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Title

Value Chain Strategy Configurator

Construction of a renovation strategy configurator to assess value chain strategies on the progress towards the industrialized renovation of the Dutch housing stock by means of mass-customization

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1. INTRODUCTION

The presented report is submitted as a first deliverable associated with conducted research under the IEBB consortium as a contribution to Work Package 4.3 (activity 6). In the presented report a strategy assessment configurator is developed based on extensive desk research and is partially verified in practice by means of qualitative research (interviews). Based on the conducted research, the combined deployment of (1) product customization, (2) value chain configuration and (3) varying organizations of flows in production systems have been investigated. Furthermore, an indication of the current application of various strategies and the desired combination of strategies of industry parties is provided on the configurator. Hence, the configurator can be utilized as an aid for value chains to establish the directions of the strategic transitions required to effectively increase renovation capacity. In further research, the presented configurator and established directions of required strategic transitions will be used to research (1) which transitions should be made, (2) how these transitions can be made, (3) what value chains require to achieve these transitions and (4) what the consequences of these transition can be. This deliverable will be (partially) encompassed in a finalized PDEng thesis which can simultaneously be considered as the final deliverable. Therefore, the deliverable presented in this report is the basis for research which contributes to increasing the renovation capacity in the Dutch Built Environment. The problem statement, research questions and methods associated with this deliverable are discussed hereafter.

1.1 PROBLEM STATEMENT

The housing stock within the Netherlands consists of 7.8 million properties which altogether negatively contribute to carbon emission. In order to address this issue, large-scale renovations of these properties are required in the nearby future. The combined tendering of these retrofitting clusters to the construction industry is expected to significantly increase renovation market demand until 2050 (Van Loon et al, 2011; Visscher, 2017). In order to cope with the increase in demand for renovation projects, the capacity of the construction industry should be larger or equal to the demand within a specific timeframe. In order to efficiently increase capacity, products and processes have been increasingly standardized. A rapid shift from on-site construction activities, material conversions and unique end-product creation towards more off-site manufacturing-based construction of prefabricated components for on-site assembly is definable by the term industrialization. Industrialization encompasses various technologies with the goal to increase the effectiveness of supply chains by means of addressing both on-and-off-site efficiency (Girmscheid, 2005).

Modular construction concepts have been emerging which enable the construction of single properties in days instead of months. Examples of these modular concepts are (1) VolkerWessels MorgenWonen[1], (2) TBI Houtbaar[2] and (3) Barli modular construction[3]. As pure standardization in the built environment disconcerts technical and customer variances, mass-customization can be regarded as a sensible alternative for mass-production (Muhuri et al, 2019; Alaloul et al, 2020). Mass-customization regards the creation of substandard end-products which are created by means of both standardized and non-standardized process inputs and throughput processes while nearing the efficiency of mass production. As technical variations might occur in each individual property, the

[1] Home - MorgenWonen
[2] Modulaire, circulaire woningen – digitaal te produceren | HOUTbaar
[3] Barli - Prefab bouw | Houtskeletbouw | Mobiele bouw

number of variations is not containable. Hence, new challenges arise which currently impede the design and establishment of mass-customized renovation concepts and the supply chains to realize them. To enable the development of such a concept and the required supply chains, several strategic transitions are required. As various deployed strategies should be aligned to successfully achieve desired results, insight is required into the combinations of these strategies and their influence on performance. Hence, the following problem definition was formulated:

"There is insufficient insight into the varying pursuable strategies in construction industry value chains and how they should be jointly deployed to increase capacity and achieve industrialized renovations by means of mass customization"

1.2 RESEARCH QUESTION

In order to achieve the overall capacity to cope with increased market demand, strategic alignment should be achieved in construction industry supply chains. As the alignment of strategies should be viewed as a goal to achieve increased capacity, the transitions required to achieve alignment in the future (desired) state of renovation supply chains should be viewed as the means to achieve the goal. Therefore, the strategies associated with products, value chain configurations and production systems in current state renovation supply chains, should be adapted to achieve a desirable future state. The adaptations of products, value chain configurations and production systems to enable such a transition, can be considered to bridge the gap between the current and future state. To identify which transitions should be made to bridge this gap, insight is required into deployable strategies, their interdependency and influence on achieved outputs. Furthermore, insight should be provided into the current application of various strategies and the desired output in practice to determine the direction of further research. Therefore, two distinct research questions have been developed which will be addressed by means of (theoretical) desk research and (practical) field research subsequently.

Q1: Which combination of business, functional and operational strategies can and should be pursued in construction industry value chains aiming for industrialized renovations by means of mass customization?

Q2: Which combination of strategies are companies in the construction industry currently using, what are they aiming for and which combination of strategies should therefore be pursued?

