cited in Fernández-Solís 2009). However, these efficiencies have not been achieved in construction. Over the last twenty years, productivity in manufacturing has nearly doubled, whereas in construction it has remained flat (McKinsey 2017). Fernández-Solís (2009) proposes an answer to this paradigm by arguing that the part of construction moving off-site is the very efficient part, but thus, it is counted under manufacturing. So, the construction industry is being measured by all the intrinsically inefficient part, meaning that construction may be getting more efficient over time but never shows in the statistics of "construction". In "Reinventing construction" report it is presented seven basic productivity improvements in the industry, which is important to refer the one that is relevant for this study: 'rethinking design and engineering processes and increase standardisation'. Fully implementing best-practice design processes can deliver large-productivity improvements and is the key to any move to a mass-production manufacturing-style product system (McKinsey 2017).

Figure 12 *- Levers to drive productivity improvements in the construction industry. Adapted from "Reinventing construction: A route to higher productivity" (McKinsey 2017).*

2.2 **Fundamental notions + Examples**

To develop an efficient product development strategy, it is required a good understanding of current practices and trends within the manufacturing and the construction industries. This led to the research about concepts and approaches related to both industries under study. Such understanding includes the following sections:

– A. Industrialisation;

– B. Standardisation;

– C. Prefabricated systems;

– D. Ready-to-assemble;

– E. Modularisation;

– F. Product platform;

Each section includes a general description on the topic, a specific description on the manufacturing and/or the construction industry, a real-world example(s) and a list of conclusions.

A. **Industrialisation**

Industrialisation is defined as the process by which it is applied techniques, methods, principles from the industry. Industrialisation is based on high capacity for reducing the prices and betterment of quality and further access to complex products for a wide scope of people (Zabihi, Habib, and Mirsaeedie 2013) through mass production. From cars to computers, all products have become cheaper, better working, better looking and better performing due to industrialisation (Vogler 2016).

An industrial product is the result of an industrial process (Vogler 2016) based on three fundamental means: mechanization, rationalisation and automatization (Azevedo 2016). **Mechanisation** of operations frees the man from tasks that demands a high degree of efficiency and that only a machine can offer. Rationalisation is present throughout all the industrial process – design, management and technologies – allowing to produce and offer products with the best possible price/quality ratio. **Automatization** allows constant speed of tasks execution, under controlled and rigorous conditions. In the current manufacturing industry, industrialisation translates e.g. in the usage of robots to perform complex tasks, work alongside people and optimize production systems. **Figure 13** shows one of the robots used by the firm IKEA in the packaging line that enables to perform quick packaging tasks – example of mechanisation and automatization in the manufacturing industry.

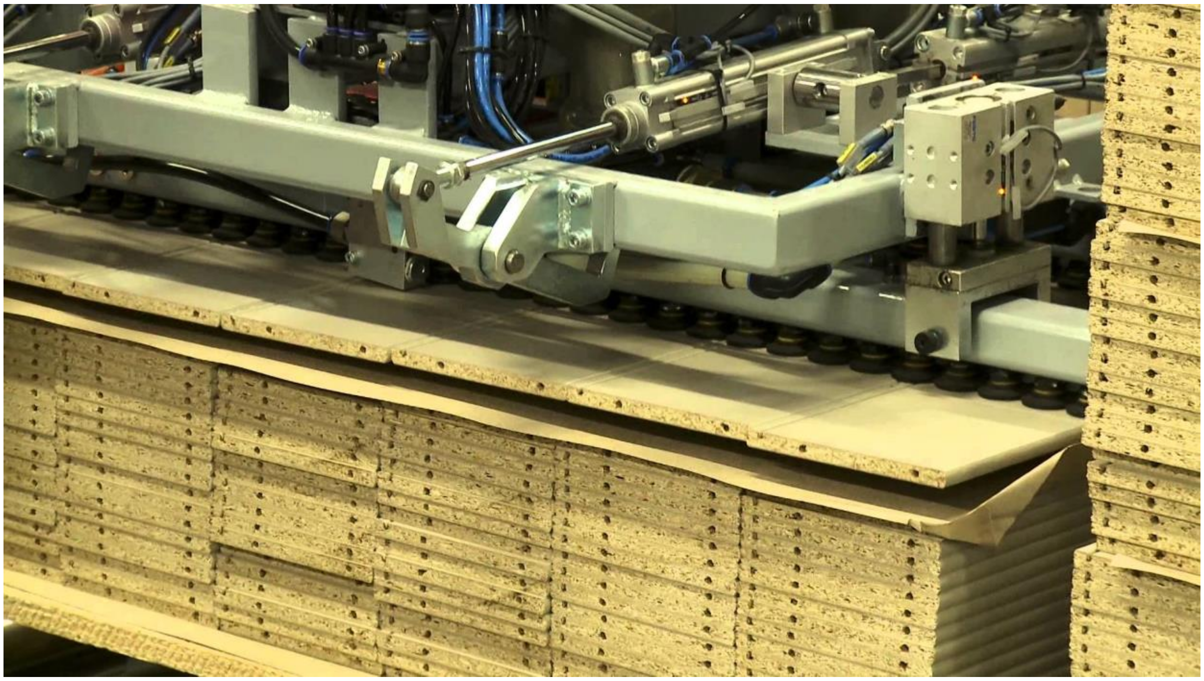

Figure 13 *- IKEA Robot packaging line made by Teamster AB (TeamsterAB 2014).*

More than often, the example of the manufacturing industry is taken to point at opportunities of industrialisation in construction, through prefabrication and innovation (Scheublin and Ligny 2005).

In the construction sector, industrialisation is usually translated into the production of construction and architectural elements, resulting in significant improvements in quality, working safety on the construction site, productivity, fulfilment of deadlines, aesthetics, costs and freedom of design (as cited in Azevedo 2016, 6). The industrialisation of building construction seeks to reduce costs through faster construction – reduce costs of manpower and time-consuming activities -, to increase construction quality, to eliminate dependence on weather conditions at the construction site, and to improve coordination of planning and construction (Scheublin and Ligny 2005). According to Crowley (1998), the main principles that stands for industrialisation of construction are standardisation, prefabrication and systems building. Influential architects such as Le Corbusier and others contributed with new methods of construction, influencing the design and construction philosophy. However, attempts to develop industrialised housing did not only emanate from building designers and users. Manufacturers played an important role in promoting industrialised systems (Gann 1996).

Considered a key factor for the industrialisation of building construction (as cited in Zhang, Skitmore, and Peng 2014), Industrial Building Construction (IBS) is a system that makes usage of prefabricated components to minimize site works. Some IBS still uses in-situ methods but still try to minimise the site works. In IBS components are manufactured in a controlled environment, either at a site or off site and placed and assembled into construction works. Figure 14 visualises off-site fabrication, considered as contributor to the industrialisation of construction. What happens is that several parts of a building are manufactured and transported to the construction site.

Figure 14 *- Off-site fabrication of components manufactured under a controlled environment (Engenharia 2017).*

Another example of industrialisation in the construction industry stems from the Japanese house building industry. Gann (1998) discusses the relative successes of the producers of industrialised housing in Japan (as cited in Crowley 1998). Japanese house building industry has been a good reference of housebuilding industrialization since it has always been higher in comparison with Europe (Gann 1996). This approach is considered by many to have an influential role in the construction industry due to its potential to improve quality, productivity, efficiency, efficiency, safety and sustainability (Zhang, Skitmore, and Peng 2014).

Since necessities of end users and sites are completely different in each case, building industrialisation cannot be reduced to a standard building, but the introduction of new process of development, distribution and application of technologies can lead construction to a more industrialised industry (Scheublin and Ligny 2005). In fact, as construction evolves and implements industrialised processes, new construction methods and building systems are also being developed.

The swiss architect Hans Schmidt refers in its theoretical research a list of relevant principles for the viability of an industrial product (industrialised building). Such are: the rational use of materials, simplicity of the construction process, clarity and technical simplicity of the building, standardisations in an habitable form and concentration of the production in a single location (as cited in Azevedo 2016). The advantages of having an industrialised construction flow include the elimination of last minute improvisations on site, the dismiss of specialized workforce, the cost optimization and reduction of waste, creation of standards and procedures, serial and mass production. Industrialisation of construction is important due to increase the quality, mass production, costs and time spent (Zabihi, Habib, and Mirsaeedie 2013).

B. **Standardisation**

Standardisation refers to the process of implementing and developing technical standards based on the consensus of different parties, including the organization(s), design team, clients, suppliers, end users, and other stakeholders. Standardisation refers to the use of common parts, components, and platforms. The main purpose of standardization is to establish mandatory criterion for the design and production of products, to reduce variations in their types and grades and to achieve quality. The standardisation process rely on the development of specifications based on the consensus of companies and their stakeholders (Wang et al. 2016). Literature shows that standardisation can be studied in different levels and emerge in different formats, influencing the entire product and process development cycles, from the idea generation to product or process launch (Wang et al. 2016). This study focuses on the standardisation of product' components and process.

A typical example of standardisation, from the car manufacturing industry, is the assembly line of the Ford model T in 1908, introduced by Henry Ford (Figure 15). According to Ford (1922) any customer could have a car painted in any colour that he wanted as long it was black. If different colours have been offered it would have meant a break in this production assembly line and involved more staff, higher error rates and higher costs (EY 2015). By applying a production system based on standardised processes the costs per unit were significantly reduced. However, Taichii Ohno from Toyota came along and demonstrated that the factory-made products, even complex ones, such as cars, did not need to be all identical. The factory could adapt, within their limits, and make what the customer wanted. In this way, customers could participate in the design of their car by choosing from a range of options (Aitchison 2017).

Figure 15 *– Ford's system designed to assemble the Model T by Henry Ford (Geekinc 2010).*

Within the manufacturing context, standardisation allows better product quality, reliability and longer life service, and through standardisation of components it is possible its mass production at a lower cost and to easily have available parts for replacement and maintenance. This process also helps to reduce the complexity of internal variety of a range of products (Kipp and Krause 2008). Standardisation can also facilitate partnerships between companies and suppliers once they allow the company to work with a reduced number of well-known supplier brands and types of materials, components and services. Companies that standardised their production are more likely to produce in a large-scale and can take advantage of this feature to negotiate more competitive prices in the market (Fabricio and Melhado 2005). Figure 16 and Figure 17 are examples of the firsts kitchen's designed to be mass produced. Both examples were designed in the interwar period. The rational minimum dwelling at the time was clearly visible and proceeded further development of rational kitchen along Europe and history. The first example, Bruynzeel kitchen (Figure 16) was designed by the designer Piet Zawrt to be mass produced. It consisted of standardised elements that could be mounted in different ways so that customers could combine them as they wished. This kitchen took three years of research and it was considered highly progressive for its time (Iconofgraphic).

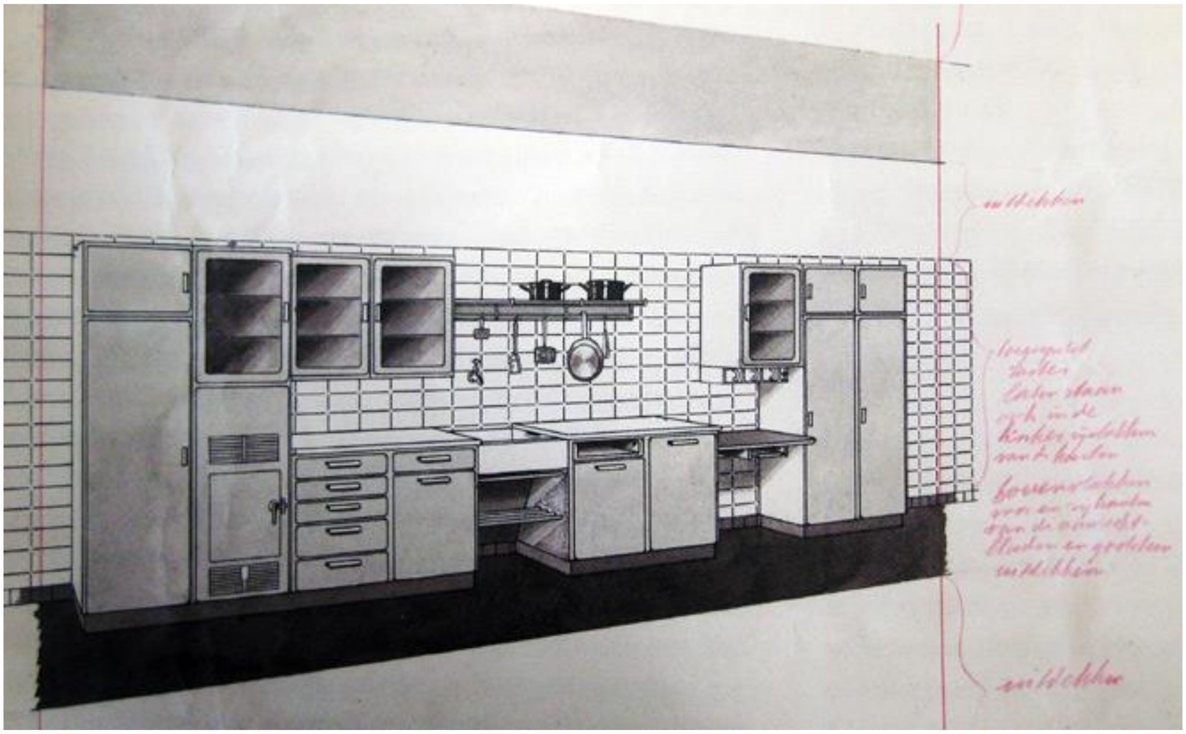

***Figure 16** – Bruynzeel kitchen drawing from 1937 – designed based on standard components in the interwar period in Belgium (Iconofgraphic).*

Cubex kitchen (Figure 17) designed by architect Louis Herman De Koninck is composed by standardized cupboard items combined in different ways. This system had a huge commercial success and was installed in thousands of Belgian kitchens (Caudenberg 2004). This kitchen is considered a solution ahead its time and the first modular produced kitchen. If today’s European standard for the width of household appliances (and therefore the basic module of the kitchen) is 60 cm, it is following the collaboration of Cubex (Cubex).

***Figure 17** – Cubex kitchen designed in 1930 (Caudenberg 2004).*

Towards standardisation in the construction industry, according to Koskela's proposal (1992), standard building products should be produced, using common techniques, materials and processes (as cited in Crowley 1998). According to Mohamad et al. (2013) standardization is an essential principle of lean management and has the goal to improve the production process in construction (as cited in Dube, Muyengwa, and Battle 2013).

Because of globalization, companies have to deal not only with the increasing competitive worldwide competition, but also with the increasing sophisticated customer and market requirements (EY 2015; Kipp and Krause 2008). More and more customers are demanding their orders to be fulfil at a highly customisable level and more quickly (Feitzinger and Lee 1997). These demands are leading to a higher variety of products offered by the market as well as shorter product life cycles. In this way, to fulfil customer requirements and high customisation levels, as well as standardised components and processes, firms challenge have been finding strategies that could deal with both poles (EY 2015). Whether in construction or in manufacturing, standardised products are more likely to integrate in a consumerist market because it is programmed to be mass produced and consequently to be very competitive (Azevedo 2016).

C. **Prefabricated systems**

While common traditional construction process involves shipping of raw material to the construction site to be handle on-site by its workers, prefabricated systems refers to construction for which most constructions processes are finished in factory following certain industry standards. Prefabrication or off-site fabrication is defined as the "production of components under factory conditions, and their assembly on site" (Gann 1996). The main goals of prefabricated components are to reduce costs, to increase speed of construction processes, having less wastage on sites, and to improve quality. Prefabricated components generally comprise two types – those produce directly off-site without knowing the design of the building, and those produced for a specific building with prior knowledge of its design (Gann 1996). Over the past century, these processes have developed a stigma of "cheapness" and "poor quality" (Construction 2011; Kakkar 2016; Thomas, Amhoff, and Beech 2016). However, prefabricated system further gained popularity with the development engineering wood products, and now-a-days manufacturers make them in many configurations and types giving construction companies a wider variety to select from, to fulfil the design and regulatory requirements (Kakkar 2016). Furthermore, great architects such as Le Corbusier, Mies Van der Rohe or Jorn Utzon approached this subject using different strategies and ideas (Jurse and Wojcik 2015).

Literature shown that modularity and prefabrication are intrinsically connected (Pero, Stößlein, and Cigolini 2015) in the way that prefabricated "products" for construction consist of multiple sections denominated as modules, that are previously design and constructed at an off-site facility to afterwards be delivered to the intended site. The main goal of using these components is the industrialisation of the components and processes while speeding up the time of a construction site production and increasing the quality, since components are prefabricated in controlled environments. According to Jurse and Wojcik (2015), smaller elements or panels with easy mounting methods is a key element to successfully design a prefabricated system.

In 1957, with the vision of connecting the design and on-site assembly of prefabricated parts, Hans Schimidt designed a list of build ready-made elements in form of a catalogue. Through this process architects would have to give up their autonomous positions outside the construction so as to be integrated through collective forms of labour (Thomas, Amhoff, and Beech 2016). **Figure 18** shows a drawing in which the architect uses prefabricated concrete elements mapped and represented with drawings. Prefabrication is now closely linked to digital production where projects using building information model (BIM) can be automatically manufactured using specialized programmable machinery (Jurse and Wojcik 2015). Prefabricated elements allow easy and fast assembly on site. Furthermore, due the fact that prefabricated elements are produced in controlled conditions they are less likely to have failures.

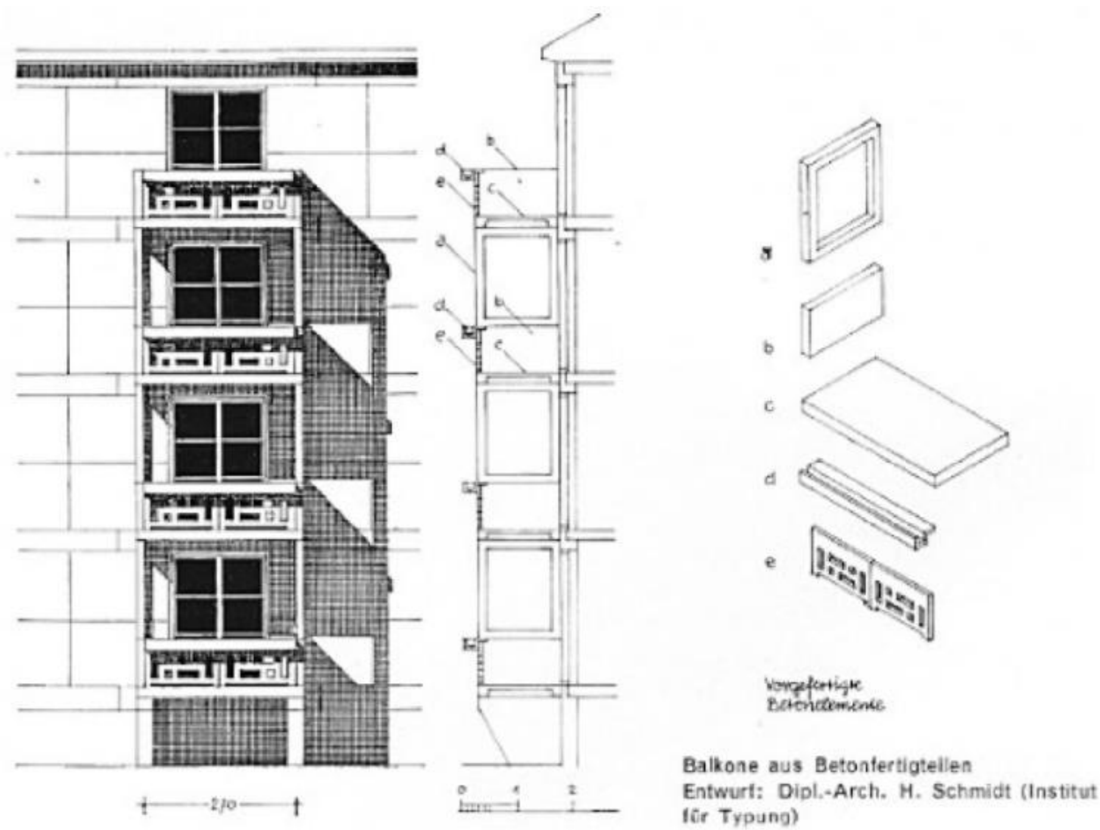

Figure 18 *- Designs for an entrance porch, stairwell windows and balconies from prefabricated concrete elements by Hans Schmidt, Institute for Typification, 1956. Deutsche Architektur, 2 (1957), 88 (Thomas, Amhoff, and Beech 2016)*

Even though much attention has been centred on the prefabrication of architecture, there has been less discussion on the influence and importance of prefabrication within the interior environment. Although interior prefabricated components attracted attention to architects and designers, predominantly for reasons of efficiency and affordability (Schneiderman 2011). Prefabricated innovations for the interior ranged from individual elements to complete assemblages. Wall, furniture, kitchen, bathroom and cubicle have defined space, either as complete prefabricated assemblages or through the repetition of modules (Schneiderman 2011).

According to Schneiderman (2011) approach, prefabricated interior elements follow three basic construction types: planar construction or screen, modular construction or module and unit construction. The first – planar construction or screen - refers to a planar element that is used to divide space, either as fixed or movable prefabricated architectonic element. The second – modular construction or module – refers to a standardize component integrated in a system. The module, as the most basic unit, by itself does not accomplish its intended function. However, in repetition – system – results in elements from furniture, to kitchens and office environments. The third – unit construction – refers to a singular unit element that is designed as all-inclusive whole.

Conclusions drawn that, within the interior, the kitchen is the most successful prefabricated architectonic element – although these prefabricated elements were not a success. A relevant fact presented in Scheneiderman (2011) research leads to a reflection about the efficiency of these designs. According to literature, adjustability, particularly in regard to vertical dimension, turns to be essential for user comfort and efficiency, yet installations typically remain vertically fixed (as cited in Schneiderman 2011). Considering prefabrication as practice of manufacturing parts in a controlled environment and then transported to its destination, we can say that this concept has some similarities with the concept of ready-to-assemble furniture.

D. **Ready-to-assemble (RTA)**

The concept of ready-to assemble (RTA) sets prefabricated in a factory and delivered to the customer is well-known and common in the furniture industry (Loferski, Kochkin, and Platt 2000). Ready-to-assemble furniture - also called flack-pack or carry-home furniture or furniture-in-a-box or knock-down furniture - is defined as a medium-quality low-priced furniture that is constructed from particle board coated with coloured melamine and shipped unassembled in boxes (Pepke 1988). This approach brings advantages both to firms - since they can save assembly costs, facilitate supply chain activities such as transportation and reduce shipping cost - and to customers - since the savings and the assembly are passed to the customer (Pepke 1988). Additionally, RTA systems replaces traditional wood connections, which require skilled workers and are time consuming with simple bolted metal-to-metal connections (Loferski, Kochkin, and Platt 2000) or order fitting/joining technology/systems/innovations (Avdan 2016).

The manufacturing processes of RTA furniture after the design stage are basically panel sizing for sides, ends, backs, and shelves; boring of holes for assembly and hardware; application of edge bands with adhesive to all exposed edges; finishing by spraying first coat, drying, sanding lightly, spraying second coat, and drying; and wrapping furniture parts, hardware, and assembly instructions and placing them in boxes on pallets for shipping (Vlosky, Poku, and Wille 2001). This approach does not require any kind of assembly line and since the machinery is automated, this kind of furniture is produced with less labour than conventional furniture. In other hand, the initial investment in equipment and design is higher, but recovered through reduced production and labour costs (Vlosky, Poku, and Wille 2001).

A relevant example to understand ready-to-assemble furniture is the 1859' chair, designed by a German Austrian cabinet-maker, Michael Thonet. Designated as Thonet's no.14 (Figure 19), this chair was made of six manually bent beech rods, two bolts and ten screws (TON 2018), designed to be mass-produced and sold at an affordable price (Thedesignmuseum). Since it has all the characteristics to be ready-to-assemble, this furniture is prepared to be transported and disassembled in a flat pack. Thonet's approach is considered a source of inspiration for IKEA, one of the most influential manufacturer of ready-to-assemble furniture today (Thedesignmuseum). Following the same approach, in 1939, Kem Weber designed the airline chair (Figure 20) commissioned for the Walt Disney Studios in Los Angeles. The author sought, not just to make a comfortable and beautiful chair, but also an inexpensively and easy to assemble product (V&A 2017). According to the Albert and Victoria Museum description, this armchair came in a flat, square box and it was considered relatively inexpensively for a manufacturer to store and ship.

Figure 19 - *Thonet's no. 14 (assemble(left) and fully disassemble (up right). In a box could be packed 36 chairs of this model (Didatticarte 2014).*

Figure 20 – *Airline Chair, designed in 1934-1935 and made in 1939 by the German Kem Weber, property of the Victoria and Albert Museum in London (V&A 2017).*

Lastly, thanks to easier solutions of assembly as well as the tool-free assembly, IKEA furniture is a relevant example of RTA furniture. A successful RTA system incorporates fabrication, packaging, transportation and assembly (Loferski, Kochkin, and Platt 2000). IKEA model spins around four clusters of activities linked: modular furniture design, low manufacturing cost, limited customer service and self-selection by customers. The success of this Swedish furniture manufacturer is associated not only to their designs but also to the well function of these four clusters (**Figure 21**).