1.3 METHODS

Desk research is conducted to identify the properties of construction industry value chains (Section 2.1). Furthermore, deployable business (Section 2.2), functional (Section 2.3 & 2.4) and operational strategies (Section 2.5 & 2.6) are investigated. Besides individual strategies, appropriate combinations of strategies are identified and the consequences of these combinations on performance indicators is established (Section 2.7). To establish an overview of co-deployable strategies which regard products, value chain configurations and the organization of flows in production systems, these strategies have been merged in a strategy assessment configurator (Section 2.8). Within the aforementioned sections, various methods have been discussed which enable strategy transitions and thus navigation of a value chains position on the configurator. The desk research has been executed by means of narrative literature review, which involves the analysis and summarization of a body of literature to establish a comprehensive background related to a specific topic. The execution of such a review enables the refinement, focus and drafting of research questions and is suitable for the development of a theoretical configurators (Cronin et al., 2008). Therefore, the narrative method is suitable for the development of a configurator.

Practical data is gathered at various contractors and manufacturers (Section 3.1) by means of topic-based field research (Section 3.2). These interviews are conducted to identify the current position of various companies on the developed configurator (Section 3.3). The envisioned direction and thus transition towards the application of other strategies is in the desired future state on the configurator was determined as well. Furthermore, the methods, constraints and limitations associated with such a transition are also yielded (Section 3.4) and an overall reflection on the configurator is executed (Section 3.5). The qualitative method of semi-structured interviews has been used in order to do so. This method involves the execution of interviews by means of a topic list, transcription of recordings, open coding and analysis by means of an axial diagram (Schmidt, 2004). The utilization of such a diagram enables the comparison of all fragments associated with a specific topic (e.g. all fragments which regard customization strategies established in literature).

2. VALUE CHAIN STRATEGIES

Capacity is defined under performance efficiency in the ISO 25010 standard as: *"degree to which the maximum limit of a product of system parameters meets requirements"* in which the construction capacity should be considered as the system (ISO, 2011). Capacity is typically indicated in output units over time (e.g. number of houses per day) and can be considered on (1) the value chain level, (2) the company level and (3) the production system level. As the capacity of the value chain level depends on the capacity in subsequent levels, these levels should be considered as interrelated (Shapiro et al., 1993; Bogataj & Bogataj, 2007). The process of aligning capacity to fluctuating market demand is embedded in the term capacity management and can be defined as: *"the ability to meet customer requirements with respect to the available resources"* (Zoryk-Schalla et al., 2004; Halpern & Graham, 2018; Morlok & Chang, 2004). Therefore, market requirements and competitive priorities should be established first to efficiently increase the capacity of a production system. However, it should be noted that adjusting the organization of production systems to increase capacity without appropriate strategic considerations, might result in costly under-utilization of resources (Corrado & Mattey, 1997; Zoryk-Schalla et al., 2004; Halpern & Graham, 2018). Therefore, the organization of production systems should result from the joint deployment of the most appropriate strategies in a value chain. But which strategies should be considered, which options do companies have, how should these strategies be deployed and what are the effects of deploying differing strategies on competitive priorities associated with market requirements?

In this chapter insight is provided into varying strategies which can be pursued by companies in value chains to increase their capacity. In order to do so, a strategy assessments configurator is developed to assess current renovation strategies, desired renovation strategies and their influence on market-based performance indicators. Based on alignment of these strategies with competitive priorities, various companies can be enabled to achieve a transition towards industrialized mass customization. To aid companies and value chains to identify the means to execute such a transition, guidelines are provided which regard changing product customization strategies, value chain configurations and the organization of flows in production systems. The composition of a strategy assessments configurator for renovation value chains is captured in the first research question which is formulated as follows: *"Which combination of business, functional and operational strategies can and should be pursued in construction industry value chains aiming for industrialized renovations by means of mass customization?"*.

The first part of this chapter is dedicated to the properties of a renovation value chain (Section 2.1). In the second part of this chapter varying competitive and growth strategies which can be pursued in value chains are considered (Section 2.2). To capture the competitive priorities which result from competitive and growth strategies, various product customization strategies are discussed in the third part of this chapter (Section 2.3). As the configuration of collaborating value chain parties should be aligned with product customization strategies, various configurations and attributable properties are discussed in the fourth part of this chapter (Section 2.4). In subsequent chapters the operational organization of material and information flows in production systems are discussed (Section 2.5-2.6). The performance indicators related to the competitive priorities associated with the output of value chains are discussed in the seventh part of this chapter (Section 2.7). The chapter is concluded with the combination of deployable strategies in an assessment configurator for renovation value chains (Section 2.8), answering the aforementioned research question.

2.1 RENOVATION VALUE CHAINS

The value chain consists of a set of activities which are executed by a company in order to deliver value by means of its products or services to the market. The concept of the value chain was first described by Porter (1985) and since then, has been widely applied within industry (Porter, 1985; Porter, 2001; Holweg & Helo, 2014; Sushil, 2018). The underlying idea of the value chain regards the consideration of an organization as a system with several sub-systems in which inputs, transformation processes and outputs are encompassed. In order to add value along the value chain, acquisition and consumption of resources such as (1) materials, (2) labor, (3) equipment and (4) money is required (Porter, 2001; Sushil, 2018).

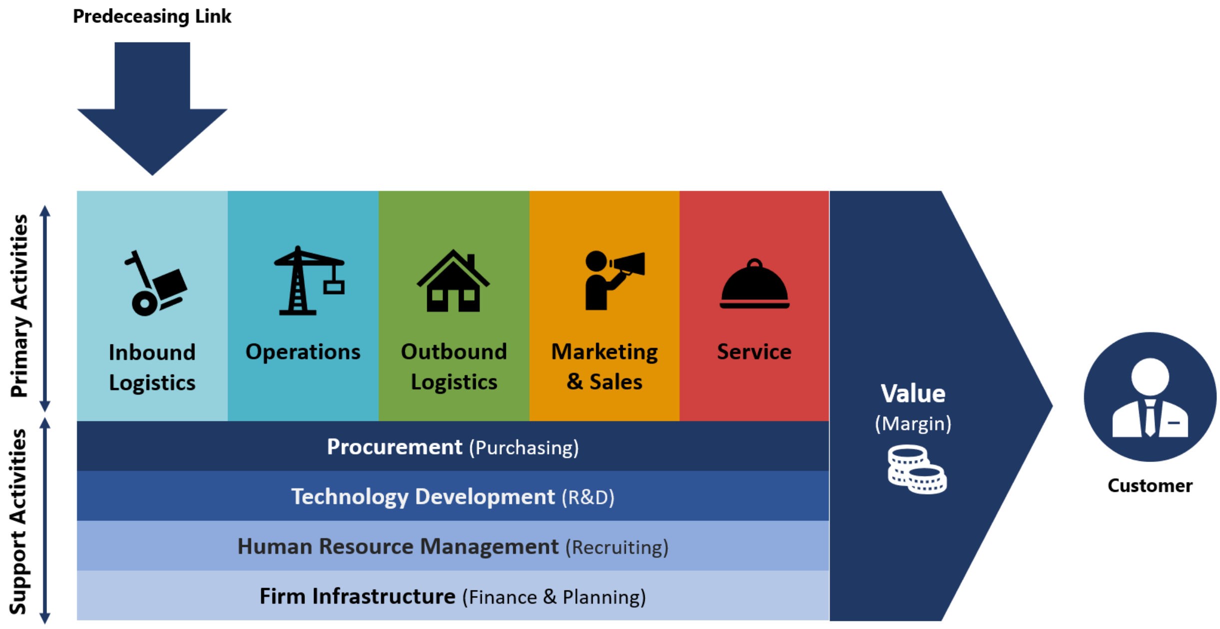

Figure 1 Interpretation of Porters Value Chain

Within the value chain a distinction is made between primary activities consisting of (1) inbound logistics (materials & prefabricated components), (2) operations (conversion of input into output), (3) outbound logistics (storage & movement of final product), (4) marketing & sales and (5) services. Furthermore, supporting activities which enable the execution of primary activities consist of (1) procurement, (2) technology development, (3) human resource management and (4) infrastructure (e.g. accounting & quality assurance). The profit margin which is attributable to the product/service which is provided to the market is embedded within the (perceived) value for which customers are paying (Porter, 2001; Holweg & Helo, 2014). The value chain system encompasses the linked value chains of all involved suppliers which enable the creation of a product (Vrijhoef & Koskela, 2000). Hence, the value chain views the addition of value to a product or service by each subsequent company, viewed from the perspective of the customer. In order to clarify the value chain and encompassed activities, a graphical representation is depicted in **Figure 1**.

2.1.1 SUPPLY CHAINS

A supply chain is defined by a network of all parties which commit resources (labor, material and assets) into the creation of goods or services. A supply chain starts at the initial moment of creation and lasts until final destruction or extinction of products or services (Behera et al, 2015). Supply chain networks can be defined according to their length and depth. The length of supply chains are determined by the number of tiers in a supply chain. Tiers can be defined as a group of varying parties which are bundled by an equivalent task or role, which they fulfil at a corresponding stage in the supply chain. Therefore, tiers can be related to certain roles within a supply chain (e.g. raw material miner, manufacturer, supplier, retailer or customer). As these tiers are linked to each other in a subsequent manner dependent upon their relative position in comparison to a focal company in the middle, tiers are defined as either supplier or customer. The rank of a tier is dependent upon their proximity in relation to the focal company. The depth of a supply chain is determined by the number of nodes which are present in a single tier (Hall, 2001; Larsson et al., 2014; Vrijhoef & Koskela, 2000)

Dependent upon the focal company (or system integrator), which is considered within a construction supply chain (e.g. main contractor) the supply chain consists of a large number of mainly supplier tiers. As constructions are composed of a high amount of varying materials and elements, and therefore require many different disciplines, the number of nodes within a construction supply chain are significant. In order to clarify the structure of a construction industry supply chain, the length of a generic construction supply chain is depicted in **Figure 2.** The depth of this supply chain is not depicted as this would be dependent upon the number of parties within each tier. Although parties have been exemplary described in each tier, these parties as well as their relations are interchangeable and can be present within each of the tiers. The focal point or system integrator in this example is considered to be the building project itself as this is where the first tiers of the customer and supplier side of the supply chain converge (Hall, 2001; Vrijhoef & Koskela, 2000; Segerstedt & Olofsson, 2010; Behera et al, 2015).