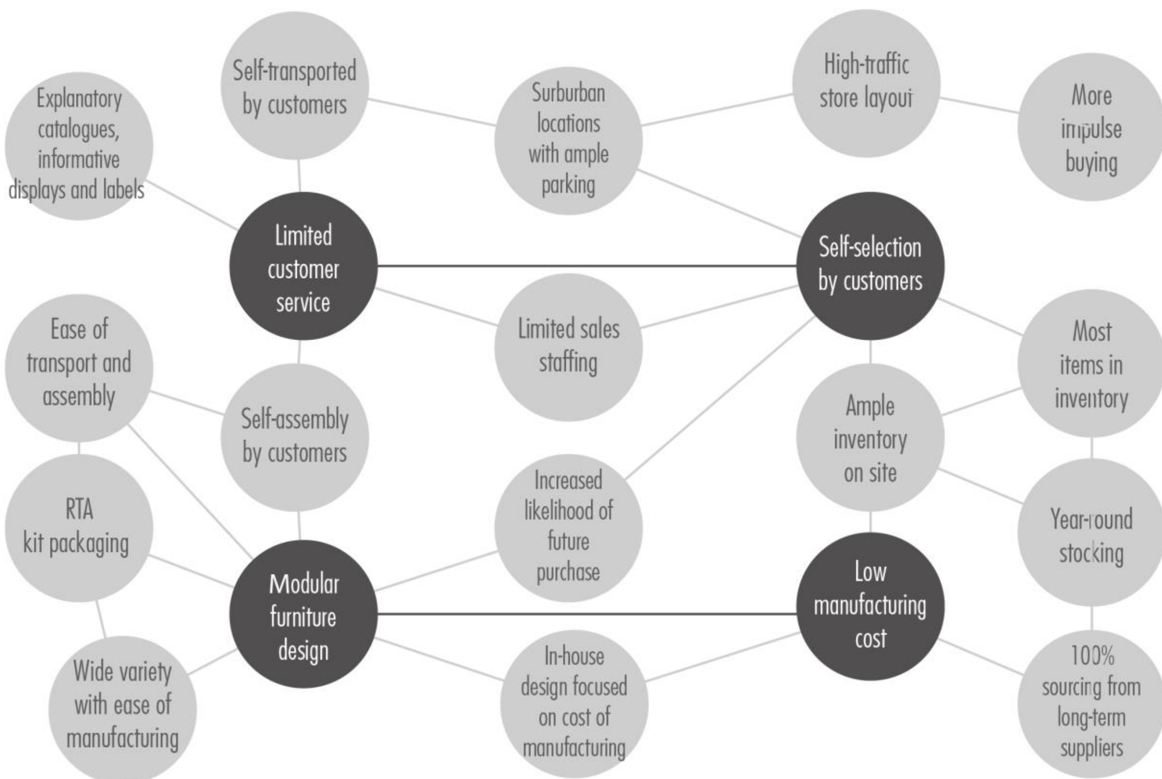

***Figure 21** – Activity linked clusters map showing IKEA strategy. Adapted from "Strategy for business: a reader" (Mazzucato 2002).*

Although RTA furniture was considered as an inferior alternative to solid wood furniture, there has been significant improvement in quality while still being offer at lower price points (Vlosky, Poku, and Wille 2001). There is enthusiasm for stepping up RTA furniture across a wide spectrum of home office, entertainment, bedroom and kitchen items. Ready to assemble furniture is growing and maturing as a product line. "It does not look like RTA furniture anymore" (Vlosky, Poku, and Wille 2001).

E. **Modularisation**

In age of increasing demands for product variety and customisation, companies are facing changing business conditions (Miller and Elgård 1998). Firstly, the focus on the customer needs is demanding customized products and consequently demanding for escalating product variety to meet different customer needs (Miller and Elgård 1998; Swaminathan and Lee 2003). Secondly, the competitive market, the increasing complexity and the continuous search for efficiency, such as reduce costs, increase quality and reduce time-to-market, have been leading companies to adopt new strategies to strive these obstacles (Miller and Elgård 1998). Modularisation is often mentioned as a means for handling these demands (Dube, Muyengwa, and Battle 2013; Miller and Elgård 1998; Pero, Stößlein, and Cigolini 2015; Swaminathan and Lee 2003; Vrijhoef and Voordijk 2004), awakening interest for companies.

Modularity arises from the way that a product can be divided into several components – modules – allowing the standardisation of these independent parts. Baldwin and Clark (1997) described modularisation as a strategy to increase companies' flexibility to satisfy the global market (as cited in Santos and Forcellini 2012) and increase competitiveness (Miller and Elgård 1998). The term modularity is used in several areas of activity and used in many ways. In the design of complex engineering systems, the term refers to the use of independent units (Ulrich 1994). In construction and architecture, a module can be described as a "large group of standardised components that is physically coherent as a sub-assembly and which often has standardised interface designs" (Ulrich 1994; Vrijhoef and Voordijk 2004). In manufacturing, the term usually refers to the application of interchangeable units to create product variants (Ulrich 1994). The term module is evident in architecture through the most basic unit of the brick, and also in interior design as a system for fabrication of any number of elements from furniture, to kitchens and office environments (Schneiderman 2011). Modularisation concepts were originated in the manufacturing industry (EY 2015) and is connected with other manufacturing concepts such as mass customisation (Feitzinger 1997; Hu 2013; Miller and Elgård 1998), standardisation and rationalisation. This concept is also inherent to the platform strategy concept (more information about modular products platforms will follow in the next chapter).

Table 3 organises the definitions found in literature of five underlying concepts inherent to modularisation.

Table 3 *- Definition of modularization terms. Adapted from "Modularization in Balck-Box Design: Implications for Supplier-Buyer Partnerships" (Hsuan Mikkola 1998).*

Modularity	A special form of design which intentionally creates a high degree of independence or 'loose coupling' between components designs by standardizing component interface specifications Division of a product into independent components (Ulrich 1994). Approach for managing and developing complex products and processes efficiently by decomposing them into simpler subsystems without compromising the system's integrity (Baldwin and Clark 1997). NPD strategy which interfaces are shared among components in a given product architecture become specified and standardized to allow for "greater substitutability" of components across product families (Dube, Muyengwa, and Battle 2013)
Modular System	A system composed by units (or modules) that are designed independently but still function as an integrated whole (Baldwin and Clark 1997).
Modular Components	Supports one or more functions (Dube, Muyengwa, and Battle 2013).
Modular Product Design	Allows a firm to differentiate its product to a high degree by combining a limited number of standard parts Decreases time to market, increases the number of product variants, increased flexibility, reduce cost and decreases the number of unique parts in the product architecture (as cited in Dube, Muyengwa, and Battle 2013). Emphasizes the minimization of interactions between components in order to design and produce those components independently (Dube, Muyengwa, and Battle 2013). Products cannot be classified as either modular or not, but rather exhibit more or less modularity in its design (Ulrich 1994).
Modular Product Architecture	An architecture in which each physical 'chunk' (major physical building block) implements a specific set of functional elements and has well-defined interactions between the 'chunks' (Ulrich and Eppinger 2012). Used as flexible platforms for leveraging a large number of product variations (Dube, Muyengwa, and Battle 2013). Concept that facilitates standardization of product components – since can be easily broken down into a number of standard building blocks - allowing for a huge variety of products by rearranging different configurations and variants (EY 2015).

A difference between what is perceived as module and as a building block, is highlighted by Miller and Elgård (1998). These authors sustain that a module, besides being an independent and standardise component from a major set, must possess a certain considerable amount of functionality and must be independent enough for testing. In **Figure 22** it is visualised what is considered a module, according to Miller and Elgård definition –a prefabricated standard module of a bathroom being installed in a more complex structure, the building.

Figure 22 *- Prefab bathroom unit installation (Folj 2017).*

Moreover, the authors also defined the concept of building block, describing it as a component that is reduced to a more limited functionality compared to the final product. According to their definition, a prefabricated wall, for example, cannot be considered a module but a building block. This “building block” approach was started by the German architect Walter Gropius during the Bauhaus era (1919-1933), combining the idea of standardisation and industrial production (Miller and Elgård 1998). In **Figure 23**, it is visualised the installation of a modular wall – building block - in a construction site. These precast concrete standard blocks are designed and produced independent from each other by casting concrete in a reusable form, on off-site facilities with a controlled environment and delivered to the intended site of use. Building blocks can be compared with Lego-blocks, since they also do not retain a considerable amount of functionality from the set which they are a part (Miller and Elgård 1998).

***Figure 23 -** Prefabricated building blocks' implementation on a construction site (Voordijk and Adriaanse).*

Throughout the years, in the construction industry, these processes have developed a stigma of "cheapness" and "poor quality" however, thanks to modern technological implementations, that images changed (Construction 2011). Modularisation has been considered a driver of productivity, including schedule, cost, safety and quality for construction projects (Construction 2011). It is also considered a driver for creation of variety, use of similarities and reduction of complexity (**Table 4**). Together with prefabrication, modularisation can measurably reduce project schedules, decrease purchase and installation costs of materials – and consequently decreasing the project budget -, increase construction safety – resulting in the reduction of the number of accidents and lower insurance costs -, eliminate significant amounts of construction site waste – turning the project environmentally more friendly – and allow the specification and installation of better quality and more sustainable building materials (Construction 2011). Still, in the construction industry, tools such as BIM are considered as drivers for the increasing use of modularisation and prefabrication, improving worksites productivity and the overall project (Construction 2011).

Literature shows that the main benefits related to product modularisation are: increasing variety of products, economy of scale, decreasing time-to-market, project time and costs reduction, task distribution among the supply chain, improvements in the relationship between suppliers and partners in the supply chain, easier maintenance, repair or recycling and better control of uncertainty (Santos and Forcellini 2012). Miller and Elgård (1998) consider that the creation of variety, the use of similarities or/and reuse of resources and the reduction of complexity are the three main drivers for modularisation (**Table 4**). Authors such as Feitzinger and Lee (1997) stated that products should be designed so it consists of independent modules that can be assembled into different forms of the product easily and inexpensively. Product modularity seems to be considered, according to literature, as a way to approach good design (as cited in Ulrich 1994) and identified as an aspect of environmentally-friendly product design (Bonvoisin et al. 2016).

Table 4 *- Modularisation three basic important drivers: creation of variety, utilization of similarities/reuse of resources and reduction of complexity. Adapted from "Defining Modules, Modularity and Modularization"(Miller and Elgård 1998).*

Drivers behind Modularisation		
Create variety (mass customisation)	**Use similarities (reuse resources and standardise)**	**Reduce complexity**
… to provide the customer a well-fitted product.	… to gain rationalisation benefits.	… to increase overview and better handling.
- Provide useful external variety – the customer wanted variety created by combination of modules; better control of uncertainty (Santos and Forcellini 2012); - Increase flexibility (Vrijhoef and Voordijk 2004); - Faster design changes - Upgrade, adapt or modify the product for extending the service life of a product or parts (Bonvoisin et al. 2016); - Possibility of producing product variations that have only limited impact on production and assembly processes (Vrijhoef and Voordijk 2004);	- Avoid unnecessary work; - Working faster and better by learning effects and supporting tools; - Reduce risks by using well-known solutions; - Reducing internal variety, because it generates costs, but adds no value to the customer; - Better control on project schedules and budgets; - Reduction in production costs due to postponement (Bonvoisin et al. 2016);	- Break down in independent units; - Work in parallel; - Tasks distribution; - Better planning; - Less waste; - Separate testing; - Reduction of the number of errors and accidents; - Speed up development time (Fixson 2005) and increased time-to-market (Santos and Forcellini 2012); - Easier product maintenance, repair, reuse, remanufacturing, recycling and disposal (Bonvoisin et al. 2016; Santos and Forcellini 2012);

The operation of modularity along the different development stages is the strategic result of a search for a potential specific solution. The earlier modularisation process is applied, the more freedom to define architectural content – such as the product architecture (Liu, Wong, and Lee 2010) (**Figure 24**). When modularity is applied in the concept development phases, it is possible to explore conceptual product architecture and gain an early insight. Functional modularity offers a proactive platform development. Physical modularity assumes that the basic physical element is fixed. For this kind of approach modular product architecture are generated by arranging these elements into larger units (modules) – typically used for product or platform redesign. Parametric modularity considers a fixed product structure and the product characteristics varied only within the boundaries of the individual elements or parameters. Less freedom to change the product structure is provided in this kind of approach.

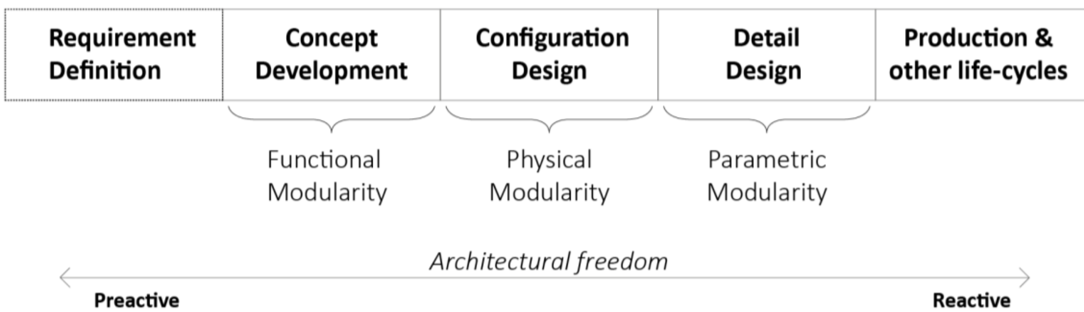

Figure 24 *- Modularity occurrence along the product creation process. Adapted from "Modularity analysis and commonality design: a framework for the top-down platform and product family design" (Liu, Wong, and Lee 2010).*

The provision of product variety also comes with some few negative aspects. Among them are: the possibility to produce very similar products and similar product families, the effort in initial research that needs to be putted into the design of a system of modules, as well as it may ease competition per imitation (Bonvoisin et al. 2016; Santos and Forcellini 2012). AlGeddawy and ElMaraghy (2013) argue that modularisation may contradict the design for manufacturing and assembly approach because it may lead to an increased number of parts and, therefore, increase the number of assembly errors (as cited in Bonvoisin et al. 2016). Other constraints such as the high initial investment (Liu, Wong, and Lee 2010) and the dependency of suppliers (Pero, Stößlein, and Cigolini 2015; Santos and Forcellini 2012; Vrijhoef and Voordijk 2004) are referred in literature.

Within the domestic interior, the module is most significantly represented in the design of kitchens and furniture. Le Corbusier, along with Marcel Breuer, has been credited as the first architect to conceive modular furniture (Schneiderman 2011). In the mid-twentieth century, George Nelson conceptualized 'Storagewall' as a built-in element that would not only house all the necessary storage for the home within the typical space of a wall but would also entirely replace the wall with modular furniture-like elements. This furniture, visualised in **Figure 25**, was intrinsically customizable as the units were selected by the user and could be assembled in any arrangement or direction. Other examples such as the Eames Storage Units (ESUs) from 1950 or Joe Colombo's 1969 Tube-Chair are examples of modular mass-customizable furniture.

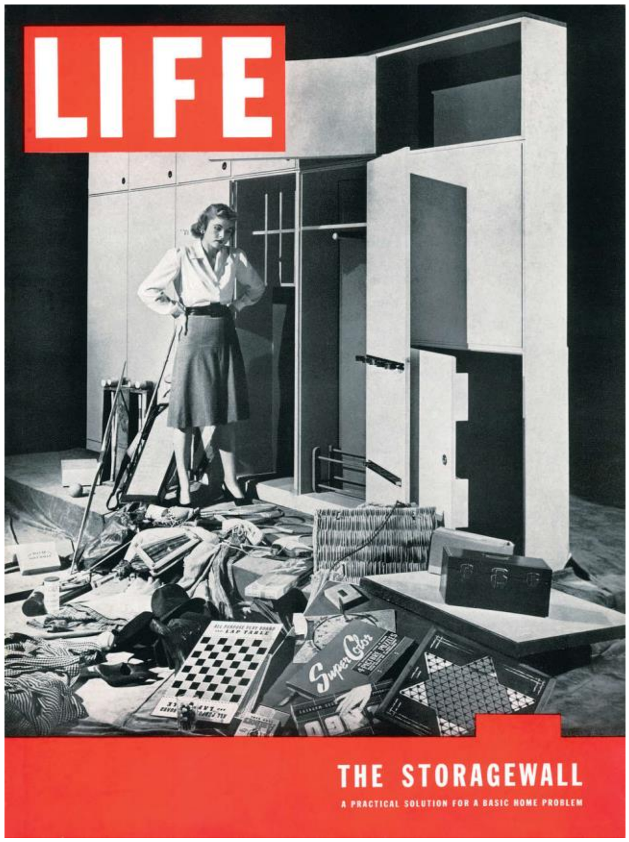

Figure 25 *– The Storagewall designed by George Nelson in 1944 on the cover of 'Life' described as a practical solution for a basic home problem.*

A timeless example of modularity is the 606 Universal Shelving System (**Figure 26**), designed by Dieter Rams in 1960 and made by Vitsoe ever since (Vitsoe 2018). This system is considered highly customizable, from one ledge to a whole library of mixed drawers, tables and shelves. At the core of the 606 Universal Shelving System is the aluminium E-track – that can be attached directly to the wall – and a pin (**Figure 27**). Shelves, cabinets and tables are all hung from the E-track by simply slipping the notched pin into position without the need of tools (Vitsoe 2018). Due to its core system, it is possible to easy interchange components, encouraging either day-to-day rearrangements (Vitsoe 2018).

Figure 26 *- Wall mounted interchangeable structure – E-track is attached directly to the wall (Vitsoe 2018)*

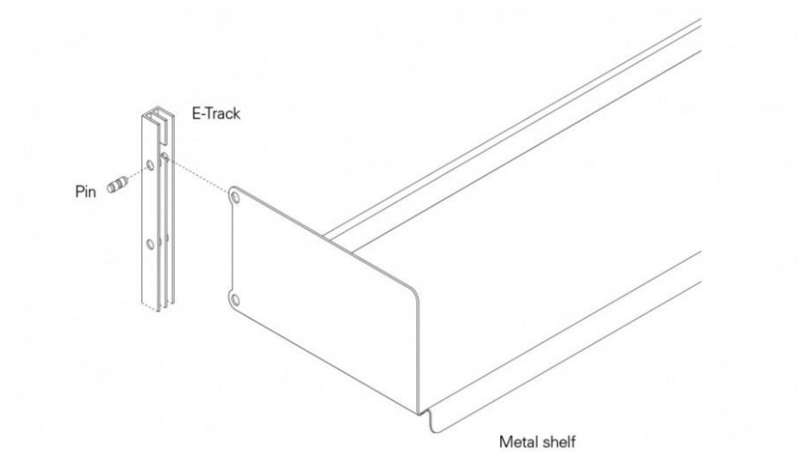

Figure 27 *- E-track and pin as core system of the 606 Universal Shelving System (Vitsoe 2018)*

In the case that no walls are available – or it is uneven – the E-Track may be attached to an aluminium X-Post. The system can then stand on the floor and avoid many obstructions allowing the system to be installed accurately in a wide variety of environments. Modules vary from cabinets, integrated tables, desk shelfs, hanging rails, 18 and 79 degrees sloping shelfs, mounting panels, internal shelfs, drawer dividers, aluminium trays, pencil trays and bookends. Extra components can be add at any time, enabling future upgrades safe in the knowledge that components will be available and compatible (Vitsoe 2018).

Variety and interchangeability would not have meaning unless there are more than one module and if each module belongs to a major system. It is not possible to clearly define a module from the module itself and without knowing the system to which the module belongs, but at the same time a module itself must have essential and self-contain functionality (Bonvoisin et al. 2016). Often a system is composed by related products, called as product family, and accompanied by terms such as modular architecture and product platform (these two concepts are further explained in previous chapters). A very straightforward example to understand these concepts of modularisation, module, self-functionality and system is YOUMO, the smart modular power strip (Sheth 2015). This system is composed by several modules - powerline, wireless speaker, triple EU, solo US, wireless charging, sensor/security, multi USB - connected to a base cord (**Figure 29**). Often a system is composed by related products, called as product family (**Figure 30**). A product family is the group of related products, that share common features components and sub-systems, all of which can be combined to satisfy customers' needs and markets (Johannesson et al. 2017).

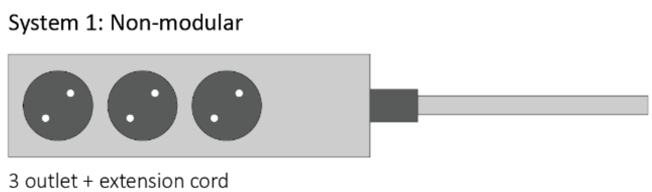

Figure 28 *- Non-modular power strip composed by three outlet and an extension cord. Adapted from "I've got the power!" (Sheth 2015).*

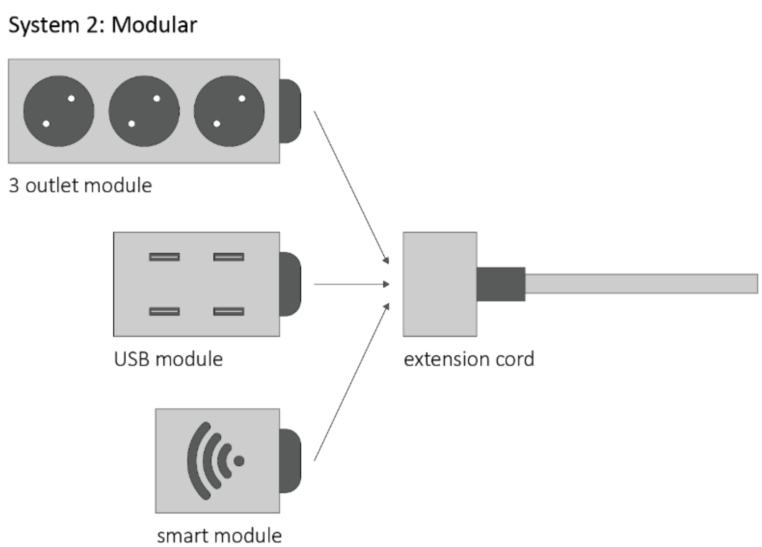

Figure 29 *- Modular power strip composed by several modules that are designed to fit with the extension cord. Four modules from the YOUMO modular system are visualized in the figure. Adapted from "I've got the power!" (Sheth 2015).*

***Figure 30** - YOUMO product family (Sheth 2015).*

F. **Product platform**

A product platform is a set of elements – for example technical components, parts or technology – interlinked and shared across a range of a family of products. This platform, in which components are added or removed according to product requirements and specifications, is defined as base from which products can derive (Van den Broeke et al. 2017). According to Meyer and Lehnerd (1997) a platform can be defined as a "relatively large set of products components that are physically connected as a stable sub-assembly and are common to different final models" (Vrijhoef and Voordijk 2004). The platform concept is closely tied to concepts of product architecture, modularisation and standardisation (as cited in Vrijhoef and Voordijk 2004).

A product platform-based strategy is considered an effective method for constructing a product line that satisfies diverse customer requirements while keeping design and production costs and time effective (Liu, Wong, and Lee 2010). Platform based strategies have proved to be a successful approach for achieving balance between standardisation and variation in many industries (Veenstra, Halman, and Voordijk 2006). The product platform approach offers significant advantages in new product development, such as increased speed in developing new products, manufacturing can be flexibly adjusted to create new products, reduced development costs, ability to upgrade product easily and reduce testing on new products as common components are used (MBASkool 2018; Santos and Forcellini 2012). Besides these advantages, the product platform strategy facilitates the ability to upgrade products easily. In this way, by using a platform approach, a company can develop a set of different products and derivates using common components, parts or technology. Koufteros et al. (2002) argue that this strategy is particularly suitable for new product development in uncertain and equivocal environments (as cited in Vrijhoef and Voordijk 2004). Despite its advantages, product platforms might bring disadvantages such as the leading to the development of very similar products and the fact that initial effort and investment are highly costly since a lot a research need to be put into the initial products (MBASkool 2018).

Platform strategies have been applied in the manufacturing industry to achieve goals of agile and lean production, and mass customisation. These strategies have had consequences for manufacturers supply chains (Vrijhoef and Voordijk 2004). Current platform approaches are generally based on the idea of mixing components in different configurations, but this alone does not provide the support needed to achieve increased development efficiency (as cited in Johannesson et al. 2017). To apply a platform strategy, it is essential to have an integrated product development approach and an integrated production planning (Vrijhoef and Voordijk 2004). Also, it is necessary to consider that platform development project can take from 2 to 10 times more time and money (Ulrich and Eppinger 2012). **Figure 31** visualises the leverage of an effective product platform. The critical strategic decision at this stage is whether a project will be developed from an existing platform or developed an entirely new platform.