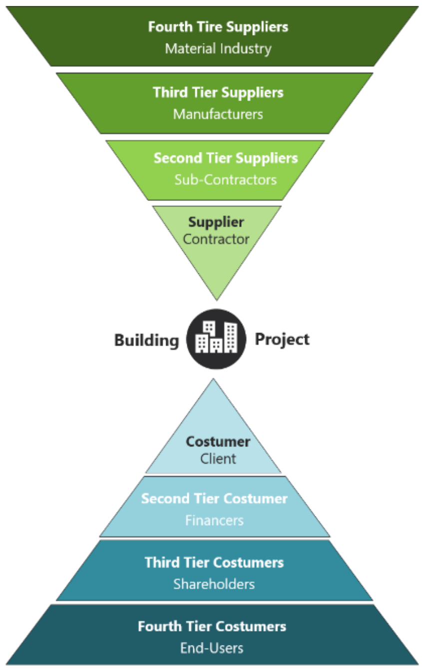

Figure 2 Construction Industry Supply Chain based on the work of (Segerstedt & Olofsson, 2010)

2.1.2 CONSTRUCTION & RENOVATION PHASES

Green field construction project consists of the following subsequent phases (1) concept/initiation, (2) definition/design. (3) preparation/execution, (4) turn-over/exploitation and (5) demolition/renovation. Usually a public or private organization/individual conceptualizes a construction project based on their needs and initiates a project. Based on the contract format, relations in the subsequent supply chain are arranged. Within traditional UAV 2012 contract formats, which are most common within the Dutch construction industry (Eitjes, 2017), the concept is defined and processed into a design through employment of consultants (e.g. architect & engineers). During the preparatory and execution phase, the construction works are outsourced (to a contractor). Furthermore, construction activities are prepared and finally executed. After execution of the construction works, the building is delivered to the commissioner, is operated and needs to be maintained. After operation by the original commissioner and/or other user has been ended, a structure is either renovated or demolished (Vrijhoef & Koskela, 2000; Segerstedt & Olofsson, 2010; Behera et al, 2015).

Renovation projects and thus the identified phases do not majorly differ from green field developments. However, a few distinctions can be made as renovations regard the retrofitting of existing structures. Renovation projects can differ based on the type of structure (e.g. multi-story or semi-detached house) and components (e.g. facades and/or bathrooms) which require renovation. The renovation process is initiated by a customer, after which properties of the existing structure and client requirements are merged in a design. After the design has been completed and permits have been granted, a (specialized) contractor is selected directly or by means of a tender procedure. Typically contractors or other consultants are already selected and involved during the design process as their expertise is required to establish the design. After successfully establishing a contract, a contractor enters the preparation or purchasing phase in which secondary and tertiary parties are selected to supply materials and/or conduct sub-contracting. The required specialties are often varying based on the nature of the existing structure encompassed in the project. During the fabrication stage required construction components are manufactured and pre-assembled. Finally, resources are converged on-site and the renovation is executed in the assembly phase. All described renovation phases are depicted in **Figure 3**. In order to clarify the parties participating in a renovation project, a description of these parties is provided hereafter for both the customer side, as well as the supply side.

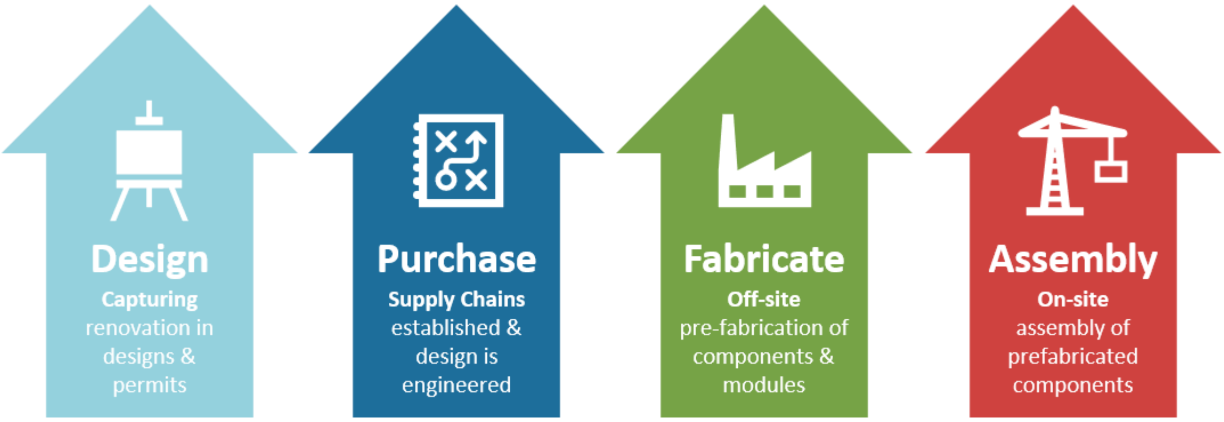

Figure 3 Renovation Project Phases

2.1.3 CUSTOMER SIDE

The client is considered to be the commissioning party of a construction project. The client initiates a project based on the needs of a group of end-users, society or other stakeholders. The client is optionally provided with resources from investors, shareholders and/or the government. All aforementioned groups are considered to be present at the customer side in the initial tiers of the supply chain. Clients progress the initiation of a project into a design through collaboration with hired consultants (e.g. architects, engineers etc.). Client and its consultants traditionally conduct monitoring activities to ensure that production is meeting pre-determined standards. In some instances the client does not only select a single main contractor, but can also contract a sub-contractor party directly (Lee et al., 2014; Segerstedt & Olofsson, 2010; Hughes, 1997; Hugh et al., 2000; Behera et al, 2015). Customers which are involved in renovation projects mostly consist of (1) housing cooperations , (2) private owners, (3) companies and (4) private investors/associations.

2.1.4 SUPPLY SIDE

The main contractor conducts the coordinating activities and is directly contracted by the customer. Therefore, the main contractor is present within the first tier on the supplying side of the construction chain. The remainder of the renovation supply side is established during the purchasing phase as main contractors often rely on external expertise (varying sub-contractor) and material suppliers (manufacturing parties). Sub-contractor are commissioned with parts of the renovation activities in accordance to their required expertise. Manufacturers are commissioned with the production of either raw materials, prefabricated or pre-assembled components during the fabrication stage. As these manufacturers also rely on the external provision of raw materials, indirect manufacturers are involved in renovations as well. Therefore, sub-contractors and direct manufacturers are attributed to the second tier, whereas indirect manufacturers are attributed to the third and four tiers of the supply chain. The main contractor traditionally coordinates the material and information flows of second tier suppliers during the fabrication and assembly phase. (Behera et al, 2015; Lee et al., 2014; Segerstedt & Olofsson, 2010; Hughes, 1997; Hughes et al., 2000).

2.2 COMPETITION & GROWTH STRATEGIES

Strategy can be defined as a set of actions taken by (top-level) managers in order to achieve a single or multiple organizational goals. Hence, strategy involves the composition of a general direction for a company and encompassed components to progress towards a desired future state. Therefore, strategy aims for the integration of organizational activities and allocation of a company's resources in order to achieve long-term objectives. A company's strategy results from a strategic planning process which incorporates various considerations such as (1) available resources, (2) competitor responses, (3) customer responses and (4) responses by suppliers and employees (Johnson et al., 2008; Wheelen et al., 2017).