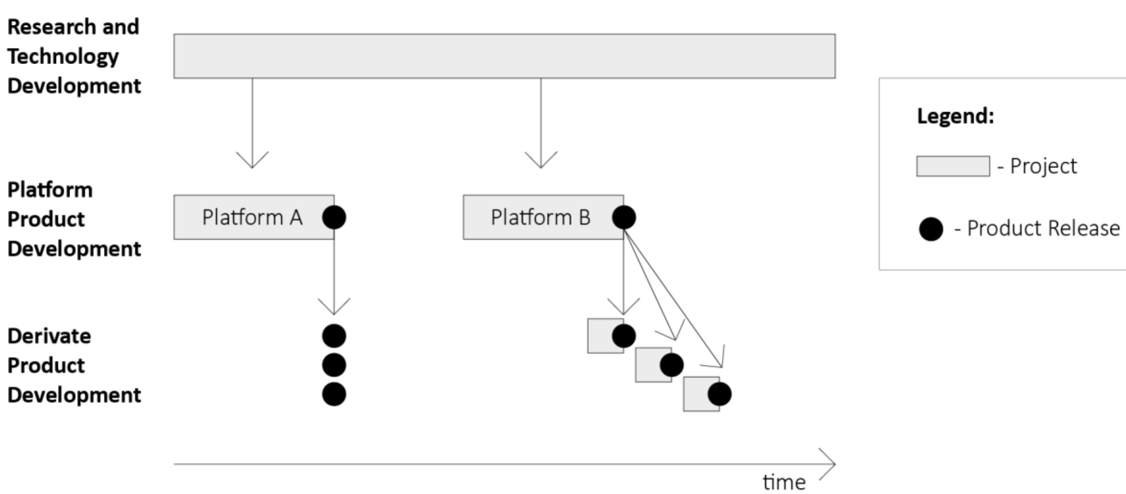

Figure 31 *- A platform development project creates the architecture of a family products. Derivate products may be included in the initial platform development effort (platform A) or derivate products may follow thereafter (platform B). Adapted from (Ulrich and Eppinger 2012).*

An example of a product platform is the case of Volkswagen Group. Besides car production, this group started to expand its commercial vehicle division to small and medium-sized transporters shareholding with other companies such as Seat and Skoda with the intention to open up access to new markets. Volkswagen has an extensive global production network in continuously expanded growth, including local manufacturers, and factories in China or Mexico. In order to accomplish versatility, advanced brand diversification and also diverse geographical production, this group committed to a platform based system, the *Modularer Querbaukasten* (MQB) strategy or Modular Transverse Matrix (Müller-Stewens and Stonig 2016). In this way their production system is configured such that their modules can be used for several Volkswagen Group brands and regardless of whether the factory location. The core idea is to use as many of the same parts as possible in different vehicles, independent of brand, location or segment. Through the use of modular platforms, parts developed can be manufactured in large quantities, since they are going to be used in several car models, reducing costs and raising efficiency (Müller-Stewens and Stonig 2016). For example, a single air conditioning model is used in diverse vehicles and afterward cladded according to the customer. With the entire group having more than 220 different models, produced in over 90 sites worldwide, the MQB enabled the group to have comprehensive standardisation of components and production processes, reducing complexity and increasing flexibility (Focus 2015). In **Figure 32** it is observed the basis of the Volkswagen MQB platform strategy. Volkswagen's MQB platform is an example of how an abundance of configuration options can be realized with a limited set of standardized modules (EY 2015).

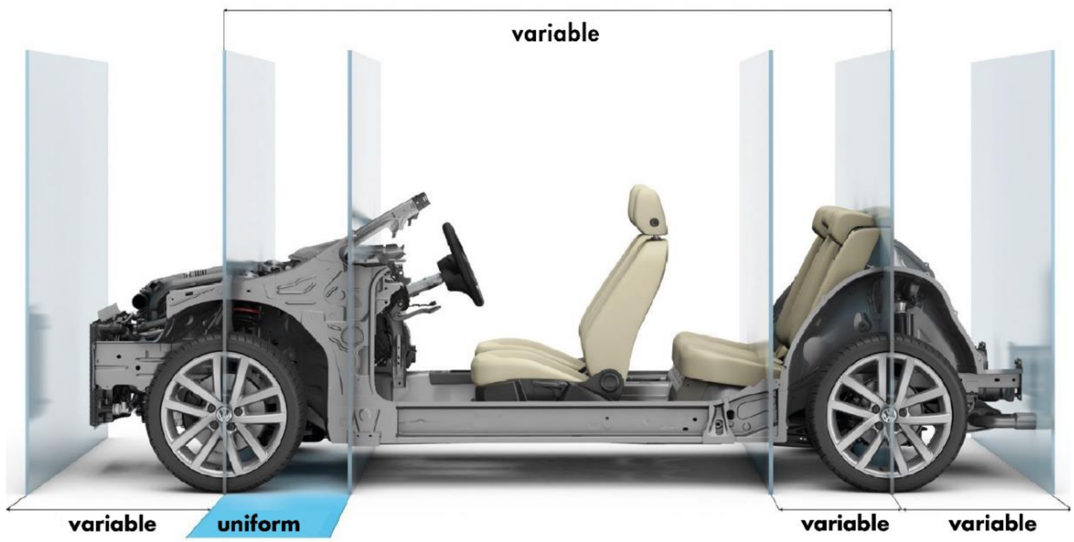

Figure 32 - *VW Group strategy for sharing modular design construction of its layout, maintaining the front-wheel-drive layout (adapted from VW MQB system 2012).*

Platform strategies could also be applied to the building construction. The following example illustrates how a production system could be configured: were the structure would be uniform and the interior would be variable (**Figure 33**). Different configurations can be executed according to the number and placement of uniform components (**Figure 34**).

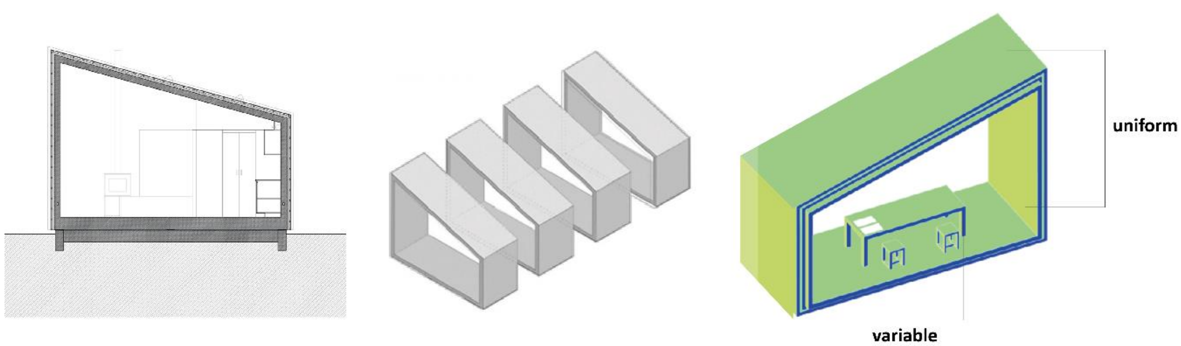

Figure 33 *– Gomos Building System composed by a uniform module. Adapted from "Gomos system" (Summary 2017).*

***Figure 34** – Housing and multi-services spaces composed with the Gomos system, in a common road-side area in Vale de Cambra, Portugal (Summary 2017).*

Platforms are therefore a successful complexity-reducing mechanism that allows a high number of model types, options and individual configurations, as well as higher flexibility within the production systems and lower cost units (Müller-Stewens and Stonig 2016). However, introducing modular product architectures is a complex tasks (EY 2015) and requires resources – time and costs - and capabilities to modularize their products. Developing the initial platform requires greater investment and more development time than developing a single product, potentially delaying the time to market of the first product and lengthening the payback time (Veenstra, Halman, and Voordijk 2006).

2.3 **Product Development Process in the setting of building construction**

Due the specific characteristics of construction, product development process is somewhat different from manufacturing (Tzortzopoulos, Betts, and Cooper 2002). The increasing complexity of building construction, rising pressure for reducing process lead-time and costs, and the growing need for fulfilling client's requirements lead to an ever-increasing importance of product development processes (Tzortzopoulos, Betts, and Cooper 2002). According to Fabricio (2002) and Romano (2003), product development management, within construction projects, tends to be sequential, that is, it is structured in an hierarchical way, with the aggravating factor that most of the projects and specialized consultancies are developed by external project companies (Fabricio 2009).

The nature of the design process is complex, involving thousands of decisions, sometimes over a period of years, with numerous independencies and under intense budget and schedule pressure (Freire and Alarcón 2002). Projects within construction are usually developed by fragmented teams, characterized by the poor consideration for client needs, are generally delivered out of budget and/or schedule (Tzortzopoulos, Betts, and Cooper 2002). In some cases, building design is usually poorly defined at the beginning of the development process. In other cases, the actual customer is only known when the design is at a relatively advanced stage. Issues such as consideration for client needs - defined by marketing -, strictness of deadlines or budgets and others have been analysed by the manufacturing industry for longer than in construction (Tzortzopoulos, Betts, and Cooper 2002).

Smith and Reinertsen (1998) state that there is a good scope for improving product development by increasing the rate of success at the 'fuzzy front end' (as cited in Formoso, Tzortzopoulos, and Liedtke 2002). Improving initial project stages is particularly relevant due to cost/time performance and the overall value of the project product (Faniran, Love, and Smith 2000). The cost of making changes increases along the project. **Figure 35** visualize the related design costs as a construction projects continues (Faniran, Love, and Smith 2000; Nobre, Santos, and Neto 2004; Univesity 2018). Therefore, the success of a product is not only the result of a smart and competitive design process but largely from the error detention on early stages of development (Nobre, Santos, and Neto 2004; Tzortzopoulos, Betts, and Cooper 2002).

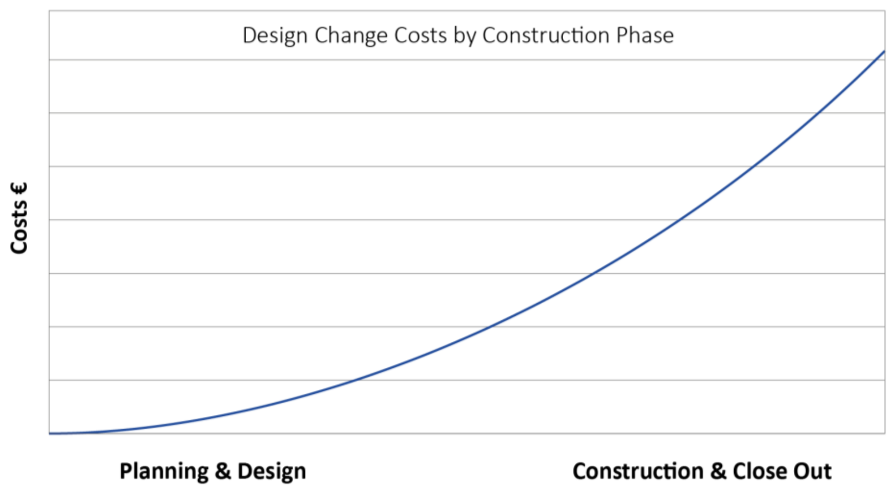

***Figure 35** - Design Change Costs vs Phase. Adapted from "Construction Project Management" (University 2018).*

Since a construction project involves such large number of personnel, the product development integrated within these projects needs to be planned and controlled in a very efficient way, to minimize the effects of complexity and uncertainty (Formoso, Tzortzopoulos, and Liedtke 2002). Oliveira (1999) reminds that it is crucial to organize and understand the information flow and the management of the design interfaces (as cited in Fabricio and Melhado 2005). Fabricio and Melhado (2005) propose a process flow of product design in a construction project, describing the main interfaces in the design process and the interactions between interfaces. This process flow is visualised in **Figure 36**. The first interface (i1), the client interface, lies between the market and the developer. This interface links the clients' needs plus budgets and the development of a design. The interface between specialities (i2) is related to the coordination and the need for multidisciplinary approach for the development of products in constructions projects. The (i3) interface is related to the feasibility of the designs and their production, involving construction methods of the subsystems in the site work according to product specifications. The (i4) interface refers the need to follow up the construction and prepare the "as built" to guarantee the feedback for future designs and the maintenance of the products in the constructed building. The (i5) interface relates to the use and maintenance phases. In this interface it is measure if the expected results were accomplished and if the client is satisfied, by means of performance and post-occupation evaluations. The performance is measured from a technical point of view as well as the perspectives of the end users.

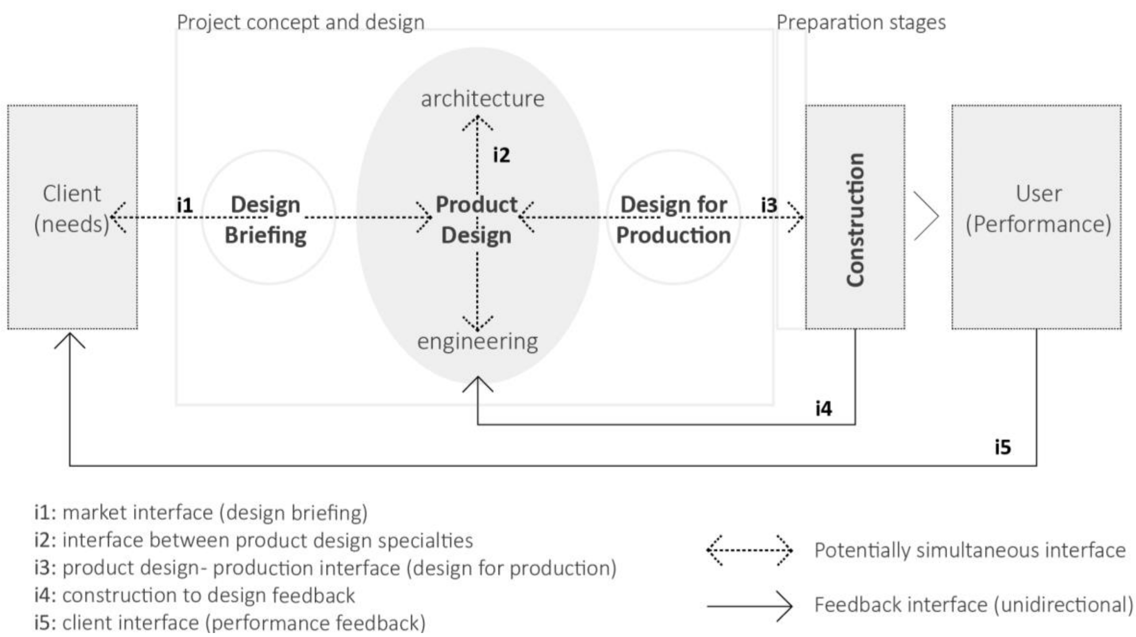

Figure 36 *- Main interfaces in the product design process. Adapted from "Integrated product development in building constructions: Case studies in Brazilian building companies" (Fabricio and Melhado 2005).*

Formoso, Tzortzopoulos, and Liedtke (2002) also presented a model for the product development process in the specific setting of house building construction, visualised in **Figure 37**. The product development process model is divided into seven stages and it was developed and readjusted for two construction companies (Formoso, Tzortzopoulos, and Liedtke 2002). The fists stage – *(1) inception and feasibility* – involves the identification of a business opportunity, definition of the project objective and a broad evaluation of its feasibility. In this stage, only few people are involved. Based on the project objectives, brief information about the site and local authorities, the architect produces a rough drawing of the proposal for a product developed. The authors suggest that in some cases the opinion of a marketing consultant or an estate agent might be considered. Based on this information, a feasibility study is carry out, involving budgets, technical details and legal issues. The second stage – *outline design* – main goal is to define the architectural design at a conceptual level. The third stage –*scheme design* – involves the development of the architectural design at the embodiment level and the sub-system definition performed by the design team and the production management representatives. Then a final evaluation of the design is carried out, in which is included customer satisfaction, approval by local authorities and economic and financial feasibility. The next stage –*design for legal requirements* - involves the preparation of all the information and documents for the submitting design, for the approval of local authorities and for the preparation of sales. The activities in this stage are very important for the success of the project since they enable the company to start the construction and to sell units. The *Detail design* stage involves many activities, including the architectural detail design, and structural and building service at an embodiment and detail level. The design is evaluated in term of integration with other sub-systems and started the preparation of drawings – it is common to exist an overlapping between this design stage and the production phases. Also, since the sales already started at this point, it may be necessary to introduce design changes demanded by clients. The *production monitoring stage* is concerned with the introduction of design changes and with the feedback from production. At this point all design changes have been documented as an in-built design drawing. The last stage involves *feedback from operation* by using two mechanisms: post occupancy evaluation and analysis of customer complaints. Feedback is considered very important for future improvements in product development. In the end, product development must be seen as a process that generates value not only for the final customer, but also for all the stakeholder involved in the project.

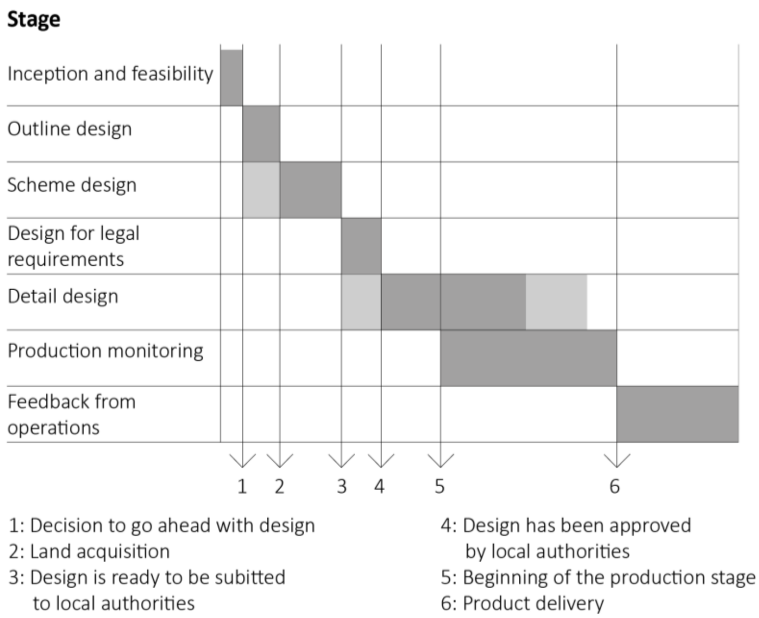

***Figure 37** - Product development stages for house building projects. Adapted from "A model for managing the product development process in house building" (Formoso, Tzortzopoulos, and Liedtke 2002)*

Since this research is focused on stationary furniture it was found relevant to classify products found in the interior in which the stationary furniture is allocated. In this way the following two sections classifies the interior design products, defines, and exemplifies stationary or fixed furniture.

A. Product design in interior building construction: classification

Products which are found in interiors and requested for building construction are normally associated to the term FF&E (**Table 5**) – (1) fixtures, (2) fittings/movable furniture and (3) equipment. FF&E are defined as fixture, fittings (or movable furniture) and other equipment that have no permanent connection to the structure of a building or utilities. Fixture (1) are items that are typically fixed to walls or floor and normally are products intended to use over long years. These products are also typically integrated in the architecture, e.g. built in wardrobes or shelf units. Fittings or movable furniture refers to free standing items or movable items such as carpets, blinds or free-standing furniture. Equipment refer to all home appliances,

__Table 5__ - Fixtures, fittings or movable furniture and equipment features and examples.

Fixtures (1)	- fixed to walls or floor; - intended to use over long years 7/10 years; - typically integrated in the architecture; - permanent; - affixed to the property;	- Electric sockets; light fixtures; security alarm systems; television aerials and satellite dishes; fires and fire surrounds, central-heating boilers and radiators, plumbing installations; fixed furniture; kitchen units; built in wardrobes, cupboards or shelf units;
Fittings/movable furniture (2)	- free standing or movable items; - hung by screws, nails or hooks;	- Carpets; blinds, curtains and curtain rails; paintings or mirror, beds/sofas and other free-standing furniture; lamps and lampshades;
Equipment (3)	- not permanent;	- ovens; refrigerators; washing machines; dryers;

FF&E can have a considerable impact in a building. In the hotel category, FF&E constitute approximately 12 to 16% of total investment (Fidlschuster 2007). In this scenario, designers are not merely decorators who arrange furniture within the premises. Their role is to use approx. half the FF&E-budget – usually approx. 6-8 percent of the total investment – to plan and design what the customer then perceives and for which he is willing to pay. FF&E are considered a value driver that should not be underestimated. This research focuses in the implementation of industrial production methodologies that will consequently facilitate the execution of fixed in building construction projects.

B. **Stationary or built-in furniture**

Furniture is defined as an industrial product that supports human activities. There are several types of furniture - ready-made, custom-designed or built-in – and several classifications can be done. Making a distinctive and obvious division of furniture is considered difficult. However, Smardezewski (2015) presents a classification to the arrangement of objects, including furniture depending on its features. Two categories are relevant for this research: categorisation according to its functionality and according to its degree of connection with the room.

Furniture can be grouped into seven groups according to their functionality: (1) furniture for sitting and lounging, (2) furniture for reclining, (3) furniture for working and eating meals, (4) furniture for learning, (5) furniture for storage, (6) multifunctional furniture and (7) complementary furniture (Smardzewski 2015). Each group is characterised by specific properties and requirements included in its design, such as anthropotechnical characteristics, sanitary and hygienic, pedagogical, construction among others. Furthermore, furniture can be divided depending on the degree of connection with the room. In this group furniture can be divided into two groups: mobile - not connected to the construction elements of the room, e.g. containers, chest of drawers, cabinets, buffets and chests - and stationary - connected permanently with the construction elements of the room, e.g. wall cupboard, shelves, partitions or tall standing cupboards - (Smardzewski 2015).

Figure 38 and **Figure 39** illustrate real examples of stationary furniture. Stationary furniture is mainly executed in wood and derivates, and are present in almost every room of an apartment.

Figure 38 *– "Alameda Eça de Queiroz Apartment": Dining room and kitchen stationary furniture. Bárbara Rangel and Ana Vale, Porto 2007.*

Figure 39 – *"Pasteleira Apartment": stationary furniture executed for a bedroom. Bárbara Rangel and Ana Vale, Porto 2008.*

C. **Process model for built-in furniture design and development**

Furniture is part of the "Fixture, Fittings or movable furniture and Equipment" project' budget. Particularly interest is given to in built furniture / fixed furniture / stationary furniture due to be the focus of this research. Although, in most cases the supply chain and the process design tends to be treated as something subsequent to the product design (as cited in Santos and Forcellini 2012), it was found relevant to understand the supply chain and processes involved in the making of an appropriate design strategy. A generic process model of the development of built-in furniture is presented in **Figure 40**.

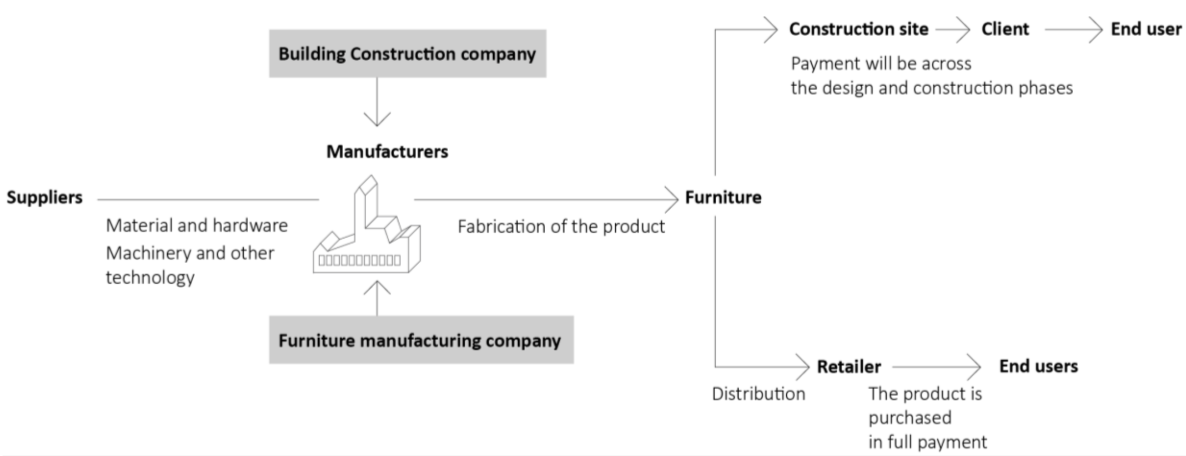

Figure 40 - *Generic model of the development of built-in furniture in the specific setting of a construction project.*

In a general process model of a construction project, e.g. a building, built-in furniture is integrated in the architecture project. Typically, this work is done by the architect, but in other cases this work is handed to an interior design studio or consultancy. After the interior design project is approved, by the client, it is given to the manufacturer in order to be fabricated. The result is affected by several factors such as the client requirements, architecture design, the knowhow of the designer and application of human factors such as ergonomics and anthropometrics, budget considerations, materials, fabrication techniques and technologies available, among other factors. Even though the project being closed, the manufacturer may propose modifications for possible improvements in e.g. the constructive system, or material or in case of budget limitations. Knowhow exchange, communication and collaboration between manufacturer and designer is considered relevant to avoid misunderstandings and increase effectiveness. Other stakeholders e.g. designers, manufacturers, contractors and building owners should be coordinated towards project success.

In the manufacturing process, apart from the documentation delivered by the designers, several internal documents are prepared to be fabricated. These documents are made for internal purposes and usually tend to transform external requirements into readable information for the manufacturing company. An example of this are: bills of material (BOM) - list of raw materials, hardware and other components with the respective quantities of each needed-, technical drawing checked and according to their layout (in case the company uses a specific standard layout), numeric code or G-code (CNC machine codification), among other. This documentation is always dependent of the manufacturer. After a final inspection is done, the products are packed and shipped to the construction site sub assembled. In some cases, the load is transported to off-site storages and its only offloaded in the right moment, depending on the construction phase. E.g. there are certain products that are only placed inside the building in the finishing phase of the construction process or need to be placed while cranes are still on construction site.

After the furniture order is manufacturer, it is transported to the site, sub-assembled. Depending on the distance between the factory and the construction site, this cargo be shipped by train, truck or ships. In the site each piece of furniture is allocated, typically using cranes. The final assembly is usually operated by carpenters or skilled workers, in the product’s destination placement.

2.4 **Product design and development: methods and strategies**

Product development can be defined as "the process in which a product is conceived, designed and launched in the market" (Ulrich and Eppinger 2012). The performance of the product development process has a critical influence on the efficiency and fulfillment of deadlines in construction projects, as well as the quality of the final product – the building (Formoso, Tzortzopoulos, and Liedtke 2002). However, with the increasing complexity of modern buildings, more and more sophisticated customer requirements and increase of product variants there is a rising pressure for reducing process lead-time and costs, to fulfill customers' demands and to reduce internal complexity without reducing the range of products (Kipp and Krause 2008). Due to all these factors product development processes and strategies are considered highly important (Tzortzopoulos, Betts, and Cooper 2002). Given the actual demands, it is relevant to get advantage from the current strategies, that outperform in the industrial production setting.