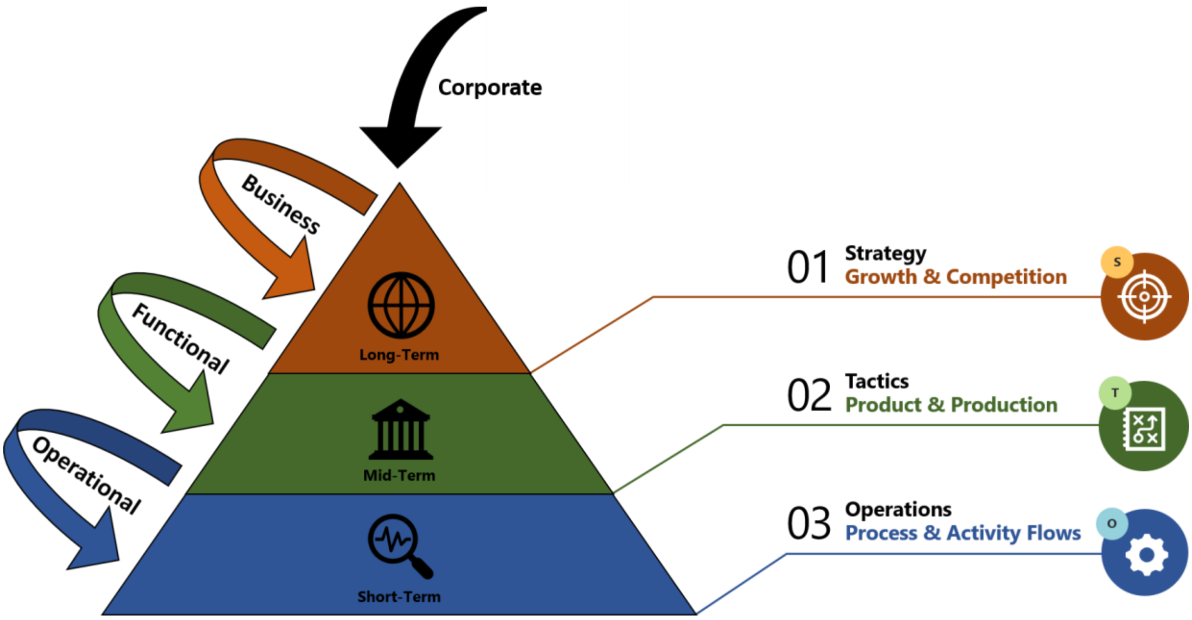

Figure 4 Strategy Levels & Hierarchy

Strategies are established on the three subsequent levels of (1) corporate strategy, (2) business strategy and (3) functional strategies. Corporate strategies consider the entirety of the company, business strategies regard specific product-market combinations and functional strategies relate to functional areas in a company (e.g. production). Tactical and operational goals/decisions aim to achieve middle-and-short-term goals which over time contribute to the achievement of strategic objectives (Wheelen et al., 2017; Steinmann et al., 2014; French, 2013). Therefore, strategy and attributed objectives can be viewed as the blueprint or roadmap. The hierarchical relationship between these decision levels is further clarified in **Figure 4**. As organizations operate on markets and due to the overall goal of organizations to generate profits in these markets to secure their existence, strategy has to regard competition as well as growth. Hence, a company's strategy is aligned or incorporates a competitive and growth strategies (Porter, 2001; Wheelen et al., 2017; Tan et al., 2012; Hussain et al., 2013). Both strategies are incorporated into the business strategy and influence functional strategies. Therefore, the determination of tactical/operational goals are dictated by business strategies as well (French, 2013; Steinmann et al., 2014).

2.2.1 GROWTH STRATEGY

In order to accumulate additional market share ensuring a company's profit and thus existence over time, growth strategies can be employed. Growth strategies can be employed in order to determine long-term corporate/business level strategic goals to which activities on a functional/tactical and operational level can be aligned. In order to capture four generic growth strategies which can be utilized, the Ansoff matrix was presented in 1957 within the publication: "Strategies for Diversification" (Ansoff, 1957). Since its publication, the Ansoff matrix has been the topic of research and debate within strategy-related academic research (Hussain et al., 2013; Abonda & Machuki, 2018). Within the Ansoff matrix the four distinct growth strategies of (1) market penetration, (2) market development, (3) product development and (4) diversification are defined as depicted in **Figure 5**.

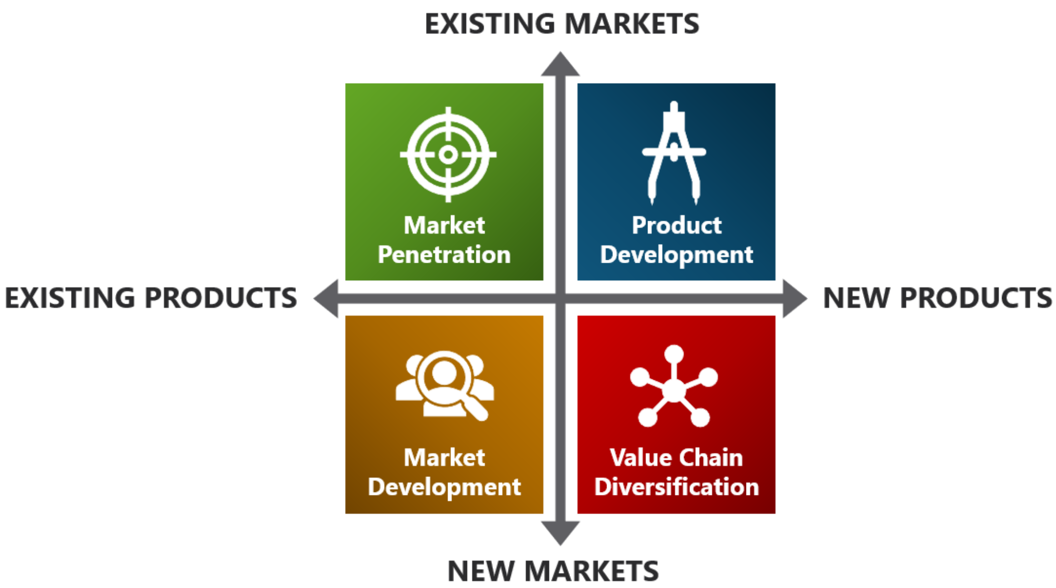

Figure 5 Growth Strategies adopted from: Ansoff, (1957)

Market penetration strategy involves companies which attempt to offer their existing products or services in markets on which they already operate. Market penetration is considered the strategy which involves the least risk and can be achieved by means of price reductions, product refinements, promotion or acquisition of rival companies operating in the same market. Market development strategies involve companies expanding into new geographical markets or market segments and is most successful when companies benefit from large output quantities and similarity to the markets it currently operates on. The product development strategy involves the expansion of offered products and services to markets on which companies already operate. A focus on product development, requires significant attention towards research & development or joint development with companies which incurs mutual benefits related to the distribution channel of each respective company. The risk which is attributed to the market and product development strategies is considered to be higher in comparison to market penetration, as these strategies either involve operations on new (unfamiliar) markets or the realization of new products/services with unproven attributes. The most risk-full strategy is considered to be the diversification as it involves the operation on new markets with new products. Hence, significant investments are required for the development of products/services on a market which is unfamiliar rendering results uncertain (Hussain et al., 2013; Abonda & Machuki, 2018; Dansoh, 2005; Kotler et al., 2016). The generic competitive strategies based on the work of Porter (1985) and the growth strategies presented in the Ansoff matrix, should be viewed as complementary to each other. This is mainly due to the inability of growth strategies to incorporate the dynamics involved with competitive reactions on markets (Wheelen et al., 2017; Steinmann et al., 2014).

2.2.2 COMPETITIVE STRATEGIES

In order to define the competitive strategies which are employed by companies operating within their chosen market scope, Porter (1997) defined three generic strategies which represent the manner in which companies pursue competitive advantages in their respective markets. These generic strategies consist of (1) cost leadership, (2) differentiation and (3) a focus strategy. Companies are able to capitalize on two types of competitive advantages which either aim to serve the focal market at a lower cost in comparison to competition or to differentiate their offer to the market along dimensions which are valued by customers (in terms of perceived cost/quality ratio). The second component, which is attributable to the competitive strategy, is the market scope on which a company focusses. Companies can either generically scope on specific segments of the markets (e.g. niches) or focus on multiple segments simultaneously (Johnson et al., 2008; Allen & Helms, 2006; Porter, 1997; Tansey et al., 2014; Akan et al., 2006). Strategic considerations regarding competitive advantage as well as the scope are both encompassed in the aforementioned generic strategies. These strategies are depicted in **Figure 6** and discussed hereafter.

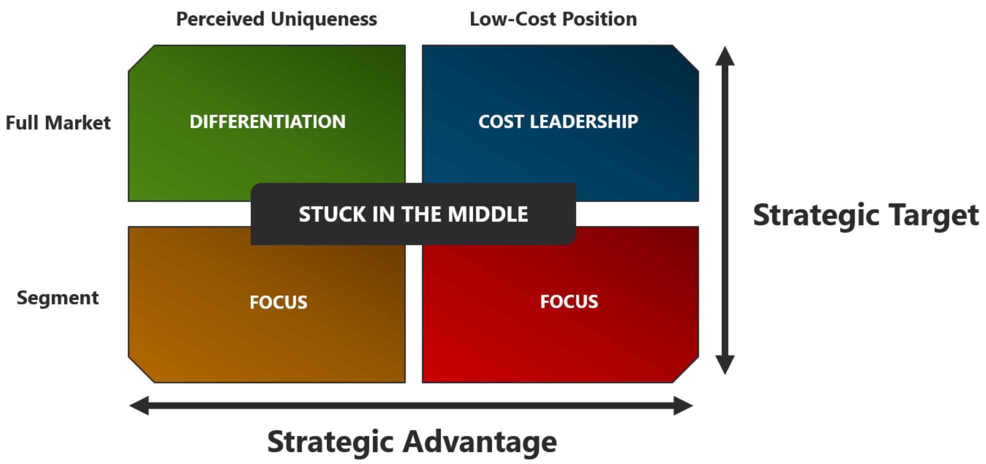

Figure 6 Porters Generic Strategies adopted from: Porter, (1997)

2.2.2.1 COST LEADERSHIP STRATEGY

The Cost Leadership Strategy (CLS) is utilized by companies which aim to obtain market share by means of targeting customers which are sensitive to low product or service prices. CLS can be pursued by means of offering products or services with the lowest price to perceived value ratio in comparison to competitors. In order to successfully adapt the CLS within companies while maintaining its ability to generate profits, three approaches can be utilized individually or simultaneously. These approaches consist of (1) increasing asset utilization, (2) reducing direct/indirect operating costs and (3) exercising control over the value chain (Porter, 1997; Tansey et al., 2014; Akan et al., 2006). To achieve high utilization of the resources and thus assets within a company or value chain, industrial production systems aim for the output of high volumes of products or services. High volumes are generated in order to effectively distribute a companies fixed costs over a large number of individual outputs. Thus, companies capitalize on the advantage of economies of scale as is the case within mass production strategies. Direct and indirect operation costs are effectively reduced within the CLS by means of increasing both the volume and degree of standardization of products. Standardization is achieved by means of limiting the customization options which are offered. Furthermore, the utilization of fewer and standardized components for the creation of a limited set of products combined with cost optimization/reduction programs ensure the reduction of production costs. In order to effectively increase asset utilization and to achieve cost reductions, control over the value chain is essential. In supply chains which rely heavily on procurement such as construction supply chains, competitive bidding and price-oriented negotiations are often used to decrease production costs. Vertical integration or supply chain integration, involves the expansion of activities of a down-stream company (e.g. contractors) into activities conducted by up-stream companies (manufacturers) to obtain and exercise control over the value chain (Porter, 1997; Tan et al., 2012; Abonda & Machuki, 2018; Tansey et al., 2014).