A strategy can be defined as a plan of action designed to achieve a long-term or overall aim (Oxford 2018). In the organisation context, a competitive strategy defines a basic approach to market and products with respect to competitors (Ulrich and Eppinger 2012). A clear and effective corporate strategy within a company is able to assess properly business opportunities, make sure that customer requirements are adequately captured and that the risk of the project being suspended is reduced, resulting in an easier involvement of designer and sub-contractor early in design (Formoso, Tzortzopoulos, and Liedtke 2002). In this way it is important that companies choose proper strategies, that focus their effort and appropriately manage their product development activities, providing a solid foundation for sustaining success and ensuring long-term growth (Nunes 2004). In **Figure 41** it is visualised factors that impact a product development company's success.

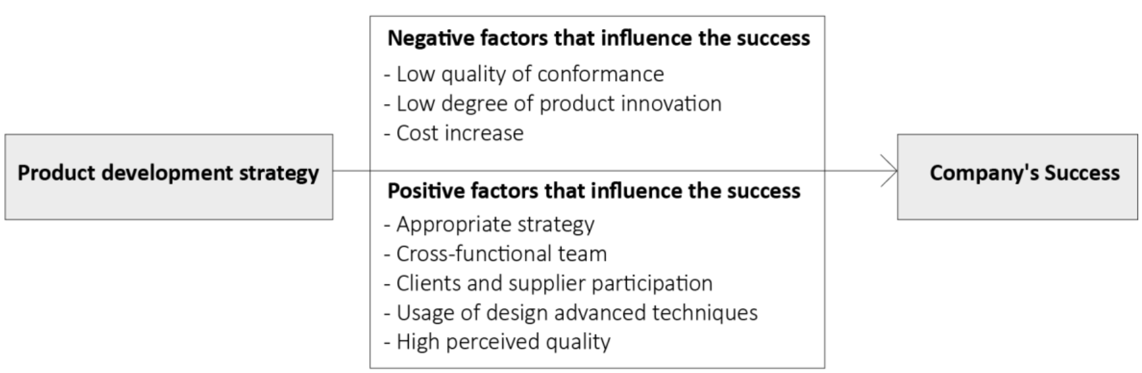

Figure 41 *- Factors that influence positively or negatively a company's success. Adapted from "Metodologias de desenvolvimento de novos produtos" (Nunes 2004).*

A study on new product development best practices, by Barczak et al. (2009), concluded that the best firms did not succeed by using just one NPD practice more extensively or better, but using a selection of them more effectively simultaneously (Vinayak 2013). Although methods are useful tools, they should not be considered 'recipes' for success. Methods should be seen as a strategic procedure(s) to help structure activities and action during the product design and development process (Boeijen et al. 2014). There are many methods to accomplish product development successfully.

Based on actual trends towards product development process success we can identify a great need to accelerate the time for product development, to reduce costs on the product and the PDP (Rauch, Dallasega, and Matt 2017). In this way it is important to configure and design the PDP along as the appropriate methods as efficient as possible. Since the focus on this research lead us to industrialisation of products and processes, large ranges of products and internal variety management, as well as time and cost consumes, it is presented in the following subchapter a list of methods or approaches that intend to handle these demands. Besides, focus was given to methodologies that target preliminary stages and supported fuzzy front-end activities.

A. **Industrial Production Methodologies Classification**

Today's designers and engineers have access to a wide range of tools, methods, approaches, and techniques that can be used throughout the product development process. To provide a clear understanding of the methodologies considered relevant for this study, they were classified (**Table 6**) in the following categories: category A: Design methods, category B: organisational methods, category C: fabrication methods and category D: simulation methods. There were highlighted the approaches, founded in literature, that obtain better results in accelerating and supporting the PDP. Furthermore, it also referred approaches that have dealt with the industrialisation in the PDP.

***Table 6** - Methodology classification.*

Category	**Category A** **Design methods**	**Category B** **Organisational methods**	**Category C** **Fabrication methods**	**Category D** **Simulation Methods**
Methods	- Lean Product Development (LPD); - Design for Variety (DFV);	- Concurrent Engineering (CE);	- Material requirements planning (MRP); - Configure to Order (CTO);	- Three dimensional models; - Technical documentation (TecDoc);

2.4.1 **Design methodologies**

Design stage can be defined as the activity that transforms a set of product requirements into a configuration of materials, elements and components. This activity has an impact on product appearance, user friendliness, ease of manufacture, efficient use of materials and functional performance, among others (Gemser and Leenders 2001). Literature shows that initial design phases are crucial and greatly influences further product development stages. Design is viewed as a key driver of manufacturing cost. Past research indicates that as much as 80% of the manufacturing cost of the product is determined by the design of the product or the process in which the product is to be manufactured (Swaminathan and Lee 2003). Design decision can dramatically impact the risk profile of the business (Omera and Alessandro 2009). It is clear that in recent years more importance has been given to efficiency of product development processes due to its impact on costs (Nunes 2004).

a) **Lean Product Development (LPD)**

Lean methods in general perform towards minimizing non-value-added activities/processes while aligning the value stream with the customer (Rauch, Dallasega, and Matt 2017). The fact remains the same when it comes to LPD basis. Lean Product Development (LPD) is based on lean thinking and lean principles that originally were developed in lean manufacturing (NPD 2016). LPD main goal is to improve the way products are manufactured throughout the reduction of resources, time management improvements and decrease work-in-progress.

LPD approaches the complete process from gatherer and generating ideas, through assessing potential success, to developing concepts, evaluating them to create a best concept, detailing the product, testing, developing it and handing over the manufacture (Rauch, Dallasega, and Matt 2016). LDP is summarised in **Table 7**.

There are six forms of waste in engineering according to LP WZL and Fraunhofer IPT (as cited in Rauch, Dallasega, and Matt 2015): lack of customer orientation, interrupted value stream, unused resources, insufficient standards, unused economies of scales and defects and rework. This lead us to the five lean principles: define and maximize customer values, identify the value stream and eliminate waste, make the value-creating steps flow, empower the team and learn and improve.

Table 7 - Lean Product Development methodology summary. Adapted from "NDP solutions" (NPD 2016).

Methodology	Lean Product Development (LPD)
Definition:	Lean approach to meet the challenges of product development.
Goal:	Reduce development time; Reduce development costs; Increase demand by improving customer value; Improve product profitability;
Guidelines:	1. Listen and understand customer needs and value; 2. Minimize waste through lean design (Design for X or Design for Excellence, Design for Manufacturing and Assembly or DFMA); 3. Platforms and design re-use to reduce the product development costs and efforts and increase product value; 4. Rapidly explore alternatives; 5. Streamline the development process to avoid unnecessary gates, process steps and procedures. (value stream mapping); 6. 5S workplace organization to minimize time needed to find information and perform development activities (Product Lifecycle Management); 7. Standardised work to stablish a common way of performing – standard processes, document templates, checklists; 8. Integration of design tools that facilitates data exchange, improves process and reduce cycle time (CAD/CAE/CAM); 9. Effective pipeline management to avoid overloading; 10. Flow process and scheduling: team planning and visual management; synchronize activities; 11. Reduce batch sizes through standardization and platform development – smoother flow; 12. Cross-functional team and workforce empowerment; 13. Right resources (number of people, tight times, right skills and experience); 14. Amplify learning (making it readily available to other to avoid costly and time-consuming re-learning);

b) **Design for Variety (DFV)**

Design for Variety is a design methodology to help design teams reduce the impact of variety on the life-cycle costs of a product (Martin and Ishii 2000). It is defined as a methodology for the development of architecture of products with a huge amount of variants (Martin and Ishii 2000). Design variety methodologies often orient for modifications of a basic design to generate various different products (Veldman and Alblas 2012), meaning that will decisions regarding DFV will have a significant impact on product design (Kipp and Krause 2008). This methodology arises to tackle the increasing number of product variants due to an increasingly sophistication of customer requirements, increasing internal complexity and its resulting costs (Kipp and Krause 2008). The intention of Design for Variety is to provide the possibility of handling many product variants – complex external variety – in a more effective way by reducing the internal complexity (**Figure 42**). It is possible to reduce internal complexity and associated costs of a large range of products through Design for Variety methods.

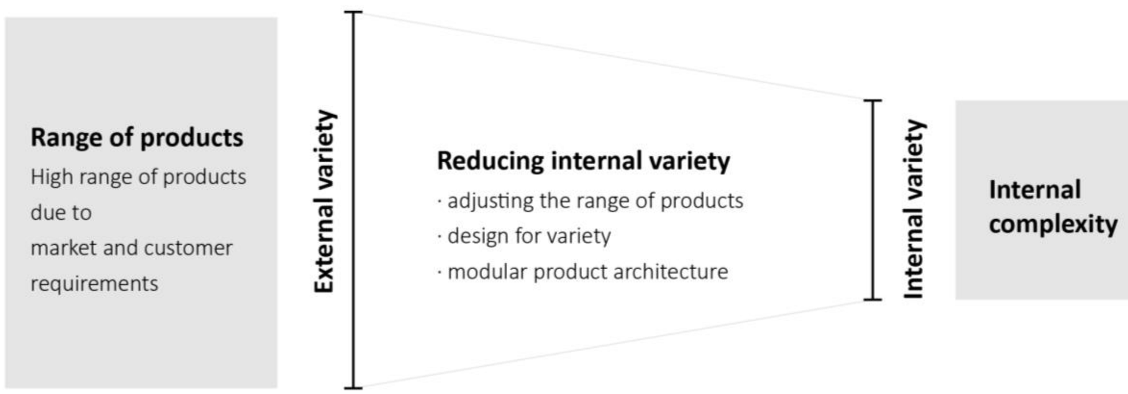

***Figure 42** - Design for variety approach: intention of reducing internal complexity and maintain the external variety. Adapted from "Design for Variety – Efficient Support for design Engineers" (Kipp and Krause 2008).*

The DFV method is a detailed, step-by-step approach to aid design teams in developing a product platform architecture that incorporates standardization and modularization which aims to reduce future design costs and efforts. Design for variety consists of three main steps described in "A methodology for developing product platforms in the specific setting of the housebuilding industry" (Veenstra, Halman, and Voordijk 2006). The first step is to generate a General Variety Index or GVI – measure for the amount of redesign effort required for future designs of the product - and a Coupling Index or CI – measure for the coupling among the product components. Design teams use these two indices to develop a decoupled architecture that requires less design effort for follow-on products (Martin and Ishii 2000). The second DFV step is to order the modules based on the GVI and CI results.

After having the modules organized, the third and last step concentrates on the standardization and modularization (Veenstra, Halman, and Voordijk 2006).

Kipp and Krause (2008) present two possibilities for the implementation of Design for Variety. The first one refers to the "increase of headroom of the specification", referred to as "overdesign". The second approach is to add elements, in this case extension elements, to adapt the specific requirements of each variant. In "Design for Variety: Efficient Support for design engineers" the authors provide a systematic compilation of Design for Variety guidelines. On **Table 8** are organized the guidelines that summarizes all major goals of this methodology.

With globalization, companies have been dealing with increasingly specific customer demands, higher variety of products, an increasing complexity due to this variety. In today's manufacturing work the domain of conflicts between internal complexity and external need for product variety has become a strategic factor (EY 2015). DFV can be a valuable strategy to allow for a greater variety of products and a manageable level of internal variety (Kipp and Krause 2008).

***Table 8** - Design for Variety summary. Adapted from "Design for Variety – Efficient support for design engineers" (Kipp and Krause 2008).*

Methodology	**Design for Variety (DFV)**
Definition:	Methodology to design and develop a range of products with a huge number of variants and reduce internal complexity for design teams.
Goal:	Provide the possibility of handling a huge number of product variants in a more effective way by reducing internal complexity.
Guidelines:	1.Use as many common components; 2. Standardise and parametrised components; 3. Overdesign to avoid variants; 4. Use symmetric and geometric designs; 5. Software instead of hardware; 6. Design module interfaces compatible; 7. Use parallel and serial configurations to create performance variants; 8. Decompose cost-intensive components with a huge number of variants to standard and variant components; 9. Use cut to fit modularity to create geometric variants; 10. Use additional elements to create variants; 11. Variant characteristics without any effect on the function should be isolated in new cost-efficient components; 12. Assign every function directly to one module of the product;

	13. Assign every variant product characteristic directly to one module; 14. Changing one product characteristic should not affect more than one module; 15. Develop new product variants based on a non-order-related variant; 16. Product variety should be created in the end of the assembly process;

2.4.2 **Organisational methods**

Companies from the industrial sectors have been approaching methodologies to develop their products in a more integrated and collaborative way, involving marketing, design and production (Fabricio and Melhado 2005). An efficient design process does not necessary lead to good design without a well-coordinated skilled and collaborative design team (as cited in Nobre, Santos, and Neto 2004).

a) **Concurrent Engineering (CE)**

Concurrent Engineering is a methodology of designing and developing products in which the different stages run simultaneously, rather than consecutively. This approach requires that the developer, from the outset, considers all elements of the products lifecycle, with a holistic approach to the design, development and procurement of a product (Love, Gunasekaran, and Li 1998). CE is a conceptualization of the product development process found in the world of product design and manufacturing (Ulrich and Eppinger 2012) that started to receive attention in the construction industry (Love, Gunasekaran, and Li 1998). Although there are several interpretations, “concurrent” refers to the “simultaneous and integrated considerations of multiple design criteria expressing the needs or wants of multiple stakeholders” (Ballard and Koskela 1998), meaning that CE method of designing and developing products requires that the different stages of the PDP run simultaneously. The difference between a traditional method and the CE is that the traditional is sequential or consecutively rather than simultaneous or “concurrent” (**Figure 43**).

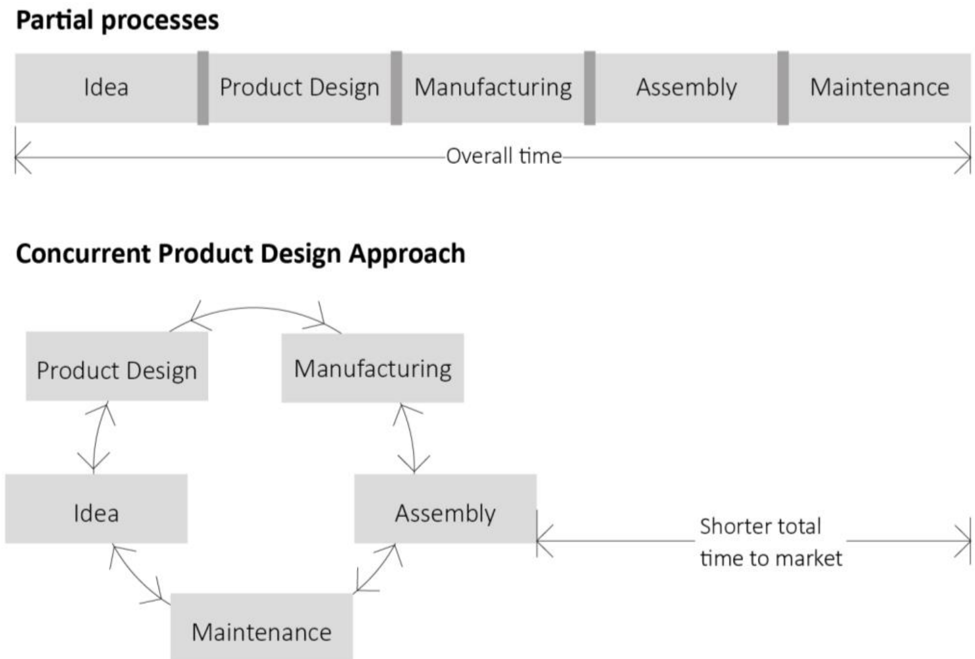

Figure 43 - *Difference between a partial process and Concurrent Product design approach. Adapted from "Concurrent Engineering" (Chandekar 2014).*

Literature shows that between 25% and 40% of time and cost can be saved by using a team-based CE approach, mainly due to function overlap. Therefore, encouraging the change of attitudes and behaviors towards a cooperative team-based environment involving parties during early design phases is a prerequisite for successful project completion time and cost (Fabricio and Melhado 2005; Love, Gunasekaran, and Li 1998). Effective communication has been linked to team achievement, thus CE effectiveness will be determined by the improvement of organizational communication (Love, Gunasekaran, and Li 1998). The information flow improvement throughout the development process will minimize variations and rework, consequently affecting on time and cost of a product and "scoring points" for a greater degree of client satisfaction (Love, Gunasekaran, and Li 1998).

Concurrent engineering can represent a significant advance in the way of focusing the product development in building construction by involving the design process and all the project life cycle allowing to improve the performance of the design process and consequently improving the building product quality (Fabricio and Melhado 2005).

Table 9 *- Concurrent Engineering summary. Adapted from "What is concurrent Engineering?" (ConcurrentEngineering 2018).*

Methodology	Concurrent Engineering (CE)
Definition:	Methodology of designing and developing products in which the different stages run simultaneously, rather that consecutively in a collaborative way.
Goal:	Decrease product development time and time-to-market; Improve productivity and costs; Implement team collaboration;
Guidelines:	1.Develop a strategy by top management; 2. Set up a multidisciplinary team; 3. Design and production integrated development; 4. Strong customer and user satisfaction orientation;

2.4.3 **Fabrication methods**

To complement efficient design and development methodologies, efficient manufacturing and fabrication methodologies are required. The manufacturing cycle time is considered a competitive advantage for companies. There has been an effort to reduce manufacturing cycles through manufacturing systems based on economies of scale. Over the last decades, these systems have been focusing on product quality and manufacturing flexibility (Nunes 2004).

Companies need to strategically manage the type and quantities of materials they purchase, plan which products are going to be produced and in what quantities to ensure that they can meet current and future customer demands at the lowest possible cost and effort.

a) **Material Requirements Planning (MRP)**

MRP is a software-based integrated information system used to schedule raw material deliveries and quantities, given assumption of machine and labour units required to fulfil a sales forecast (Investopedia 2018). It can be also defined as a planning control system for inventory, production and scheduling (Rachitsky 2018). One of the main goals of MRP is to ensure that the material required is available at the appropriate time and place. Therefore this method requires direct contact with suppliers (Nunes 2004).

MRP consist of three basic steps: (1) identification of quantity requirements – by determining what quantity is on hand to, in an open purchase order, planned for manufacturing, already committed to existing orders, and forecasted -, (2) MRP calculation run – creating suggestions for materials that are considered critical, expedited, and delayed –, (3) completion of the orders – delineate the materials for the manufacturing orders, purchase orders, and other reporting requirements (Rachitsky 2018). This method works through a framework of process and calculation organized in **Figure 44**.

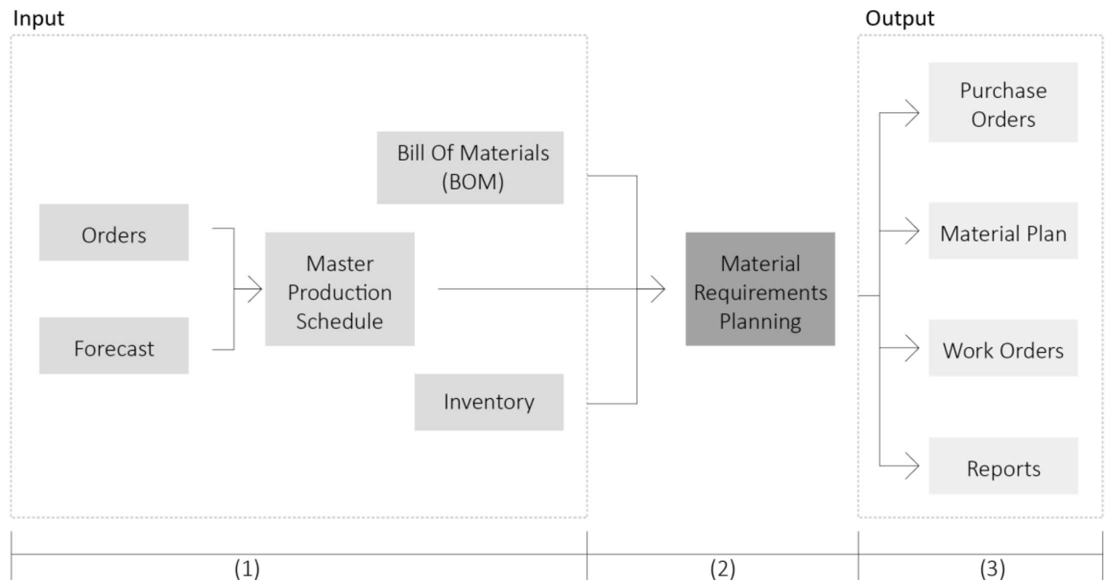

Figure 44 *- Material requirements planning steps and processes. Adapted from "Not just for manufacturing, Material Requirements Planning (MPR) is indispensable for any business." (Rachitsky 2018).*

MRP helps companies maintain low inventory levels by helping them plan manufacturing, purchasing and delivering activities. By maintaining an appropriate level of inventory, manufacturing is empowered to better align their production to rising and falling demand. Inventory is divided into two categories: independent demand – finished products, such as a cell phone or a car - and dependent demand – components, parts or sub-assemblies. Since this method avoids delays of materials, MRP is especially important for manufacturing cycle time reduction and productivity improvements (**Table 10**).

Table 10 *- Material Requirements Planning method summary. Adapted from "Not just for manufacturing, Material Requirements Planning (MPR) is indispensable for any business" (Rachitsky 2018) and "A model for Material Requirements Planning Implementation" (E. and E. 1986).*

Methodology	Material Requirements Planning (MRP)
Definition:	Method for planning and control inventory, production and scheduling especially suited to manufacturing settings.
Goal:	Improve productivity and communication To ensure the availability of the desired quantity at the appropriate time and place. Reduction in excess inventory
Guidelines:	1. Improve the accuracy of Bill of Materials (BOM); 2. Consider the integrating the BOM in the MRP system; 3. MRP system archives information to drive essentially all the functional areas of manufacturing; 4. Need to change the way the organisation views its processes, responsibilities, employees and relation with external environments; 5. Installation of necessary hardware and software; 6. Review the MRP reports to solve problems or to propose improvements;

b) **Configured-to-order (CTO)**

Configure-to-order (engineering-to-order or built-to-order) represents the ability for a user to define the product final configuration at the moment of ordering that product. In this way products are assembled and configured based on customer requirements. Whenever the customer is demanding options or product variantes, confire-to-order products are often introduced (Egan 2004), meaning that they are compiled using a variety of pre-developed 'builiding blocks' (Levandowski, Jiao, and Johannesson 2015). This means there is no need for engineering or re-designs. As the number of product variants increases, supporting a CTO product line often calls for a increse capacitity to maintain or reduce development times (Egan 2004).

Table 11 *- Configure-to-order or CTO summary. Adapted from "Implementing a successful modular design – ptc's approach" (Egan 2004) and "CTO solution" (Kadu 2007).*

Methodology	Configure-To-Order (CTO)

Definition:	Method in which products are assembled and configured based on customer requirements at the moment of ordering that product.
Goal:	Lower distribution costs; Reduce cycle time; Client satisfaction;
Guidelines:	1. Solution design to build capability; 2. Define configurations to capture customers' requirements; 3. Procure and Manufacture to demand; 4. Include Pick to order (PTO) and Assemble to order (ATO) models; 5. Monitor and correct;

2.4.4 **Simulation methods**

Real or digital simulation methods are useful to solve real-world problems safely and efficiently. Across industries and disciplines, simulation provides valuable solutions by giving clear insights of a specific product that its being developed. This subchapter provides what, considering the goals of this research, were considered helpful to articulate the final strategy proposal.

a) **Three-dimensional models or Prototyping**

A three dimensional model is defined as a "physical manifestation of a product idea" (Boeijen et al. 2014). A prototype is defined as an initial or preliminary version of the final product. This provides insights into the functionality of the design and the possibility of changes to make the final product the best answer possible. In industry, models are used to test product aspects, change constructions and details, and to reach consensus within the design team. In mass production, working prototypes are used to test functionality and ergonomics (Boeijen et al. 2014).

Building models could be as time-consuming and costly processes (Boeijen et al. 2014). However, spending resources in models during design and development initial phases can bring to light design mistakes that would otherwise cost a lot more time and money in more advanced product development stages.

Table 12 *- Three-dimensional model or prototyping method summary. Adapted from "Delft Design Methods" (Boeijen et al. 2014).*

Methodology	**Three dimensional models or prototyping**
Definition:	Method of using three dimensional models (virtual or physical) to the manifestation of a product idea.
Goal:	Express, visualise and materialise product ideas and concepts.
Guidelines:	1 Idea generation and development phases should start with sketches and prototypes; 2. The process of sketching, making sketch models, drawing and making second sketches interactive; 3. A dummy mock-up or a VISO (visual model) is a 1:1 scale model of a product idea – these only have the external characteristics of the product; 4. Proof-of-concept prototypes or FUMOS (functional models) are used to verify whether certain technical principle works; 5. Harness the expertise of people working in model workshops;

b) **Technical documentation (TecDocs)**

Technical documentation (**Table 13**) is defined as the "recording of designs, using standard-compliant digital 3D models and technical drawings" (Boeijen et al. 2014). TecDoc is closely related to the materialisation phase, since this documentation provides information about production techniques and specific materials to be applied for each component. However, this documentation can also support earlier design stages.

Design software's, such as *Rhinoceros 3D, Autodesk Inventor* or *Solidworks*, are used to generate parametric digital 3D models (Boeijen et al. 2014). These models should be generated based on the feature-modelling concept, which means that the different parts are built by combining or extracting basic forms (cylinders, spheres, or other organic shaped bodies). After having a 3D model, it is possible to generate renderings, exploded views of the (dis)assemble product and animations. TecDoc can support product presentation, packaging development and production, and manuals.

To guarantee and certify quality and tolerances, technical drawing must be made according to valid standards. In the end, several documents and information generate to this point will be the communication bridge between developers and manufacturers, and later between the company and the clients. So it is relevant that it is in the right 'manufacturing language' (Boeijen et al. 2014) .

Table 13 *- Technical Documentation (TecDocs) methodology summary. Adapted from "Delft Design Methods" (Boeijen et al. 2014).*

Methodology	**Technical documentation (TecDocs)**
Definition:	Method to give clear registration of designs, using standard-compliant 3D models and technical drawings.
Goal:	Communication; Visualisation;
Guidelines:	1. Make a first digital 3D model during conceptual phase to study behaviour of possible mechanisms; 2. Use the model to choose materials and to perform additional simulations to predict component's behaviour during manufacturing processes, to do a failure analysis and study form, colours and textures; 3. In the end of the study generate a final 3D model and a set of technical drawings; 4. Use the digital 3D model to control production; 5. Generate all TecDoc regarding the final 3D model and only after this design is approved; 6. Develop a modelling strategy and time schedule in advance; 7. Develop a strategy for Product Data Management (PDM); 8. Build 3D models of parts and assemblies as geometrically as possible; 9. Think about manufacturing at an early stage; 10. Use drawing standards to produce proper technical drawings; 11. Make backups very often; 12. 3D model can be combined with sketching;

B. **Measuring methodology performance**

Assessing the product development strategies' performance

Methodology performance measurement is the process of collecting, analyzing and reporting information regarding the performance of a specific methodology, to see whether output is in line with what was intended or should have been achieved. According to Neely et al. (2005), a performance measurement system can be defined as the set of metrics used to quantify both efficiency and effectiveness of actions.

The systematic evaluation of PDP, the identification of critical success and unsuccess factors in PDP and the establishment of actions to improvements can significantly reduce the failure rate of product development (Nantes 2015). Most measures of product development performance are based on outcome results that encompasses the overall project performance such as customer satisfaction, time-to-market-development cost, product quality (Ahmad, J., and H. 2004).

Among the recommendations to improve the PDP, literature highlights the use of performance indicator (Nantes 2015). Lebas (1995) describes performance measurement as the process to quantify the effectiveness of a company, a process or an activity (as cited in Nantes 2015). However, the practice of measuring PDP performance is not frequent among small and medium companies (Nantes 2015). This explained with the fact that companies do not have a formal and systematic process to evaluate PDP.

Whereas the last measurement systems were focused on measuring processes effectiveness, Ulrich and Eppinger (2012) present a five-assessment category evaluation system for assessing the quality of industrial design. Performance rating is done in a three-size scale – low, medium and high – along the different assessment categories – quality of the user interface, emotional appeal, ability to maintain and repair the product, appropriate use of resources and product differentiation.

It is important that the company uses a set of performance measures for understanding whether their methods are successful or whether they need to improve certain factors of their PDP. The indicators gathered from literature in this chapter are summarised in **Table 14**.

***Table 14** –Performance indicators categorised in five dimensions.*

Dimensions	Measures

Financial	- Profits; - Growing sales; - Market presence; - Difference between budget and final cost;
Operational	- Costs; - Development cycle time; - Number of workers needed; - Volume transported; - Wastage; - Number of changes per number of drawings; - Number of errors per number of drawings (and documents);
Quality	- Consumer acceptance; - Market sustainable time; - Conformance-reliability in use; - Design-performance and customer satisfaction; - Yield-factory and field; - Number of error;
Productivity	- Engineering hours per project; - Cost of materials and tooling per project; - Actual versus plan;
Time-to-market	- Frequency of new products introduced; - Time to market introduction; - Number stated and number completed; - Actual versus plan; - Percentage of sales from new products; - Response time;

Chapter 3 **Case Study**

This research involved an up-close, in-depth and detailed case study (**Figure 45**) within two companies from the same Group - Casais Engineering and Construction and Carpin - Casais, Wood & Metal. The case study was conducted regarded a real-world specific situation: This group wanted to improve their carpentry product development strategy, by achieving a balance between standardisation and variation of their products. This 6-month case study was performed as action research (i.e. the researchers themselves took part in the project).

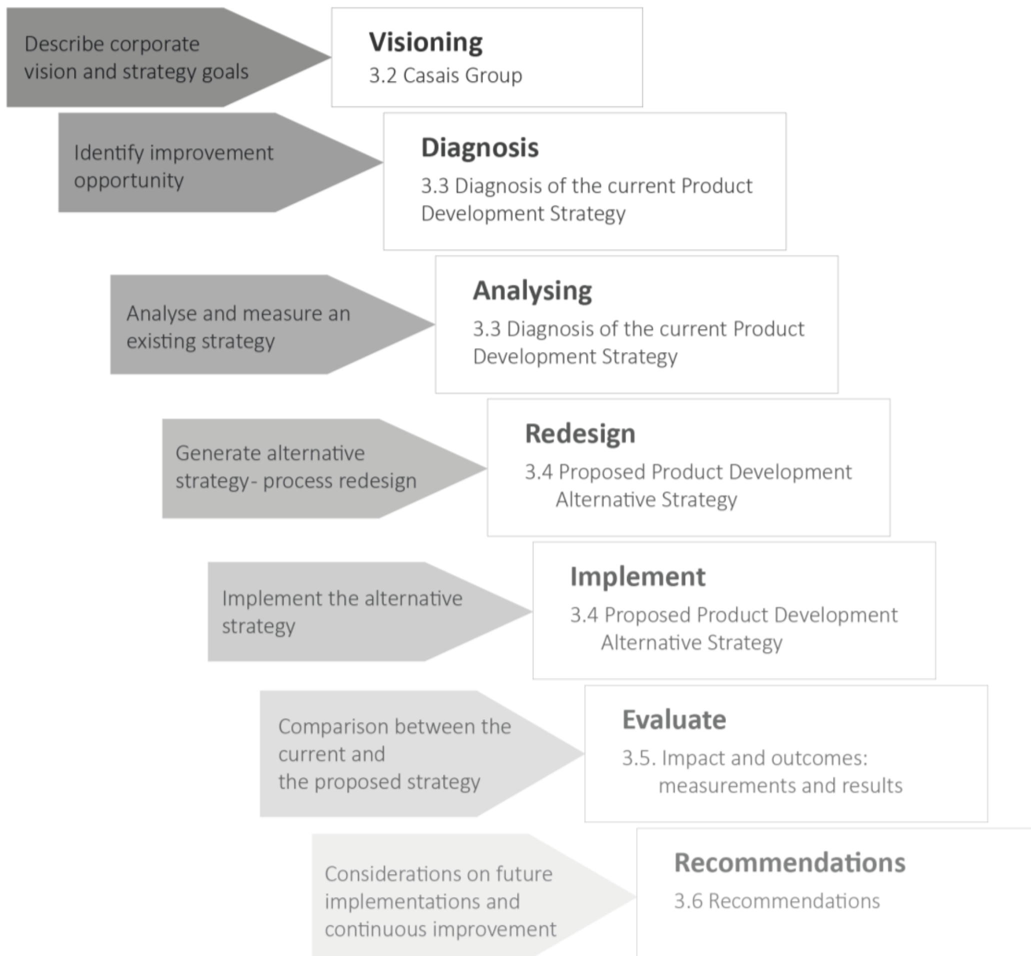

***Figure 45** - Steps followed to perform the case study.*

The following chapter includes a brief description of the companies involved and a deconstruction of the current product development strategy. It is proposed an alternative strategy to develop stationary furniture for construction projects and the PDP is redesign according to this alternative path. Strategy implementation takes place after the design and development of the first product family. Product presentation, product development cycle time, manufacturing costs, assembly time and design freedom are measured in the current strategy and the alternative proposed. Finally, comparisons between the different strategies are made and recommendations are reported.

The case study approach was relevant to this research because it demonstrated how successful the alternative strategy proposed was, giving more credibility to the research. This case study was partly carried out within an eight months internship in the technical office of CASAIS, Engineering and Construction.

Within the case study several it was applied other complementary methods such as value stream mapping (VSM), interviews, field observation. Using a VSM during the diagnosis was relevant for visualise and understand all the steps required for the development of stationary furniture. This lean method also gave insights on wastage, or non-value adding activities, as well as improvement opportunities. Two one-to-one unstructured interviews were performed. Interviews' outcome gave new insights about the current company product development strategy – primary data. This method provided a valuable opportunity to contact with experts and to reach documents that enabled to carry out the design and implementation of a new strategy.

The strategy proposed is assessed using the Ulrich and Eppinger (2012) five-assessment category evaluation system. Five categories are measured: product presentation, product development cycle time, manufacturing efficiency, assembly efficiency and design freedom.

3.1 **Framework**

A construction product, e. g. a 'building' is a unique and expensive product. The same concept seems to be applied to the stationary furniture inside these buildings. For a given project, furniture is being designed and developed individually and uniquely – made to measure - in compliance with the customer requirements. Since this furniture is so unique due to its very specific dimensions, or to a very particular detail request by the customer, these models are not being reused for any other construction project.

Two companies are involved. The first company, CASAIS, Engineering and Construction, is responsible for developing the building project - which several times includes architecture and therefore the design of stationary furniture. The second company, Carpin - Casais, Wood & Metal, is responsible for the development, production and implementation of stationary furniture and other carpentry products into these construction projects. Their goal is to industrialise their products in a way that they could standardise a large range of products without increasing internal complexity. Within this context it is relevant to approach the current PDP and strategy to develop a new alternative that could offer this companies a standardised and varied solution, fulfilling the companies' goals and clients' preferences and tastes.

Several industrial production strategies have proved to be a successful approach for achieving this balance between product variation and standardisation. In this way, the goal of this study case is to prove that by integrating an alternative strategy to design and developed stationary furniture employing industrial production methodologies, the company can achieve economical, technical and time advantages. **Figure 46** schematises the general framework of this case study.

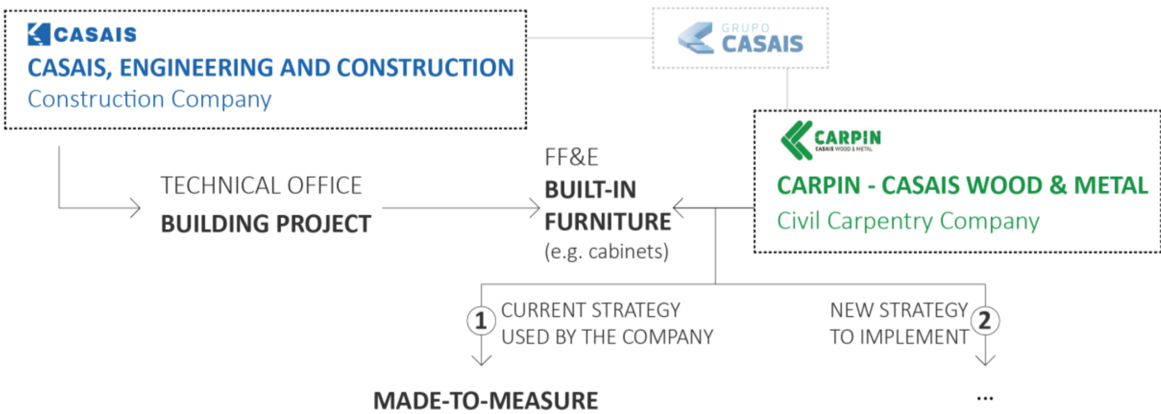

Figure 46 *- Current strategy used by the company and the and new strategy developed. The intention is not to eliminate the current one but to add an alternative strategic way to implement built-in furniture in construction projects.*

3.2 **Casais Group**

Casais group is a group of companies with diversified activities in several areas: engineering and construction, commerce and industry, real estate, environment and services, concessions and partnerships and EPCM (engineering, procurement and construction management). Engineering and construction is effectively the core business of the group and is assumed as the engine of international activity and new business areas.

A. **Casais, Engineering and Construction S.A.**

Casais, Engineering and Construction S.A. is a company that belongs to Casais Group, and it is considered one of the largest construction companies in Portugal with head office in Braga and delegation in Lisbon. This company develops project in different sector of infrastructures such as special works, public buildings, industrial buildings, sports, hotels, residential, institutional, service, social and health.

A structured process of internationalization is the key to the business development of *Casais*. The company started expansion in 1994 in Germany, based on adapting to the local culture and focusing on strategic partnerships. Currently the group operates in 16 countries: Portugal, Germany, Angola, Belgium, Gibraltar, the Netherlands, France, Morocco, Mozambique, Brail, Qatar, Algeria, UK, Spain, United Arab Emirates and United States of America, having also operated in other countries such as Russia, Kazakhstann, China and Cape Verde (Casais 2018)..

B. **Carpin - Casais, Wood and Metal S.A.**

Carpin - Casais, Wood and Metal is a company that belongs to Casais Group, developed throughout the history of Casais. It was considered a carpentry's department and previously associated with Casais - Engineering and Construction and now is an autonomous and legally independent company. This allowed Carpin - Casais to offer not only proper and high-quality services to Casais Group, but also its openness in the market.

A commitment to quality, drove the implementation of a quality management system, based on the NP EN ISO 9001 model, for conception, production and assembly of carpentry solutions for construction and public works, which has been recognized by SGS. Due to this system this company is recognized in the field of Conception, Production and Assembly of Carpentry in Civil Construction and Public works. In 2006 the company started the process of internationalization, starting with Gibraltar, followed Angola, Belgium, Brazil, France, Mozambique, Switzerland and Algeria.

In the last years the company increased its production capacity with the acquisition of new machinery and equipment. It was also created a department of design and development. The creation of the label "ArchiwoodXXI" provided products to meet the technical requirements of the current legislation, fully designed and manufactured in Portugal. This department developed several products such as wooden fire doors (**Figure 47**), wooden windows and acoustic attenuation products with the respective CE marking, fulfilling legal requirements to be a qualified company.

Figure 47 *– Wooden fire door with CE marking: project developed by the department of design and development. CarpinCasais was the first company to design a door targeted at architectural and design firms. (Carpin - Casais 2018)*

3.3 **Diagnosis of the current PDP strategy**

A diagnosis of the current product development process strategy was performed to: (1) fully understand the process, activities, information and material flows, (2) seek for improvement opportunities, (3) consult experts, (4) find a direction for the development of the new strategy. Three methods where used: direct field observation within the company processes, structured interviews and value stream mapping (VSM).

Through direct field observation and interviews several relevant aspects were noticed and reported.

A. Made-to-measure approach to built-in furniture – Considering that each building is unique, so is its furniture. Currently the furniture is designed and developed within a several weeks, with a certain deadline, during the preparation of a building project. This furniture complies for unique specifications for a specific construction project and customer or main contractor requirements. Thereby, built-in furniture is design and developed exclusively for the on-going project in such tailored way that those designs cannot be used for any other future project.

This strategy implies that whenever it is necessary develop stationary furniture, a new design has to be tailored from scratch to the project on demand. The result depends on the experience from the workers involved in the product development process. Besides, this requires higher development cycle times and increases the margin of error, considering it is a new model on development.

B. Batch production – Since a diverse range of products is produced and each component has a unique number assigned to the customer order, furniture is currently batch produced – customer-based production order. Meaning that a specific quantity of products is produced in a 'batch' all at one, before the next batch is manufactured. This results in an optimum use of resources and low stocks. The manufacturing plant is organised in units of production, and according to the operations needed, components go through the different units of production.

As each piece of furniture is unique, requiring greater attention and effort from developers and workers in the factory. Every time a new component comes in, new information is introduced in the production machines, such as the CNC.

Product development at this firm works within a BTO or built to order production approach. This means that products are not built until a confirmed order for product is received.

C. From pre-assembly in factory to the final assembly on site – Furniture assembly is partial, and it is performed by specialised worker or carpenter. Generally, products are transported sub-assembled. Product are sub assembled in the factory (**Figure 48**) because is the place were carpentries have their tools and machines that allows then to do their work – sub assembly under a controlled environment. The assembly in not finished in the factory due to the loads handling. Furniture fitting is generally done using wood dowels, glue and screws.

After the furniture is inspected and approved it is packed with extruded polystyrene or tyrofoam boards and plastic film.

Figure 48 *– Assembly of a drawer fixed with wood dowels and glue at CarpinCasais.*

D. Identification of failures and defects – there have been noticed several types of failures and defects of built-in furniture inspections on site. Some are due to manufacturing defects, other due to packing collapse, others due to moisture. A sample of failures and defects is visualised in **Figure 49**.

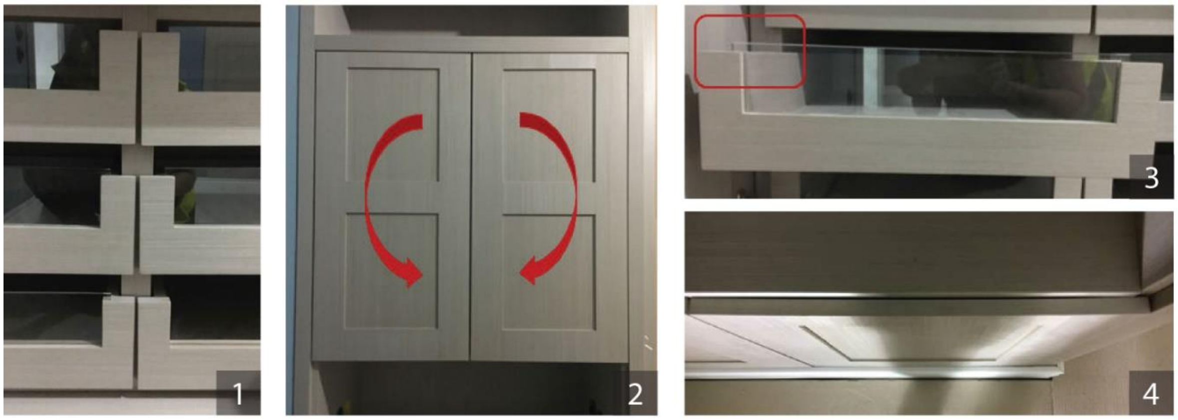

Figure 49 *– Detection of failures and defects of stationary furniture, in an on-site inspection of a hotel room in Lisbon. [1] incorrect drawer assembly (not aligned with each other); [2] cabinet doors were assembled on reversed; [3] the drawer glass has not proper dimensions; [4] door board is warped;*

After direct field observation and conducted the interviews, a VSM was carried out. A value stream mapping helped in the visualisation of the process flow followed by these two companies and all the activities involved in the design, develop, manufacture and assemble built-in furniture for their building construction projects. The VSM was relevant to identify activities that added value and the activities that did not added any value to the final product.

The VSM (**Figure 50**) visualises the current process, divided into five stages. Firstly, in case the project includes an architecture work, which includes stationary furniture design, the technical office is responsible for its design and development (stage 1). After designing a general outline sketch, in accordance with the client requirements, the furniture project is sent to CarpinCasais, Wood & Metal. This company performs a feasibility study (stage 2), to check whether the project is viable in terms of materials, constructions system and/or hardware available in the market. Communication flows between a construction manager and the architect responsible for the project. The construction manager redesigns the project and makes it into a feasible project so that CarpinCasais can produce and implement it. This counter-proposal is sent back to the architect, requesting for approval. Several back and for communication happens until the design is aligned with the project and client requirements, and with the carpentry means. With the project approved, the construction manager may start preparing the information needed to produce the product (stage 3). This stage includes decomposing the product in to components, introduction of the model in the computer, to get a fabrication order and to order material/hardware from suppliers or in case of woods and derivates, to verify whether the material needed is available in stock.

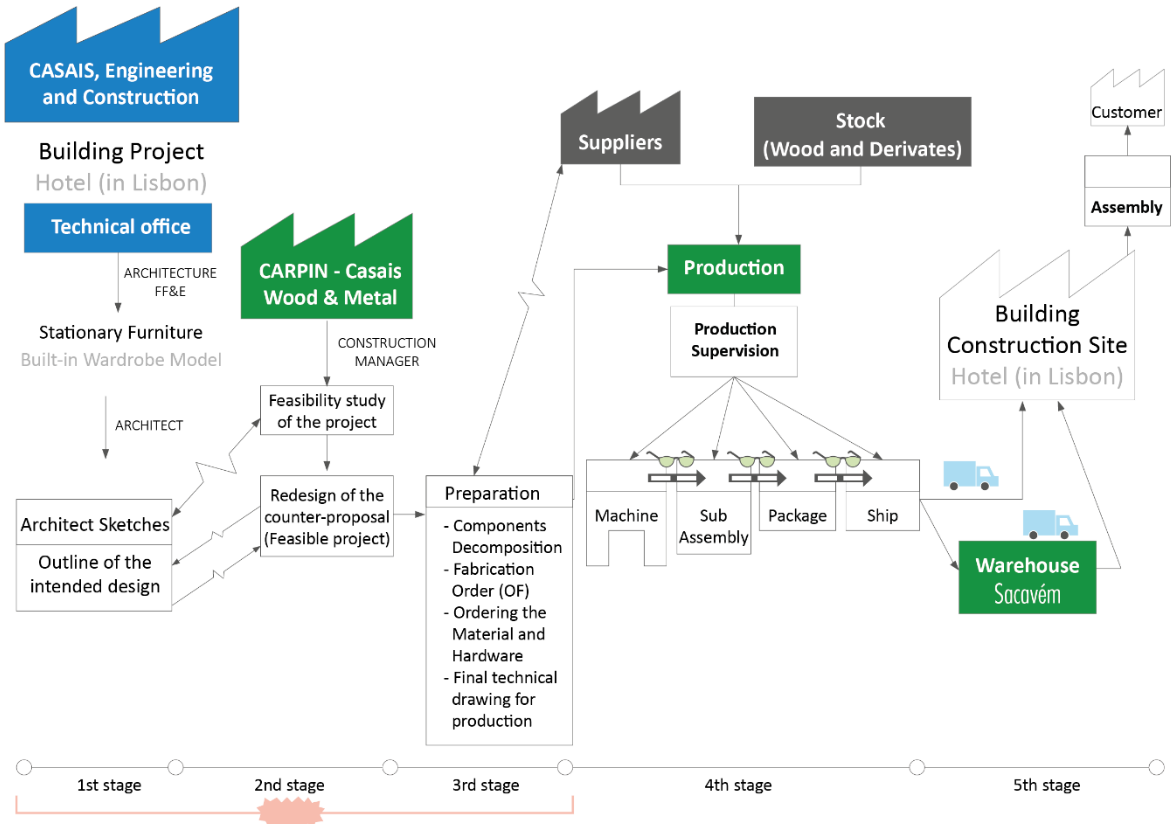

Figure 50 - *Value Stream Map of the current design and development process for stationary furniture.*

The first finding is that there is a great amount of work and information flowing in the first and second stages – from the moment that the architect has an idea of the intended design to the preparation of a feasible design ready to production. Two types of waste were considered in this map. The first one refers to the over work: due the lack of standardisation, every time there is a new project, a new model of furniture must be designed. This repetitive work is not only a waste of resources, but bring risks for the organisation, since they are always producing a new model of furniture which feasibility depends on the experience and know-how of its workers. Besides, the attention given to this over processing could be spent to other activities that truly add value to the customer. The second waste founded refers to time spent in the design and development stages: which includes design and redesign, waiting for approval and in some cases even waiting for testing. Since every time a new project comes in, new stationary furniture needs to be design from scratch it is considered that the actual time used to invest in the design is not being as efficient as it could be.

Taking into consideration all the literature review, insights from the interviews (Check appendix I-VIII), analysis and diagnosis of the current strategy and the organisation characteristics, an alternative strategy for design and develop stationary furniture was proposed.

3.4 **Proposed Product Development Alternative Strategy**

To reply appropriately to all the input described in this case study chapter, it was found that the most appropriate strategy had to allow the development of standardised and modularised products in a platform. This strategy arises from the idea that anticipation of design and development work can drastically speed up the PDP. This subchapter describes the strategy (A.), the implementation (B.) in this case study.

The platform approach allows to manage a wide range of products, organized in families while reducing the internal complexity (**Figure 51**). The start of the platform should begin with the modularisation and standardisation of the most common typologies of products: built-in cabinets (e.g. storage, wardrobes, and so on).

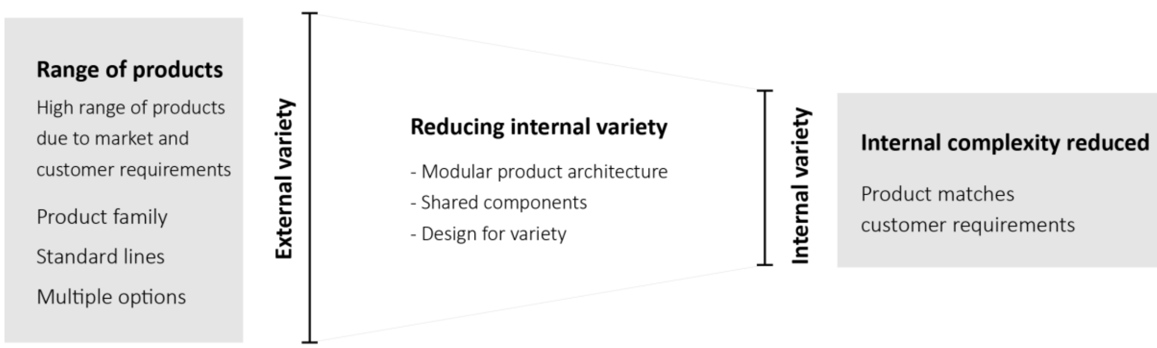

Figure 51 *- Approach proposed for product platform - Alternative Strategy.*

Thus, this strategy required designing from scratch the first product family, generate product information, start the new product platform, archiving the first family and place this platform as alternative in the overall product development process. In the end this strategy is compared with the current. Assessing the performance of this strategy was a mandatory task to determine whether this strategy accomplished its goals or not. Both strategies were ranked in five measured variables. This ranking includes an explanation, a seven-point scale evaluation and comparison. In the end recommendations are made for a more appropriate use and efficiency of this alternative.

A. Description of the Strategy

The strategy proposed is a platform-based strategy that aims to offer product previously designed and developed, available for projects that integrate stationary furniture. It is intended to be implemented on construction companies that want to industrialise the design and development and standardise their stationary furniture. The purpose of this strategy is to avoid unnecessary or repetitive work, saving resources and speeding up the PDP. That is, in cases where stationary furniture has to be designed and developed for a construction project, a product platform provides to the architect and the client a large number of products designed in advance.

This approach arises from the following concepts: industrialisation and standardisation, prefabricated systems, ready-to-assemble (RTA), modularisation and product platform – described in the previous chapter. The main idea of this strategy is that, by designing modular standard families of stationary furniture, based on a prefabricated RTA constructive systems - archived in a product platform - can significantly improve the time of response and the quality of the product. Besides, since this furniture has a modular product architecture, it is possible to create a large number of combinations with a small set of components and consequently to develop a large number of product variety. Different combinations lead to different final product solutions.

This strategy requires a collective of steps. Firstly, (step 1) furniture must be designed according to the Design for Variety (DFV) methodology. This strategy is used due to the fact that supports the development of products with modular architecture. In this step the designer has to make sure that the first set of components designed can be shared among the product family. Within this strategy, a product family or line refers to the group of products derived from a common group of components.

After a product family is designed, (step 2) it is necessary to develop product information according to the directory proposed. That is, each product archived in the platform shall be accompanied by a list of visual, CAD, marketing/trading and fabrication data. This data, generated in advance, provides e.g. material to present a certain product to the client, such as renderings or illustrations or videos of the product. It also provides CAD files that enable the architect to introduce a certain product in the architectural project in a very efficient way, reducing the possibility of making an error in the implementation plan. Fabrication data is also included has the goal to accelerate the PDP and reduce the rate of production errors.

This strategy is powered by a product platform (step 3). This ‘digital library’, software based, archives all the product families designed. Each product is named with a code, according to its categorisation(**Figure 52**).

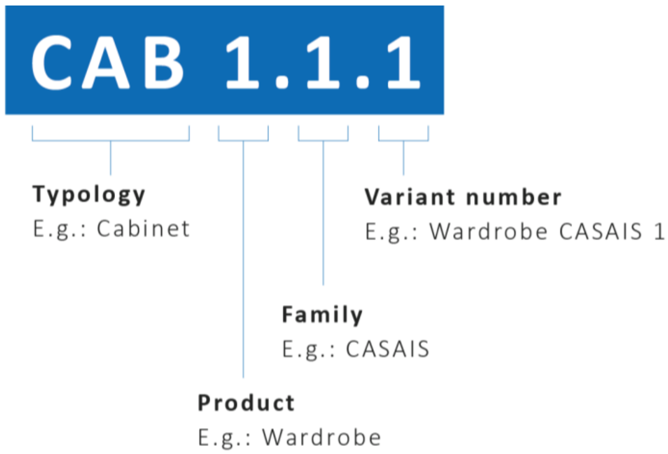

Figure 52 *- Product codification in the platform.*

This method not only allows to share information from the platform with clients, workers, construction manager, construction owner, carpenter but also, this platform approach allows the design team to manage a wide range of products and allows the platform users to effectively find what they wanted. The implementation of the product platform in the process of developing stationary furniture is proposed in **Figure 53**.

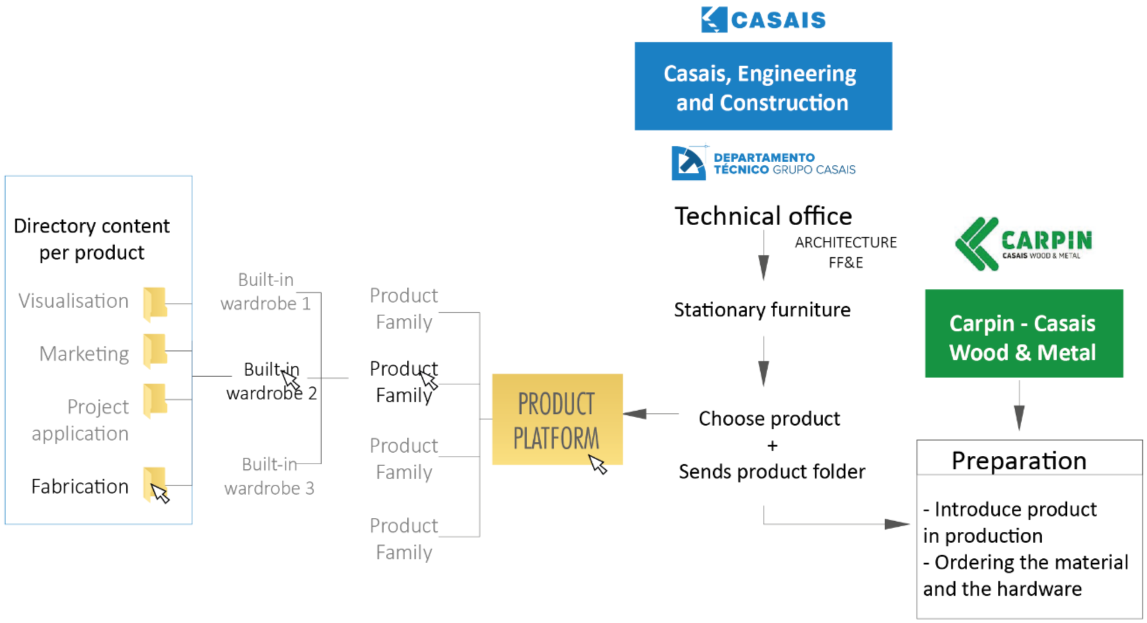

Figure 53 *- Product platform is consulted by the architects and designers from the technical office in case there is the need of implementing stationary furniture in a project.*

The last step of this strategy (step 4) refers to the integration of the product platform in the overall PDP of the organisation. **Figure 54** shows the alternative strategy proposed, integrated in the PDP of the group. It is visible that this strategy focuses in the initial stages (1 and 2), eliminating one stage of the current model - the stage that includes the moment that the architect had an idea of the intended design to the preparation of a feasible design ready to production. Since documentation and files are upfront developed, implementation in the project, approval by the client, and the fabrication flows are very fluid and accelerated.

This strategy should be taken as an alternative option to the current process and not a replacement. Space should be left for made-to-measure stationary furniture. There will be occasions in which stationary furniture has to be designed from scratch due the fact that none model available on the platform matches customer/project requirements.

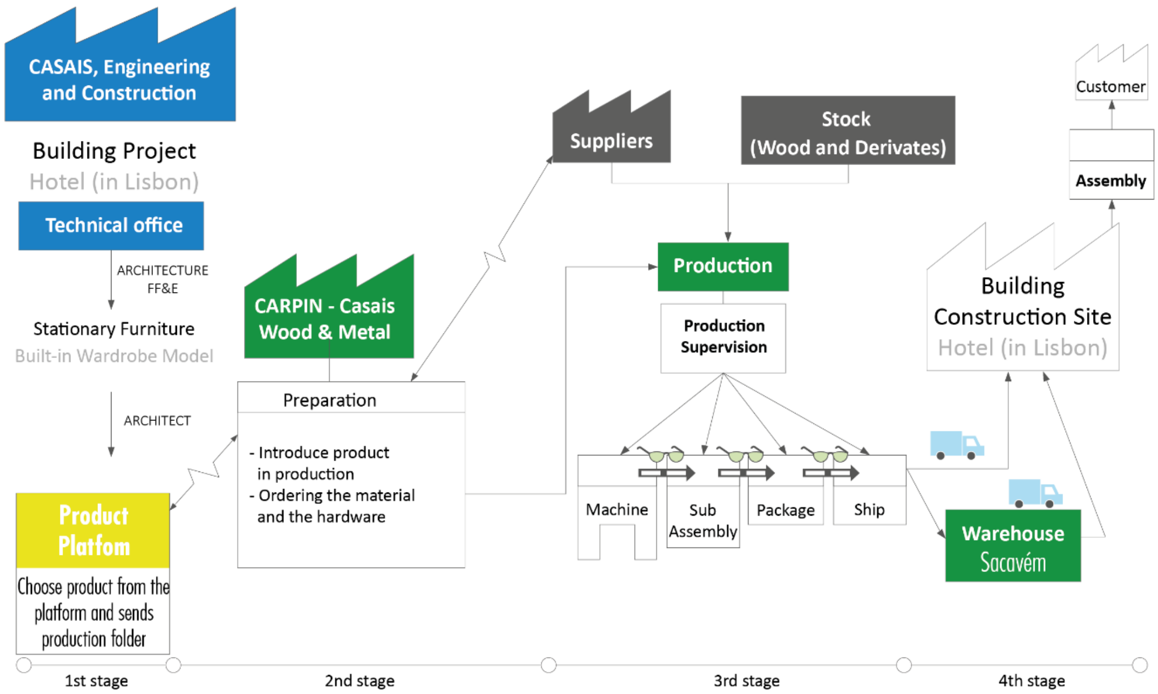

Figure 54 *- Value stream map of the alternative PDP for stationary furniture.*

B. Implementation

The implementation of this strategy is firmly rooted in respect of the following factors:

- cost reduction through a higher resource efficiency – eliminating the need of rework and the need of specialised workforce;

- guarantee of a fast response through preparing furniture in advance for projects in an strategic way;

- quality improvement and perceived quality, by presenting the product in a more clear and attractive way;

- increasing variety while reducing internal complexity – better leeway to meet customer wishes and needs;

- increase reliability by predicting failures and correct them in advance, greater assertiveness in budgets and greater confidence in the products developed;

- PDP acceleration and simplification.

The implementation of the proposed alternative strategy is divided in three actions: 1 – design the first product line and ramp up the product platform, 2 – development of the product directory or product data and 3 – comparison with the current strategy. The first action refers to the design of the first product family to ramp up the strategy in this company. This first product family is designed and developed to test, measure and compare this alternative strategy with the one currently used by the organisation. The opening product family to be designed was a line of built-in wardrobes, since the organisation considered it was the most current type of stationary furniture.

Firstly, storage areas were defined to answer the following question: 'which components should be design and developed in this product family?'. To get the most storage space possible, organizational recommendations were taken into account (**Figure 55**).

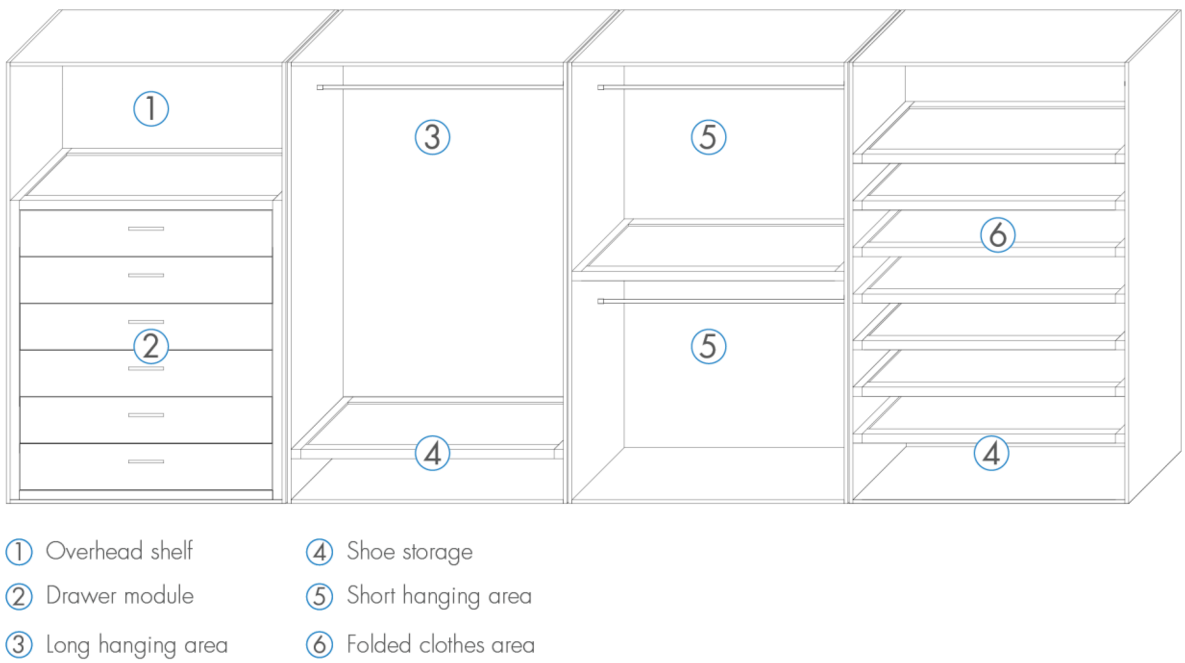

Figure 55 *- Spatial organisation and storage areas definition.*

The following specification for the constructive systems were considered: total dimensions 2000x1200x600 mm including doors and adjusting foot; bolt and screw fixing system and minifix system, metallic rod with fixing brackets, metallic rod with fixing brackets; metallic aluminium door handles; surface boards in white melamine panel, predrilled vertical panels for personalized shelf placement; metallic shelf support; metallic concealed and plate hinge; shelfs should allow light system placement.

According to the storage area required, specifications and requirements, the fists components and compositions were studied. This is a phase that takes considerable effort and development time since all components should share similarities in term of design and constructive system.

Figure 56 shows the final component designs. This list of components represents the internal variety from with the external variety will be studied. Notice that the internal complexity must be less than the external variety according to this strategy.

Sub-assembly	Components
1 Doors	Boards
	Door handle
	Concealed hinge
2 Box	Vertical panel
	Horizontal panel
	Back panel
3 Shelf	Side frame
	Horizontal frame
	Panel
4 Rop	Rail
	End rail support
5 Drawer Module	Front panel
	Side panel
	Back panel
	Bottom panel
	Drawer handle
	Concealed runner
6 Structural	1x vertical frame
	2x vertical frame
	3x vertical frame
	4x vertical frame
	5x vertical frame
	6x vertical frame
	7x vertical frame
	Horizontal frame
	Side frame

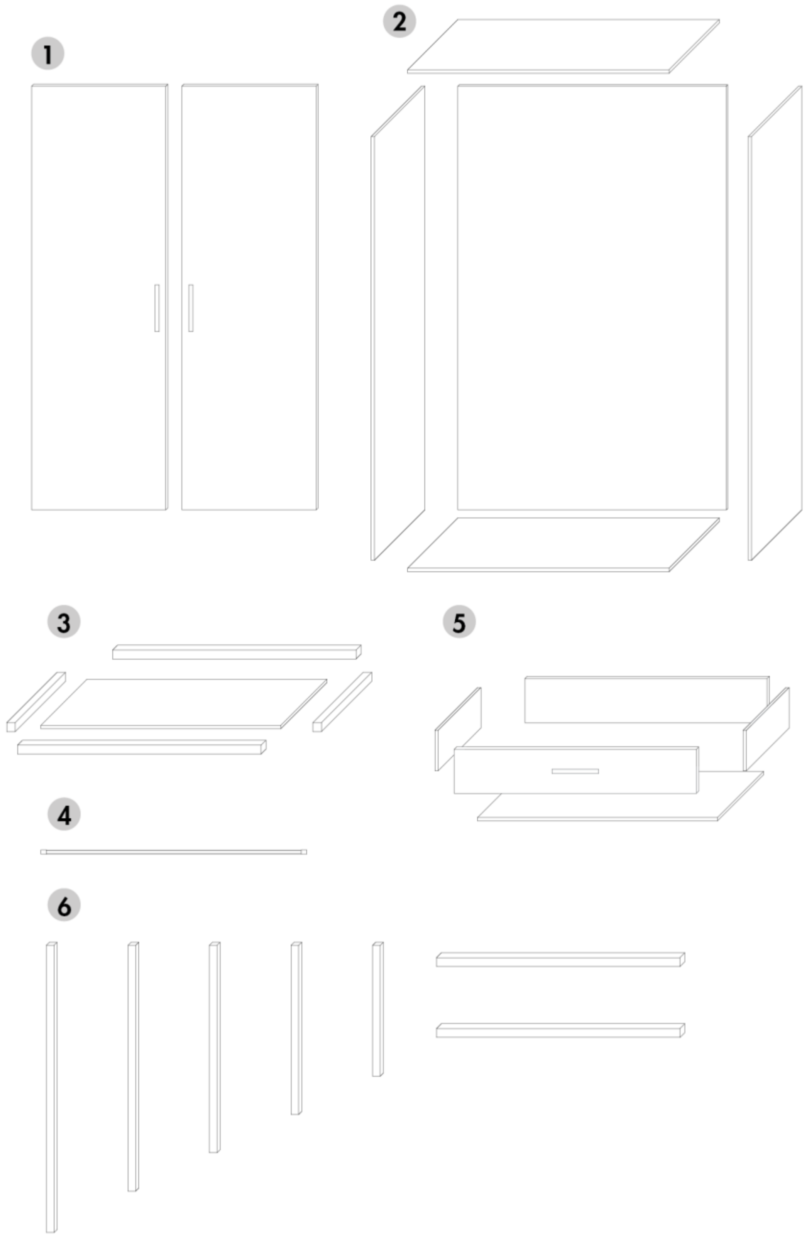

Figure 56 - Components designed for the product family. Hardware is not represented due the fact this organisation does not manufacture these components – they were ordered from the manufacturer Hafele.

Through the combination of the designed component, the entire construction of the wardrobe offers many different modules design types (**Figure 57**). Hardware and fittings are always common to all the models from the same family.

***Figure 57** - Variants generated from the designed components - external variety.*

Figure 58 maps all the combinations generated with the components developed. With this matrix it is possible to check a model outline and the quantity of components (grouped in sub-assemblies) that a certain model requires. Though this map several conclusions can be drawn: (1) door and box sub-assemblies are common to all the models, (2) 10 of 32 models do not include shelf, (3) 12 of 32 models do not include drawers, (4) there is only two 7-drawer module models available, one with shelfs and other without shelf, (5) any model that includes a drawer module, must include 'horizontal frame' and 'side frame' structural components;

Sub-assembly	Components	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14	Model 15	Model 16	Model17	Model 18	Model 19	Model 20	Model 21	Model 22	Model 23	Model 24	Model 25	Model 26	Model 27	Model 28	Model 29	Model 30	Model 31	Model 32
Doors	Boards	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Door handle	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Concealed hinge	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Box	Vertical panel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Horizontal panel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Back panel	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Shelf	Side frame	2	4	6	x	x	x	2	2	2	2	x	x	x	x	x	x	x	2	4	6	8	10	12	14	16	14	12	10	8	6	4	2
	Horizontal frame	2	4	6	x	x	x	2	2	2	2	x	x	x	x	x	x	x	2	4	6	8	10	12	14	16	14	12	10	8	6	4	2
	Panel	1	2	3	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	2	3	4	5	6	7	8	7	6	5	4	3	2	1
Rop	Rail	1	1	1	1	1	1	1	1	1	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	End rail support	2	2	2	2	2	2	2	2	2	4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Drawer Module	Front panel	x	x	x	1	2	3	1	2	3	x	1	2	3	4	5	6	7	x	x	x	x	x	x	x	x	1	2	3	4	5	6	7
	Side panel	x	x	x	2	4	6	2	4	6	x	2	4	6	8	10	12	14	x	x	x	x	x	x	x	x	2	4	6	8	10	12	14
	Back panel	x	x	x	1	2	3	1	2	3	x	1	2	3	4	5	6	7	x	x	x	x	x	x	x	x	1	2	3	4	5	6	7
	Bottom panel	x	x	x	1	2	3	1	2	3	x	1	2	3	4	5	6	7	x	x	x	x	x	x	x	x	1	2	2	4	5	6	7
	Drawer handle	x	x	x	1	2	3	1	2	3	x	1	2	3	4	5	6	7	x	x	x	x	x	x	x	x	1	2	3	4	5	6	7
	Concealed runner	x	x	x	2	4	6	2	4	6	x	2	4	6	8	10	12	14	x	x	x	x	x	x	x	x	2	4	6	8	10	12	14
Structural	1x vertical frame	x	x	x	2	x	x	2	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x	x
	2x vertical frame	x	x	x	x	2	x	x	2	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x
	3x vertical frame	x	x	x	x	x	2	x	x	2	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x
	4x vertical frame	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x
	5x vertical frame	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x
	6x vertical frame	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x
	7x vertical frame	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2
	Horizontal frame	x	x	x	3	3	3	3	3	3	x	3	3	3	3	3	3	3	x	x	x	x	x	x	x	x	3	3	3	3	3	3	3
	Side frame	x	x	x	2	2	2	2	2	2	x	2	2	2	2	2	2	2	x	x	x	x	x	x	x	x	2	2	2	2	2	2	2

Figure 58 *- Component's combination Matrix generated that characterises this product family.*

The second action for implementation refers to the development of a product directory or product data (**Figure 59**). Each furniture model is attached to a list of documentation that allows the visualisation of the product, CAD application – technical drawing and files that allow the implementation of the product in an architecture plan –, marketing/trading material and fabrication. This directory has the peculiarity of being restricted to three types of access: public, private and internal, meaning that information is available depending on the profile of the platform user. For example, an architect would have access to the private files, whether a client would only have access to the public information.

Figure 59 *- Product platform information categories.*

This strategy also includes the standardisation of templates and documents to achieve more efficiency along the product development process. It also helps to ensure that the final product is consistent, which is very important for this strategy. In this way, all the documentation is presented under templates upfront defined. **Figure 60** shows an example of the template developed for the document 'exploded view', in which is included in the fabrication category. **Figure 61** shows some 'material' that was developed and was included in the product platform. **Figure 62** shows several steps of the first model being prototyped by Carpin - Casais, Wood & Metal.

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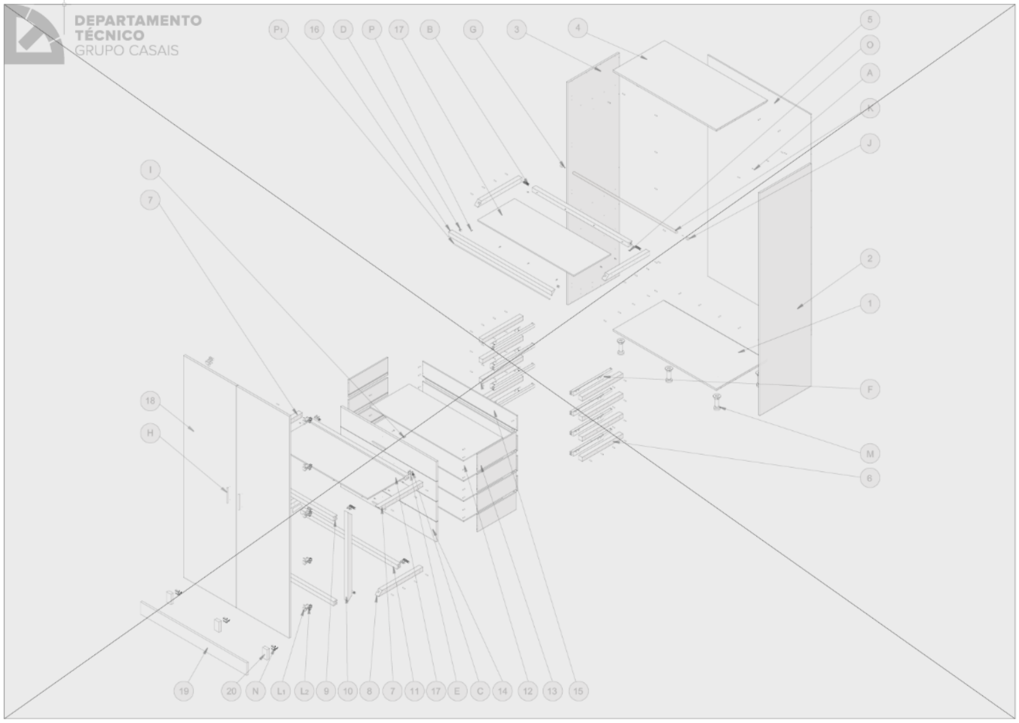

TABLE OF COMPONENTS:

ITEM NO.	PART NAME	QTY.	ITEM NO.	PART NAME	QTY.
1	XX	x?	A	XX	x?
2	XX	x?	B	XX	x?
3	XX	x?	C	XX	x?
4	XX	x?	D	XX	x?
5	XX	x?	E	XX	x?
6	XX	x?	F	XX	x?
7	XX	x?	G	XX	x?
8	XX	x?	H	XX	x?
9	XX	x?	I	XX	x?
10	XX	x?	J	XX	x?
11	XX	x?	K	XX	x?
12	XX	x?	L1	XX	x?
13	XX	x?	L2	XX	x?
14	XX	x?	M	XX	x?
15	XX	x?	N	XX	x?
16	XX	x?	O	XX	x?
17	XX	x?	P1	XX	x?
18	XX	x?	P2	XX	x?
19	XX	x?	P3	XX	x?
20	XX	x?	P4	XX	x?
			P5	XX	x?
			P6	XX	x?
			Q	XX	x?
			R	XX	x?

Exploded View | **XXX ?.?.?** | **CASAIS** Design and Quality | www.casais.pt

Figure 60 *– 'Exploded view' template (private access).*


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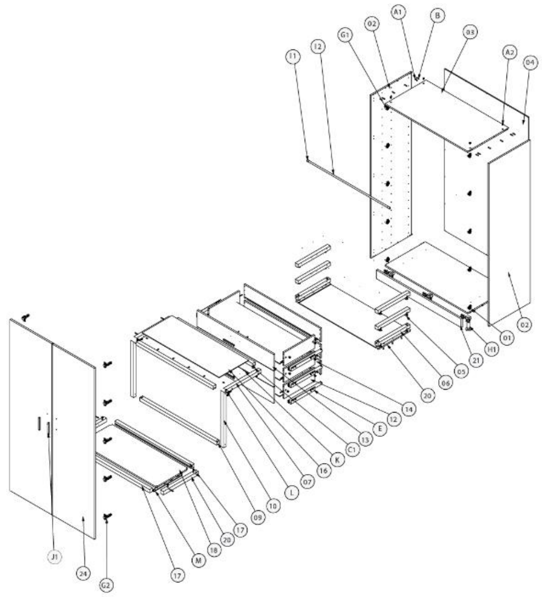
1



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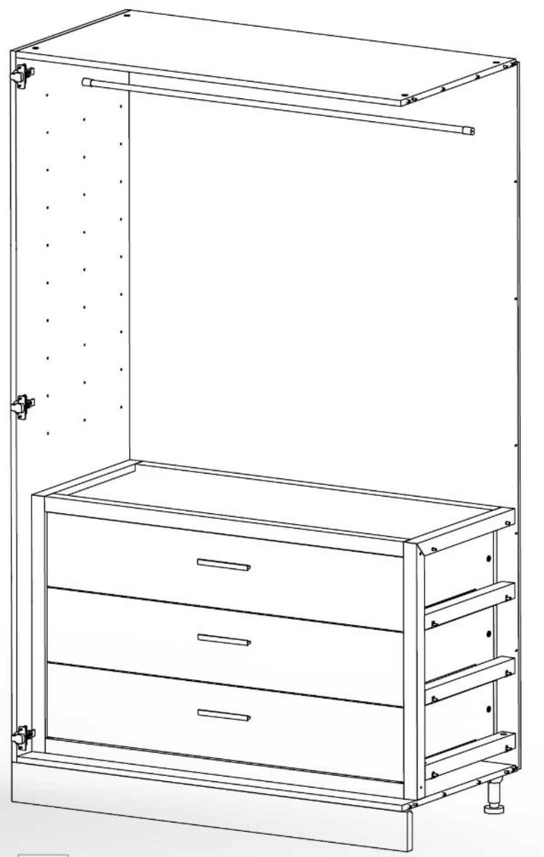

4

Figure 61 *– Visual information developed. [1] Catalogue for commercial purposes; [2] Exploded view of components; [3] realistic rendering of the model developed; [4] illustration found in the assembly guide of this model.*

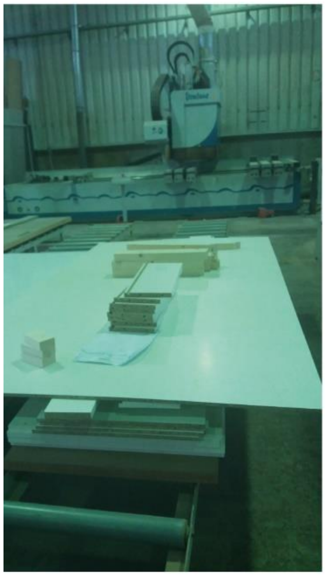





Figure 62 - Prototype generated for time/cost measurement and constructive system evaluation.

Finally, the choice for using the alternative or the current strategy should consider the situation in which stationary furniture is requested. Three case scenarios are presented in which it is appropriate to use the current strategy to develop a solution, and in the opposite way case scenario (3) is presented in which the alternative strategy is the most appropriated (**Figure 63**).

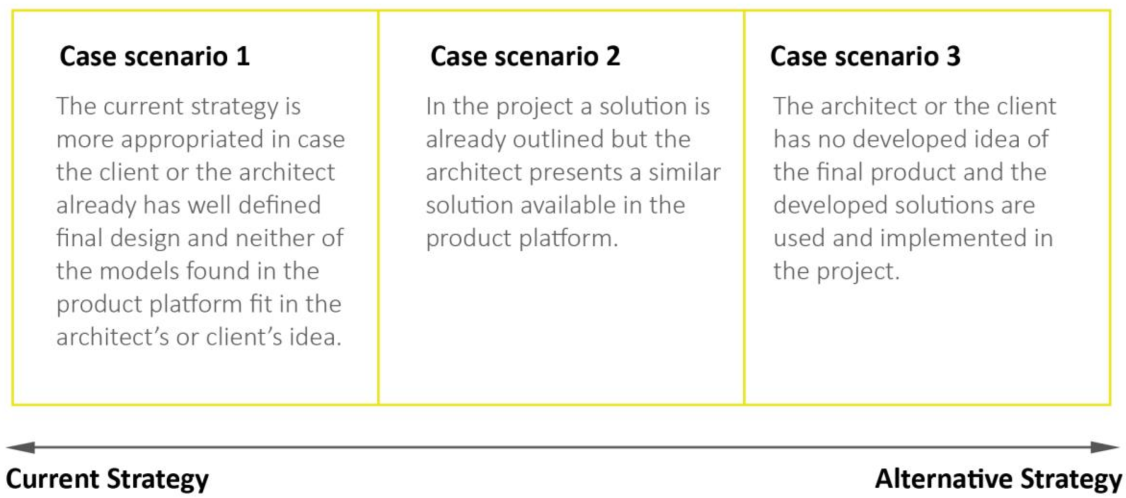

***Figure 63** - Different case scenario and orientation towards the correct strategy to adopt.*

3.5. **Impact and outcomes: measurements and results**

The following chapter presents the outcomes of the comparison between the actual and the implemented strategy. It is important to state that the time spent to design and develop the first product family was not considered for measurements. Thus, comparison is made with the built-in wardrobe line, previously designed, available in the platform (check previous subchapter).

To measure the current strategy and the alternative strategy developed, five performance indicators, based on the Ulrich and Eppinger (2012) are presented : (1) product presentation that refers to the quality of documents (used to present the products to the clients during the design stage) that provides visual information about the product; (2) product development cycle time refers to time spent in designing a concept, checking for feasibility, validating the product, preparing the product, manufacturer, full production, assembly on site and support, (3) manufacturing efficiency refers to time and effort spent in the manufacturing process, (4) assembly efficiency refers to time and effort spent in the assembly process, and (5) design freedom refers to the degree of decision given to the architect or to the client for the final design. **Figure 64** shows the rating that each measured variable received in each strategy.

Measured variable	Strategy	Performance Rating (Low / Medium / High)	Explanaition of the Rating
1. Product Presentation	Current Strategy		- technical drawing from CAD model; - no time dedicated for rendering or any 3d visualisation; - none standard template;
	Strategy Proposed	3 points +	- the product is presented to the client with renders (realistic images of the product); clear drawings; - the quality of this visuals increases the perceived quality of the product; - detail visualisation proved to be useful in fabrication taks and assembly; visual information is valued;
2. Product Development Cycle Time			- development cycle time is uncertain; - the poor visualisation of the final model during the design phase leads to modifications that had to be carried out during the preparation process, generating unexpected development time for the project.
		3 points +	- clear understanding and visualisation of customer needs in initial developemnt stages; - well defined produdct development cycle time; - since a list of standard products are designed upfront the design stage is almost immediate;
3. Manufacturing Efficiency			- need of specialized workforce (carpenteers); - manufacturing cost are known after a feasibility study is maded by the construction manager in the carpentry;
		1 points +	- manufacturing costs are known upfront when choosing a model in the product platform; - specialized workforce is dismissed;
4. Assembly Efficiency			- need of specialized workforce (carpenteers); -- assembly time is known after a feasibility study is maded by the construction manager in the carpentry. - need of specialized workforce (carpenteers);
		2 points +	- assembly time is known upfront when choosing the model in the product platform - any worker is capable of assembling the product - no need of special tools or glue - the usage of assembly guides facilitated and reduced the chance of error;
5. Design Freedon			- the customer gives all the specifications and requirements he whats to see in the final products - made to measure and high customisation
		4 points -	- design choice is limited to the models presented in the product platform; - products can be configured by the client or the architect within the available options;

Figure 64 *– Comparison of five variables in the current and the alternative strategy.*

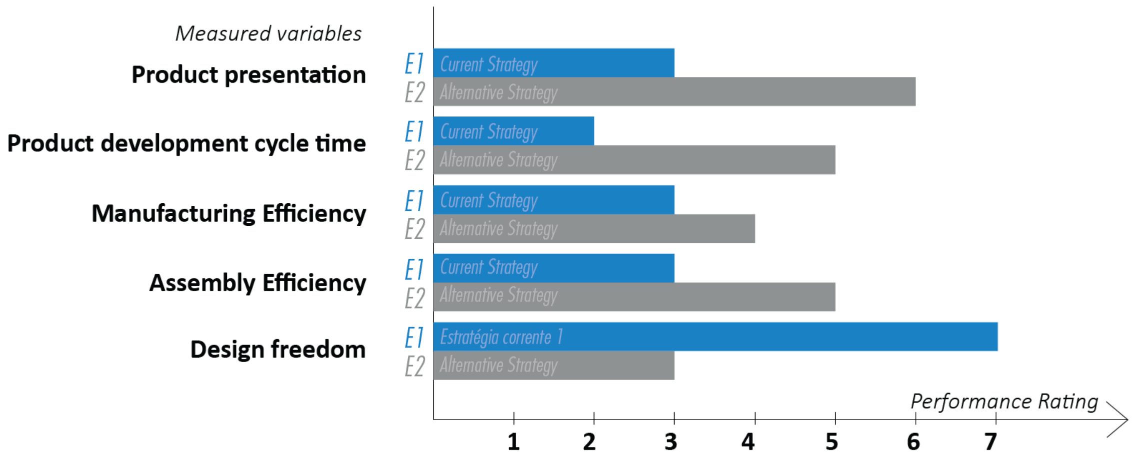

Figure 65 *– Histogram of the measured variables and the respective rating.*

From the case data and analysis (**Figure 64** and Figure 65), it follows that there exists a difference between both strategies. And significant differences were found in variable 1, 2 and 5.

At product presentation (1), the alternative strategy seems to stand out with a 3-point difference in the performance rating. This strategy provides images, drawings, 3D models that when using the current strategy would not be possible to have available. This happened due the fact that, since all this information is developed in advance before any project, when working in a new architecture project, the team does not have to develop this information during that time. These visuals increased the quality perceived of products, and consequently added value to the final solution.

Results from the product development cycle time (2) should also be highlighted. Time spent in the PDP suffered a fundamental reduction due to the work done in advance and with a large external variety. Additionally, the alternative strategy proved to be more certain when it comes to predict PDP time.

The last significant result applies to the design freedom (5). The current strategy seems to perform better that the alternative proposed. This is explained by the limited choice of models available when using the alternative strategy.

With the measures taken it is possible to alleged that this strategy had a considerable positive impact in the product presentation and in the product development cycle time. On the opposite way, this strategy is limited to the models archived in the platform. Therefore, design freedom turned to perform worst.

Chapter 4 **Conclusions and future work**

In the building construction setting, a product is considered unique. However, this feature does not have to be applied to the stationary furniture. This research aimed to propose a strategy – based on industrial production principles and methodologies, namely the ones related to modularisation and product platforms – to respond to the demands of the construction companies, the market and the customers.

This chapter provides an overview of the findings of this research and a summary of the conclusions drawn are set out. Finally, suggestions for future work and research in the field are presented.

4.1 **Conclusions**

This research contributed to both product development literature and building construction literature. The results hold important guidelines for developing a platform-base strategy in the specific setting of a construction company.

This strategy is an example of how many configurations can be realized with a limited set of standardised parts. It is proved in this research that concepts, approaches and methods, originating from the manufacturing industry can successfully be applied in the construction industry.

It is concluded that the current strategy that this company used is focused on giving an answer with a high personalisation level – design of unique pieces of furniture. Three key features are highlighted: (1) longer development cycle and slower response, (2) products are extremely personalised, and (3) quality varies according to the budget and client requirements. On the other hand, the alternative proposed strategy focuses on offering many products, while at the same time to decrease internal processes and complexity. Products are developed in advance and archived in a digital platform – which was considered constrictive. Although this negative aspect, this strategy allowed to reduce costs, and the need for specialised workers. Also, it gave the company an alternative approach to answer to project that include stationary furniture. We can conclude that the choice of strategy used for the development of stationary furniture should be guided by the client requirements and project specifications.

Developing the initial platform requires greater investment and more development time than developing a single product. In this way the implementation of this strategy should be seem as a progressive implementation, since it grows with the addition of new products. It also requires a bigger effort, since the design of the components must be carefully assessed – x number of components have to generate y variation of a product (x < y). A lot of effort must be putted into the design to developed components that can be shared along the product family.

A fundamental aspect that is necessary to emphasize is that it is very important to understand at what point this strategy fits best that the current. The path should always consider client requirements and project specifications. This product platform complexity increases with time, so it reaches maximum effectiveness when a considerable number of products are archive.

To conclude, the successful results from the application validates the use of the strategy. The application of this strategy in this specific setting, generated PDP time and cost improvements, reduced error, cycle times and increased effectiveness to the process of developing stationary furniture for construction projects.

4.2 **Future Work**

The need to develop products faster, better and cheaper continuous to be a major goal for companies. In this way the study of other types of strategy could contribute. For future work, it is suggested the design and development of other stationary furniture products, following the same approach as the one presented in the case study.

In this research, the use of modular product in platforms has been demonstrated in the building construction setting. It is also suggested the implementation of this strategy in other scenarios. The integration of this strategy could be implemented in situations where products are batch produced and made to measure.

Other possible topics of research includes furniture parametrization, ergonomic factor within this strategy and integration of this strategy with BIM. Lastly, since this strategy requires greater investment, it could be interesting to understands at what point is that a company sees the return of the investment in this strategy.

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Appendix

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PORTO, 21 A 23 NOVEMBRO 2018

APLICAÇÃO DE MÉTODOS DE PRODUÇÃO INDUSTRIAL NA EXECUÇÃO DE MOBILIÁRIO FIXO NUMA EMPRESA DE CONSTRUÇÃO. O CASO DA EMPRESA *CASAIS – ENGENHARIA E CONSTRUÇÃO*.

Cláudia de Lima[1]*, Miguel Pires[2], Jorge L. Alves[1 e 3] e Bárbara Rangel[1 e 4]

1: Faculdade de Engenharia
MDIP – Mestrado em Design Industrial e de Produto da Universidade do Porto
e-mail: up201607608@fe.up.pt
2: CASAIS – Engenharia e Construção
Grupo CASAIS
e-mail: miguelpires@casais.pt
3: INEGI, Faculdade de Engenharia
Universidade do Porto
e-mail: falves@fe.up.pt
4: Departamento de Engenharia Civil, Faculdade de Engenharia
Universidade do Porto
e-mail: brangel@fe.up.pt

Palavras-chave: Desenvolvimento de produto, mobiliário fixo, design industrial, construção civil

Resumo. *A eficácia do desenvolvimento de produto é encarada como um ponto inerente ao sucesso de uma empreitada. Tipicamente o mobiliário fixo é desenhado e desenvolvido individualmente e exclusivamente para um determinado projeto – feito à medida – de acordo com as especificações do projeto e os requisitos do cliente. Este modelo de mobiliário é tão único e está tão adaptado a determinado projeto que não pode ser reutilizado para outro projeto. Deste modo o design e desenvolvimento de mobiliário fixo torna-se uma tarefa repetitiva que tem de ser executada cada vez que um projetista tem em mãos um projeto novo. Dada as exigências atuais no sector da construção, é pertinente orientar de forma estratégica as atividades de desenvolvimento de produto para tirar maior proveitos dos recursos e dos processos.*

A revisão bibliográfica permitiu assinalar as semelhanças e diferenças entre o sector industrial e da construção e identificar métodos de produção industrial adequados para a execução de mobiliário fixo no âmbito da construção. É dado maior foco às abordagens que permitam desenvolver um grande número de variantes de produtos a partir de um número reduzido de componentes, que encurtam o tempo de desenvolvimento e que permitam a gestão de informação dos produtos desenvolvidos. A relevância deste estudo é justificada pela necessidade de alcançar a normalização dos produtos integrados na arquitetura e ao mesmo tempo conseguir dar resposta às variadas solicitações a que este tipo de produto está sujeito.

Um caso de estudo, realizado na Casais – Engenharia e Construção, comprova que ao integrar métodos de modularização e gestão de produtos, é possível proporcionar uma ampla variedade de produtos, normalizados na empresa, sem comprometer a complexidade interna. Propõe-se uma estratégia para desenhar e desenvolver mobiliário fixo baseada numa plataforma de produto, apropriada para uma empresa de construção que, para além de executar a obra, participa também no projeto de pré-construção e arquitetura.

Os resultados mostram que esta estratégia contribui positivamente para a redução do tempo de desenvolvimento de mobiliário fixo e para a qualidade da apresentação do produto, porém, apresenta limitações pela escolha restrita de modelos.

1. INTRODUÇÃO

O desempenho do processo de desenvolvimento de produto influencia um projeto de construção de um edifício. Dada a sua importância e as atuais procuras do setor da construção, tais como o aumento da complexidade dos edifícios e das exigências dos clientes, o número reduzido de mão de obra especializada, custos altos de estaleiro e de operação, os altos padrões de qualidade e a competitividade no setor, é importante orientar a construção para a normalização e industrialização [1]. Deste modo, é relevante abordar o modo como os produtos integrados nos edifícios, como é o caso do mobiliário fixo, são executados no setor da construção e que métodos de produção industrial poderão contribuir para normalização e industrialização destes.

Tipicamente, o mobiliário fixo é desenhado e desenvolvido única e exclusivamente para um determinado projeto – feito à medida – de acordo com as especificações do projeto e com os requisitos do cliente. Este modelo de mobiliário é tão único e está tão adaptado a determinado projeto que não pode ser reutilizado para outro projeto. Assim, o design e desenvolvimento de mobiliário fixo torna-se uma tarefa repetitiva que tem de ser executada cada vez que um projetista tem em mãos um projeto novo. Torna-se necessário repensar os processos de design e desenvolvimento de mobiliário fixo para aumentar a normalização e implementar métodos que permitam a industrialização destes produtos. No entanto, na construção, um edifício é considerado um 'produto' único e portanto, exige o desenvolvimento de um mobiliário único. Este estudo procura dar resposta à questão: 'Como é que o podemos equilibrar a normalização e a variedade de produtos - mobiliário fixo – de modo a obter vantagens?'

A forma como o mobiliário é executado no setor industrial e no setor da construção, nunca poderá ser o mesmo, visto que apresentam características próprias de cada setor. Inclui-se neste estudo uma análise que compara os dois setores, distinguindo as peculiaridades de cada uma, e uma análise dos métodos correntes de produção industrial – métodos de modularização e gestão de informação – para o desenvolvimento de produto.

Num caso de estudo, realizado na empresa de construção – Casais – Engenharia e Construção -, é realizado um diagnóstico relativo ao processo de desenvolvimento de produto, aos recursos existentes e às oportunidades de melhoria. Após alinhar as recomendações retiradas da literatura revista e as características particulares desta empresa foi definida uma estratégia alternativa para o desenvolvimento de mobiliário fixo modular. Para avaliar a eficácia desta estratégia, é feita uma comparação entre estratégia corrente e a alternativa, na qual são medidas cinco variáveis: a qualidade da apresentação do produto (i), o tempo de resposta (ii), a eficiência da produção (iii), a eficiência na montagem (iv), e a liberdade de opções no design (v).

Os resultados provam que a estratégia baseada na modularização do mobiliário fixo em plataforma teve um impacto positivo nesta empresa de construção, trazendo benefícios principalmente no tempo de resposta por parte do arquiteto ou projetista. A estratégia alternativa distingue-se da corrente, por investir na apresentação do mobiliário, o que consequentemente se refletiu na melhoria significativa da qualidade da apresentação do produto ao cliente/dono de obra, ao arquiteto, ao projetista e a outros que, de uma forma ou outra, tenham de comunicar/apreender informação referente ao mobiliário fixo de uma obra. No entanto, prova-se que a modularização de mobiliário fixo deve ser considerada como uma alternativa, não conseguindo dar resposta a todas as solicitações de clientes e de projeto.

Depois da introdução, o artigo apresenta um capítulo de análise comparativa entre o setor industrial e da construção, um capítulo do caso de estudo, na qual se descreve, implementa e avalia a estratégia proposta e um capítulo de resultados. Por fim, são tecidas as considerações finais a respeito da estratégia.

2. ANÁLISE DO SETOR INDUSTRIAL E DA CONSTRUÇÃO

A indústria e a construção apresentam semelhanças e diferenças nos seus processos, metodologias, abordagens e produto final. Para perceber as características que separam estas duas indústrias é importante reconhecer as diferenças entre a dimensão do 'produto' final de um processo industrial e de um processo de construção, assim como o número de 'produtos' resultantes deste processo. Na figura 1 apresenta-se a definição de determinado produto conforme a sua dimensão e a quantidade em que é produzido. A produção em massa refere-se tipicamente à indústria e exige maior número de produtos de menor tamanho – p. ex. produção de garrafas de vidro. O projeto, refere-se tipicamente à construção, p. ex. a um edifício ou lote, e é caracterizado pela sua grande dimensão e um pequeno ou único número de produto(s). Entre estes dois extremos surge a produção em lote, que se refere à produção de pequenas séries de produtos que visam responder a indicações individuais de clientes ou de grupos – como é o caso do mobiliário fixo.

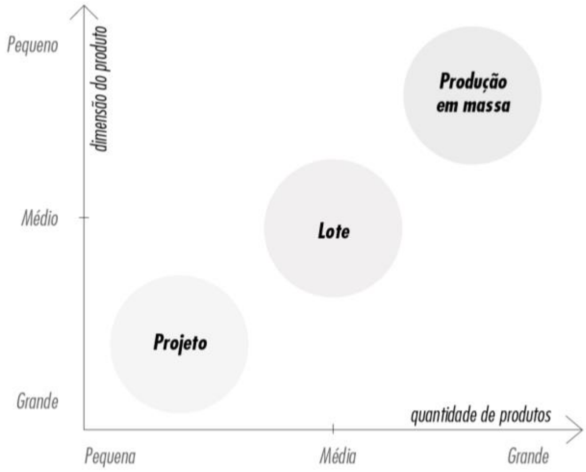

Figura 1 – Comparação da dimensão e quantidade do 'produto' no sector industrial e da construção. Baseada em [2].

A indústria e a construção apresentam bastantes similaridades. O nível de qualificações (i) exigido para ambas, depende das atividades e implica diversos tipos de qualificações, desde o mais baixo até ao mais alto [3-5]. No que toca ao cliente (ii), na indústria o produto passa por uma cadeia de produção até chegar o cliente, que inclui a transformação de matéria-prima até à entrega do produto a um cliente(s) [2, 5]. Desta forma, ambas são sensíveis ao preço da matéria-prima (iii) [2, 6]. Relativamente aos fluxos de informação (iv), apesar de na construção serem complexos e envolverem um grande número de equipas de trabalho [7], na indústria existe também um grande fluxo de informação, dependendo da complexidade do produto final [8].

O processo de desenvolvimento de produto difere de uma indústria para a outra devido às particularidades do produto final [9]. No que toca ao ambiente de trabalho (v), enquanto que na indústria o produto é produzido sob um ambiente controlado, dentro de uma fábrica [2], a construção trabalha tipicamente no exterior [5]. A manufatura do produto (vi) na indústria é caracterizada pela grande quantidade de unidades do mesmo produto [2, 8]. Na construção, o produto final é caracterizado pelo seu grande tamanho e a sua imobilidade. Além disso, é um produto composto por um número enorme de partes únicas que tem que ser produzido para durar durante longos anos; é considerado um produto caro [10]. Existe diferenças significativas no que toca a implicações que um produto final sofre aquando de qualidade fora dos padrões (vii). No caso da indústria, quando é produzido um produto com alguma falha, este perde valor e clientes traduzindo-se em resultados negativos para a empresa [5]. Na construção, quando um produto apresenta uma qualidade fora dos padrões, é considerado inseguro e não é aprovado em inspeção [5]. Quando existem erros ou inconformidades (viii) num produto da indústria, este é descartado, enquanto que na construção o produto é refeito [11]. As atividades típicas (ix) também diferem consideravelmente nestas duas. Prototipagem e maquetas são atividades da indústria [8]. Devido à natureza da construção, não é possível realizar protótipos [8]. Para além disso, a coordenação, gestão e métodos (x) na indústria são comuns a todos os produtos para o seu desenvolvimento [3], enquanto que na construção estes são orientados e específicos para cada tipo de projeto [12]. A última grande diferença entre a indústria e a construção listada, refere-se à mão de obra e à mecanização (xi). Na indústria, a mecanização – indústria 4.0 – tem eliminado operações realizadas pela mão dos trabalhadores para ser substituída por máquinas [6]. Pelo contrário, o produto da construção implica um

trabalho altamente dependente do trabalho físico da mão de obra *in situ* [13].
Um paradigma emergente perante estes dois setores, deve ser referido como fator diferenciador [11]. A produtividade da construção tem-se mantido estagnada ao longo dos últimos anos, enquanto que a linha de produtividade da indústria parece estar a crescer [1]. Tem havido um esforço de investigação, procurando propor alternativas para a construção, baseadas em metodologias tipicamente utilizadas pela indústria. Mas pouca atenção tem sido dada ao desenvolvimento de produto dentro da construção [14]. De acordo com a consultora *McKinsey Global Institute* [1], será necessário repensar os processos de design e engenharia e aumentar a normalização. A implementação de metodologias de produção industrial poderá ser um caminho para uma contribuição do aumento da produtividade no setor da construção [14].

3. CASO DE ESTUDO

O caso de estudo aborda uma empresa de construção - *Casais – Engenharia e Construção* -, e foi incluído num projeto-estágio com a duração de seis meses no núcleo de Pré-construção do Departamento Técnico da empresa. Por estar incluída na execução do mobiliário fixo da empresa, neste caso é referida também a empresa *Carpin - Casais, Wood & Metal*, pertencente ao mesmo grupo – Grupo Casais.
O principal foco de análise é o desenvolvimento, implementação e avaliação de uma estratégia alternativa mais 'industrial' para desenvolver mobiliário fixo para obras. O objetivo é acelerar o tempo de resposta por parte dos arquitetos e/ou projetistas, melhorar a apresentação do material de comunicação técnica/visual do mobiliário fixo e aumentar a eficiência de produção e montagem.

3.1. Enquadramento

O produto final de um projeto de construção, p. ex. um edifício, é único e exclusivo. O mesmo se aplica ao mobiliário fixo dentro destes edifícios. Para determinado projeto, estes produtos são desenhados e feitos à medida, de acordo com as especificações deste mesmo projeto e dos requisitos do cliente. Como cada peça de mobiliário fixo é tão única, quer devido a dimensões muito específicas, quer por detalhes pedidos pelo cliente, estes modelos não são reutilizados para qualquer outro projeto de construção.
O processo de desenvolvimento de mobiliário fixo, neste caso de estudo, envolve duas empresas do mesmo grupo – *Grupo CASAIS*. A primeira – *Casais – Engenharia e Construção* -, é responsável pelo desenho do projeto (que neste caso inclui o projeto de arquitetura) e execução da empreitada, e a segunda – *Carpin - Casais, Wood & Metal* -, que é, paralelamente com a primeira empresa, responsável por desenvolver, produzir e implementar o mobiliário fixo nas obras. Em sintonia com os objetivos da empresa (Figura 2), pretende-se propor uma estratégia alternativa, alinhada com métodos de produção industrial, capaz de oferecer uma grande variedade de produtos, desenvolvidos previamente, sem pôr em causa a complexidade interna que pode causar.

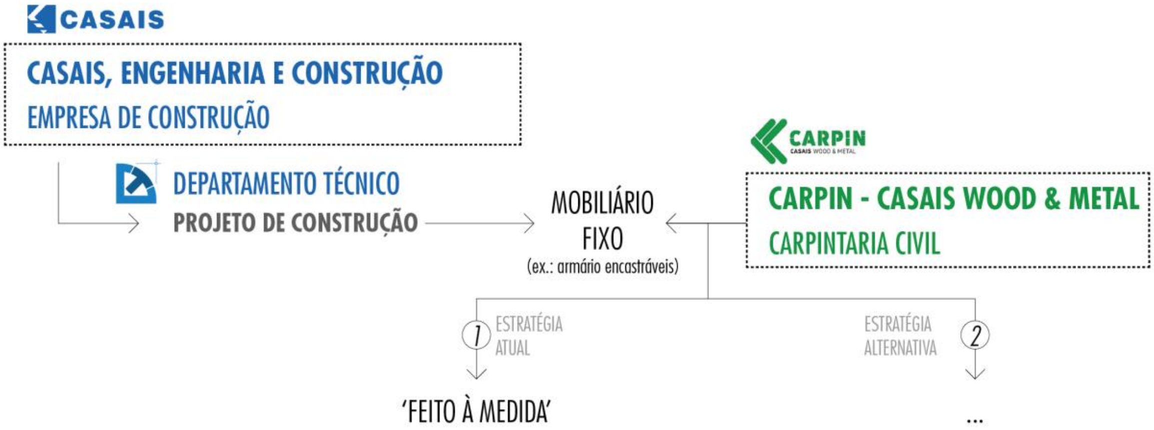

Figura 2 - Enquadramento do caso de estudo. (Fonte: Elaborado pelo autor)

3.2. Diagnóstico da estratégia corrente

Para o diagnóstico da estratégia corrente para o design e desenvolvimento de mobiliário fixo do grupo, foram realizadas entrevistas estruturadas e consultas a especialistas das duas empresas. Foi feita observação direta, e um mapeamento dos fluxos de valor ou *Value Stream Map*. Pretende-se compreender a estratégia atual, de modo a entender o processo, descobrir oportunidades de melhoria e definir o foco de ação, e poder fazer uma comparação entre esta estratégia atual e a estratégia proposta.

A partir da observação direta e das entrevistas realizadas, destacam-se quatro aspetos. O primeiro diz respeito ao mobiliário fixo feito à medida. Tipicamente este é desenhado e desenvolvido com prazos muito apertados, durante a fase do projeto de arquitetura. Este mobiliário obedece a especificações únicas relativas a um projeto e especificações do cliente/dono de obra. Como este é executado à medida do projeto, o modelo, normalmente, não volta a ser usado noutro projeto. Esta abordagem implica que, cada vez que seja necessário desenvolver mobiliário fixo, se parta do zero para criar um modelo. Tendo em conta que é um modelo novo a ser desenhado, existe sempre uma margem de erro que é maior do que se fosse um modelo previamente desenvolvido, produzido e testado. Para além disto, o resultado de um produto e o seu tempo de desenvolvimento, neste contexto, será sempre condicionado pela experiência dos projetistas e outros atores envolvidos.

A segunda observação diz respeito ao sistema de produção – produção unitária ou em lote. Isto significa que cada vez que um modelo é desenvolvido, este é produzido numa quantidade limitada, sendo a dimensão deste lote dimensionada de acordo com a quantidade solicitada para a obra. Uma vez que cada lote é único, este exige maior atenção por parte dos projetistas, operadores da fábrica e 'assemblers'.

A terceira observação refere-se ao processo de pré-montagem em fábrica e montagem final em obra. Para obras em território nacional, tipicamente, os produtos são pré-montados e transportados em camiões. A pré-montagem é realizada num ambiente controlado e executada por mão de obra especializada. O facto de esta atividade ser feita em fábrica é explicado pelo facto de evitar deslocar recursos para a obra e a facilidade de acesso a ferramentas ou outras máquinas. Para além deste motivo, a pré-montagem é feita em fabrico para evitar danos no transporte. A montagem é geralmente feita com recurso a cavilhas, parafusos e grampos (Figura 3). Depois de o mobiliário estar inspecionado e aprovado é embalado com placas de poliestireno expandido e película plástica.

Figura 3 - Pré-montagem de uma gaveta com recurso a cavilhas, cola e grampos.

O quarto e último aspeto está relacionado com a identificação de falhas e defeitos. Estes estão geralmente relacionados com: (i) erros durante a fase de produção, (ii) embalagem e condições de transporte desadequados, (iii) encomendas de ferragens desconformes com os pedidos, (iv) empenos nas peças de madeira por alterações impróprias do teor de humidade. Na Figura 4 é possível visualizar alguns dos erros e defeitos levantados numa inspeção à obra.

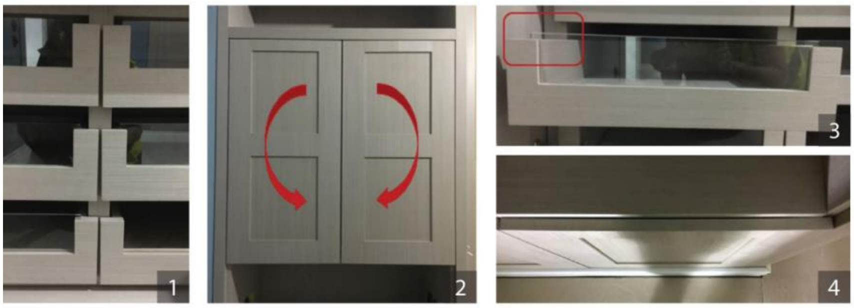

Figura 4 – Levantamento de falhas e defeitos que podem ocorrer na montagem em obra; (1) as gavetas estão mal instaladas; (2) as portas montadas ao contrário; (3) o acrílico da gaveta não tem dimensões certas; (4) a tábua/porta está empenada;

Com o *Value Stream Map* é possível concluir que existe uma grande quantidade de trabalho e de informação gerada nas primeiras três etapas – desde que o arquiteto idealiza e concretiza o desenho até que é aprovado e pelo cliente/dono de obra e finalmente considerado viável pela Carpin. Neste mapa foram identificados dois tipos de desperdício. O primeiro refere-se ao trabalho excedente: o trabalho torna-se repetitivo porque tem de ser desenhado um modelo. Considera-se que não é apenas um desperdício de recursos, mas traz também riscos para a organização, já que estes dependem da experiência e do *know-how* dos projetistas e dos operadores. O segundo desperdício encontrado refere-se ao tempo despendido nas etapas de projeto e desenvolvimento: o que inclui design e redesenho, espera pela aprovação e em alguns casos até, esperar pela execução de protótipos ou testes.

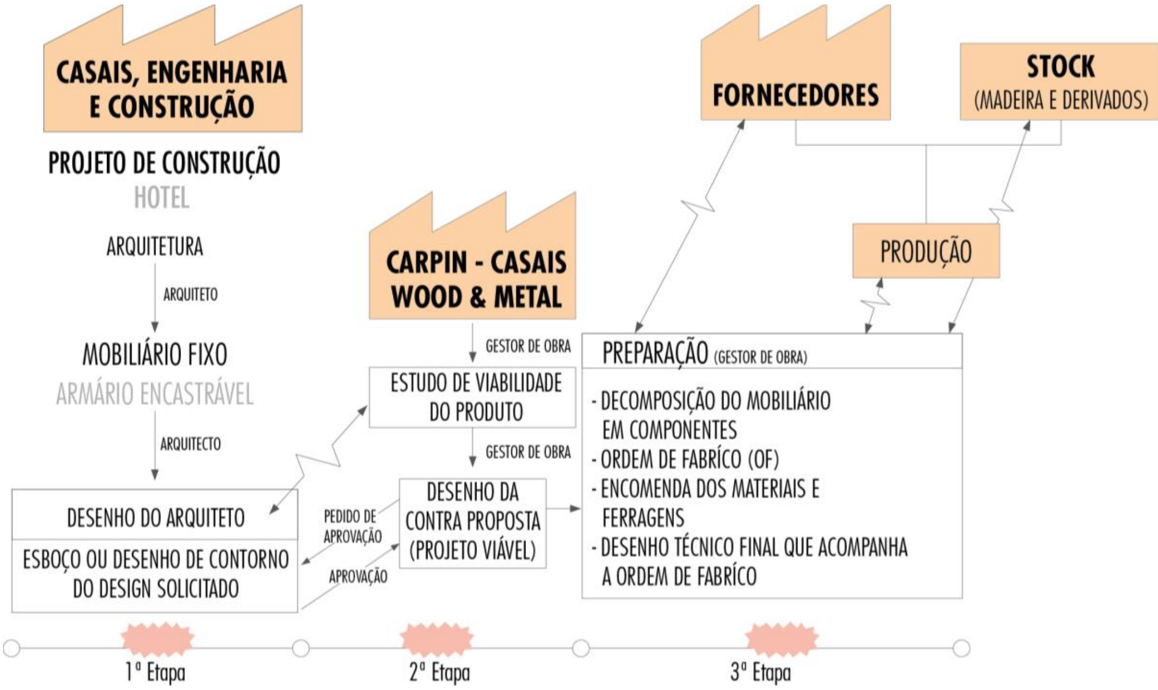

Figura 5 – *Value Stream Map* do processo de desenvolvimento de mobiliário fixo no caso de estudo.

A mudança é uma realidade no atual ambiente organizacional, e não há nada que indique, que esta situação venha a ser diferente no futuro. Os rápidos avanços tecnológicos, a competitividade e as necessidades do mercado têm vindo a exigir mudanças nas estratégias das organizações nas duas últimas décadas. Provadas as capacidades e espaço para a melhoraria de vários aspetos relativos ao design e desenvolvimento de produtos da empresa, é proposto uma estratégia alternativa para executar – desenhar, desenvolver, implementar e gerir – mobiliário fixo para as obras do grupo.

3.3. Estratégia alternativa para o desenvolvimento de mobiliário fixo

A estratégia proposta, baseada numa plataforma de produto, visa disponibilizar modelos de mobiliário fixo, desenvolvidos previamente, para projetos na qual seja necessário integrar mobiliário fixo. Esta estratégia evita assim o trabalho repetitivo, economizando recursos e acelerando o processo de desenvolvimento de produto. Ou seja, em casos em que o projetista/arquiteto precisa de implementar um armário embutido, p. ex., este dispõe de uma plataforma com vários modelos (Figura 6).

A estratégia segue três etapas fundamentais para o início da sua atividade. Em primeiro lugar (passo 1), deve ser desenhada, partindo do zero, a primeira família de produtos. Destaca-se a arquitetura modular de produto que permite gerar uma grande variedade de produtos que partilham componentes entre si. Diferentes combinações levam a diferentes soluções. Nesta estratégia, uma família de produto ou uma linha de produtos, refere-se ao conjunto de produtos derivados de um grupo de componentes específico. Depois de uma família de produtos desenvolvida, é necessário especificar informações sobre o produto de acordo com o diretório proposto (passo 2). Ou seja, cada produto arquivado na plataforma deve ser acompanhado de uma lista de dados visuais, CAD, marketing / negociação e fabricação. Estes dados, gerados antecipadamente, fornecem material para apresentar um determinado produto ao cliente, como *renderizações*, ilustrações ou vídeos do produto. Incluem-se ficheiros CAD que permitem ao arquiteto introduzir determinado produto numa planta de uma maneira muito eficiente, reduzindo a possibilidade de cometer erros no plano de implementação. Os dados de fabricação também estão incluídos com o objetivo de acelerar o processo de desenvolvimento de produto e reduzir a taxa de erros de produção.

Esta estratégia é alimentada por uma plataforma de produto (etapa 3). Esta ‘biblioteca digital’ é um software de gestão de informação na qual são arquivadas todas as famílias de produtos desenhadas. Este método permite a partilha de informações da plataforma com clientes, trabalhadores, donos de obra, gestores de obra ou carpinteiros, não só entre estas duas empresas, mas também por outras do grupo CASAIS. Por fim, essa abordagem de plataforma permite que a equipa de projeto possa gerir uma ampla variedade de produtos.

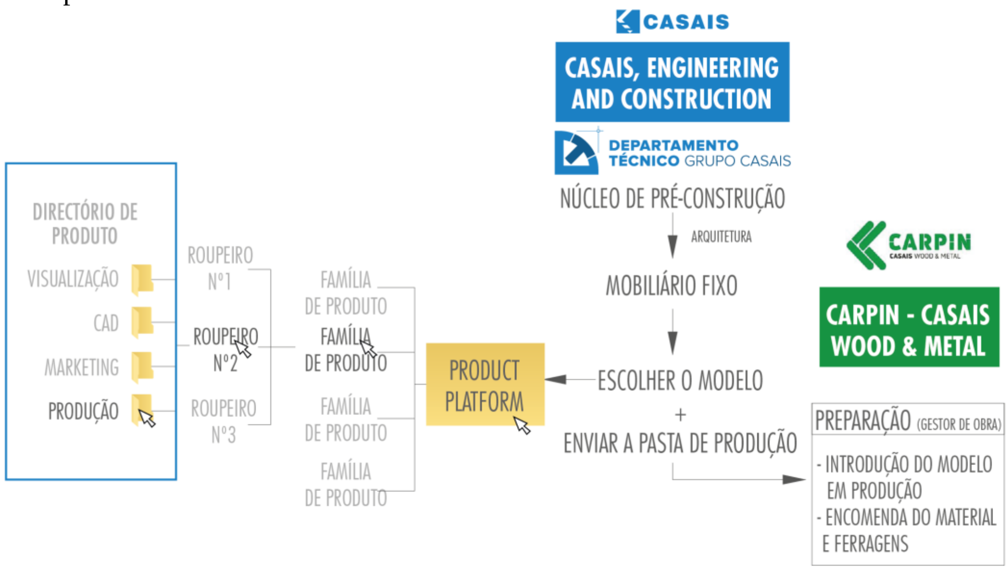

Figura 6 –Estratégia alternativa para dar resposta ao desenvolvimento de mobiliário fixo.

3.5. Implementação

Para a implementação desta estratégia foi realizado um projeto piloto, elaborado pela equipa de design do Departamento Técnico da Casais - Engenharia e Construção. Definiu-se que a primeira família de produtos seria uma linha de roupeiros embutidos, já que a empresa considerava que era o tipo mais usado de mobiliário fixo. Primeiro, foram definidas as áreas de arrumação possíveis (Figura 7) e as especificações normalizadas desta família de roupeiros: (a) volume total de 2000x1200x600 mm incluindo portas e pés de ajuste; (b) sistema construtivo com minifix e parafusos; (c) varão e suportes metálicos; (d) puxadores metálicos; (e) dobradiças e pratos simples; (f) o módulo de prateleira deve permitir a colocação de um sistema de iluminação.

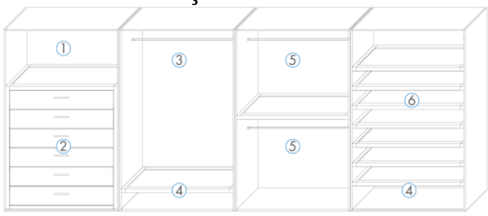

Figura 7 – Organização espacial e definição do tipo de áreas de arrumação.

Deste modo, partiu-se para o desenvolvimento do conjunto de módulos e ferragens cuja linha de roupeiros iria partilhar. Esta fase exigiu um grande esforço que coordenação, tempo e investimento pois, esta estratégia considera a conceção de diversos produtos ao mesmo tempo. Para além disto, realizou-se uma série de testes CAD, para confirmar todas as combinações possíveis de gerar. A Figura 8 mapeia todas as combinações geradas com os componentes desenvolvidos. Esta combinação permite criar 23 modelos, a partir de 6 sub-montagens de componentes (26 componentes na qual se exclui ferragens de pequeno porte, parafusos e/ou outros). Com esta matriz, é possível verificar a quantidade de modelos e a quantidade de componentes (agrupados em sub-montagens) que esta linha requer.

Sub-monatgem	Componentes	Modelo 1	Modelo 2	Modelo 3	Modelo 4	Modelo 5	Modelo 6	Modelo 7	Modelo 8	Modelo 9	Modelo 10	Modelo 11	Modelo 12	Modelo 13	Modelo 14	Modelo 15	Modelo 16	Modelo 17	Modelo 18	Modelo 19	Modelo 20	Modelo 21	Modelo 22	Modelo 23	Modelo 24	Modelo 25	Modelo 26	Modelo 27	Modelo 28	Modelo 29	Modelo 30	Modelo 31	Modelo 32
Portas	Painel porta	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Puxadores	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Dobradiças	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Caixa	Painel vertical	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Painel horizontal	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Painel costa	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Prateleira	Moldura lateral	2	4	6	x	x	x	2	2	2	2	x	x	x	x	x	x	x	2	4	6	8	10	12	14	16	14	12	10	8	6	4	2
	Moldura horizontal	2	4	6	x	x	x	2	2	2	2	x	x	x	x	x	x	x	2	4	6	8	10	12	14	16	14	12	10	8	6	4	2
	Painel	1	2	3	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	2	3	4	5	6	7	8	7	6	5	4	3	2	1
Varão	Varão	1	1	1	1	1	1	1	1	1	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Suportes de varão	2	2	2	2	2	2	2	2	2	4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Modulo de gavetas	Frente gaveta	x	x	x	1	2	3	1	2	3	x	1	2	3	4	5	6	7	x	x	x	x	x	x	x	x	1	2	3	4	5	6	7
	Lateral gaveta	x	x	x	2	4	6	2	4	6	x	2	4	6	8	10	12	14	x	x	x	x	x	x	x	x	2	4	6	8	10	12	14
	Costa gaveta	x	x	x	1	2	3	1	2	3	x	1	2	3	4	5	6	7	x	x	x	x	x	x	x	x	1	2	3	4	5	6	7
	Fundo gaveta	x	x	x	1	2	3	1	2	3	x	1	2	3	4	5	6	7	x	x	x	x	x	x	x	x	1	2	2	4	5	6	7
	Puxador gaveta	x	x	x	1	2	3	1	2	3	x	1	2	3	4	5	6	7	x	x	x	x	x	x	x	x	1	2	3	4	5	6	7
	Corrediças	x	x	x	2	4	6	2	4	6	x	2	4	6	8	10	12	14	x	x	x	x	x	x	x	x	2	4	6	8	10	12	14
Estrutural	1x moldura vertical	x	x	x	2	x	x	2	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x	x
	2x moldura vertical	x	x	x	x	2	x	x	2	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x
	3x moldura vertical	x	x	x	x	x	2	x	x	2	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x
	4x moldura vertical	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x
	5x moldura vertical	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x
	6x moldura vertical	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x
	7x moldura vertical	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2
	Moldura horizontal	x	x	x	3	3	3	3	3	3	x	3	3	3	3	3	3	3	x	x	x	x	x	x	x	x	3	3	3	3	3	3	3
	Moldura lateral	x	x	x	2	2	2	2	2	2	x	2	2	2	2	2	2	2	x	x	x	x	x	x	x	x	2	2	2	2	2	2	2

Figura 8 – Matriz de combinações possíveis que definem esta linha de roupeiros.

3.6 Resultados

Após um diagnóstico da estratégia corrente para o desenvolvimento de mobiliário fixo numa empresa de construção e com a implementação de uma estratégia alternativa com base numa plataforma de produtos modulares, foi possível executar uma comparação entre os dois. Foram classificadas cinco variáveis, numa escala de 1 a 7 pontos (figura 9): (1) qualidade de apresentação do produto, (2) tempo de resposta a um projeto, (3) eficiência de produção, (4) eficiência de montagem e (5) liberdade de design. De acordo com os resultados apresentados pela empresa, três variáveis se destacam pelo seu impacto significativo. Primeiro, com uma diferença de três pontos, destaca-se a melhoria da qualidade de apresentação do produto. Este aumento é explicado pela disponibilização de imagens foto-realistas, modelos 3D, entre outro tipo de visualização, que esta estratégia alternativa trata de desenvolver para cada produto existente na plataforma. A segunda melhoria a destacar diz respeito ao tempo de resposta. O tempo de resposta por parte dos arquitetos da empresa neste estudo, resultou ser significativamente menor do que quando desenvolvendo um modelo do zero. Neste caso, não foi considerado o tempo investido previamente para o desenvolvimento do modelo testado. O último ponto, cujo impacto foi significativo, refere-se à liberdade/quantidade de opções. A estratégia demonstra limitações pelo facto a escolha estar limitada aos modelos disponíveis na plataforma de produtos.

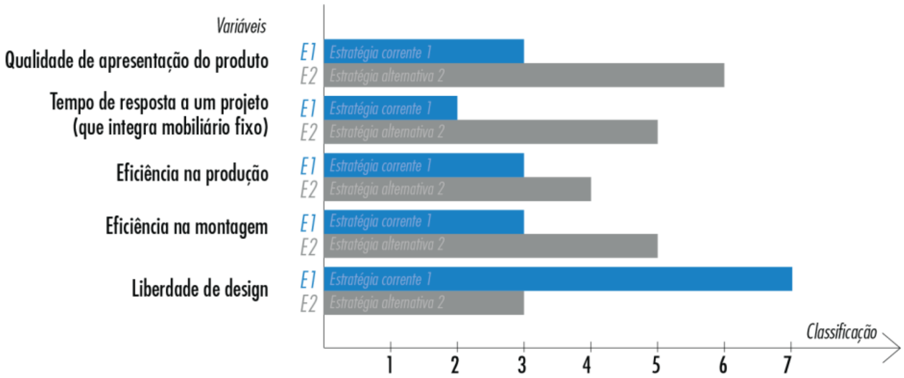

Figura 9 – Comparação das cinco variáveis entre a estratégia corrente e a alternativa.

A implementação desta estratégia pretende: (a) a redução de custos através de maior eficiência de recursos, (b) a garantia de uma resposta rápida através da preparação de mobiliário antecipadamente para projetos, (c) a melhoria da qualidade da apresentação do produto e qualidade percebida, apresentando o produto com recurso a ferramentas digitais, (d) aumentar a confiabilidade prevendo falhas e corrigindo-as antecipadamente, maior assertividade nos orçamentos e maior confiança nos produtos desenvolvidos e (e) aceleração e simplificação do processo de desenvolvimento de produto.

4. CONCLUSÕES

Na construção, um edifício é considerado um 'produto' único, porém, esta característica não tem de ser aplicada ao seu mobiliário fixo. Esta estudo procurou propor uma estratégia - baseada em métodos de produção industrial, nomeadamente a modularização de produtos em plataforma – capaz de responder às solicitações de uma empresa de construção civil, do mercado e dos clientes. Inclui-se uma análise que compara o setor industrial e da construção, distinguindo as peculiaridades de cada um.

A estratégia descrita deve ser considerada como uma opção alternativa ao processo atual e não uma substituição. Deve ser sempre deixado espaço para que se possa executar mobiliário à medida, pois, haverá ocasiões em que o modelo tem requisitos tão específicos ou o mobiliário é tão personalizado, que a plataforma normalizada, não será capaz de dar resposta.

Conclui-se que é vantajoso disponibilizar produtos em plataforma digitail porque permite o acesso global e utilização dos modelos desenhados, desde a fase de projeto em conceção interna da *CASAIS*, percorrendo a fase comercial em sede de concurso, enquanto apresentação de alternativas aos clientes, bem como na fase de execução de obra como propostas de soluções para redução de prazo, custo, etc. As soluções normalizadas, geradas com recurso a esta estratégia, provaram reduzir o tempo de resposta a projetos que incluem mobiliário fixo, facilitando o trabalho dos projetistas/arquitetos, dos operadores e 'assemblers', e contribuindo positivamente para o aumento da produtividade do projeto de construção. Para além disso, provou também garantir e melhorar a qualidade de apresentação dos produtos ao cliente/dono de obra. Por fim, é necessário considerar que, comparado ao design de mobiliário fixo tradicional, o desenvolvimento de mobiliário fixo modular requer maior compromisso por parte da empresa e da equipa de desenvolvimento de produto, maior coordenação, esforço, tempo e mais investimento, uma vez que considera a conceção de diversos modelos ao mesmo tempo.

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