2.2.2.2 DIFFERENTIATION STRATEGY

The Differentiation Strategy (DS) is used by companies which aim to compete with other companies on the market by means of offering unique or different products or services. The utilization of a differentiation strategy is most appropriate when scoping on a highly competitive or saturated market in which customers are less sensitive to pricing strategies and tend towards suppliers which are able to fulfill specific needs by means of unique resources or capabilities in comparison to competitors. By means of the differentiation strategy, companies are able to increase the prices and revenues of their products and services and/or are able to attach customers to their company. However, the differentiation strategy only results in the accumulation of higher profits when the additional production costs incurred by providing unique products is overcompensated by the additional costs customers tend to accept based on the perceived value of the product compared to competitor products. Hence, the success of the application of the differentiation strategy depends on the perceived uniqueness of offered products, which is either dependent on physical or perceived uniqueness (e.g. brand). Therefore, the focus of companies which utilize the differentiation strategy is oriented towards providing products or services with higher perceived non-monetary properties such as superior quality or technology (Wright, 1987; Porter, 1997; Kale & Arditi, 2003; Allen & Helms, 2006; Akan et al., 2006; Tan et al., 2012).

2.2.2.3 FOCUS STRATEGY

The focus strategy is similar to the cost leadership and differentiation strategies as the focus within this strategy is either on providing products which are perceived as unique or on the reduction of costs for offered products. However, the focus strategy differs from the aforementioned strategies due to the focus in specific segments of the market. Therefore, the focus strategy enables companies to gain competitive advantages by means of satisfying the needs of specific groups of customers (niches). Examples of the focus strategy with an emphasis on uniqueness in the construction industry are contractors with a sole focus on the construction of villa's for wealthy customers. An example of a company which applies the focus strategy with an emphasis on costs or price is Pepsi (Wright, 1987; Porter, 1997; Akan et al., 2006).

2.2.2.4 HYBRID

In the past it was often argued that companies should aim for the pursuit of a single strategy to prevent "getting stuck in the middle" and risk the undercapitalization or waste of its resources. Combining cost leadership strategies involving cost minimization was expected to conflict with a product differentiation strategy involving adding (perceived) value (Wright, 1987; Porter, 1997). However, more recent research indicates that companies who adapt both of the aforementioned strategies as a single hybrid strategy are able to outperform companies which retain themselves to a single generic strategy. Companies which are able to utilize the hybrid strategy are able to either alternately or simultaneously reduce costs and add perceived value to products or services. The success which can be attributed to the adoption of the hybrid strategy can be related to flexibility which is required within current markets which are highly volatile. The existence and benefits of adapting a hybrid strategy in order to ensure agility and responsiveness towards turbulent markets was later recognized (Thornhill & White, 2007; Prajogo, 2007; Baroto et al., 2012). However, aspects attributed to each of the distinct generic strategies (e.g. lowering production costs and adding perceived value) should either balance or reinforce each other to obtain higher profits. Therefore, the effects that differentiation strategy decisions have on cost-related aspects in the production process itself, should be investigated on a tactical and operational level as well (Baroto, 2012; Pertusa-Ortega et al., 2009).

2.3 PRODUCT CUSTOMIZATION STRATEGY

Based on the established corporate and business level strategies, the production strategy can be regarded as the strategy which includes (1) which products should be realized (product strategy) and (2) how value chains should be configured in order to do so (value chain configuration). As products or services are rarely produced by individual companies, the production strategy transcends the sole consideration on a company level and should also be regarded on the supply chain level. The production strategy is also referred to as the process positioning strategy as it mainly views how production systems in a supply chain are organized to produce specific products with respect to market requirements. As the nature of a product and requirements related to targeted markets encompassed in business strategies dictates the configuration of production strategy, the product strategy should be considered first (Ivanov et al., 2019; Jonsson & Rudberg, 2014; Nahmens, 2007).

2.3.1 CUSTOMER DECOUPELING POINT (CDP)

In order to enable the discussion of the various product strategies and to relate them to renovation practices in the construction industry, generic manufacturing phases are combined with the Customer Decoupling Point (CDP). The CDP can be regarded as the point in the value chain (inter-firm or extra-firm) at which production activities are triggered by customer orders. All activities or phases which occur before the CDP are driven by forecasts. For activities which are based on forecasts, required materials can be stocked in order to ensure the production flow. Therefore, the CDP is alternatively referred to as the stock point. Hence, the production strategy essentially involves the tradeoff between market push (forecast based) and market pull (customer order based) which is determined by the position of the CDP or stock point with respect to production phases (Lampel & Mintzberg, 1996; Yang & Burns, 2003; Rudberg & Wilkner, 2004). The overall phases which have been regarded consist of (1) design, (2) fabrication, (3) assembly and (4) distribution. These generic phases closely align with the construction phases of (1) design, (2) purchasing, (3) off-site fabrication and (4) on-site assembly (Jonsson & Rudberg, 2014).

2.3.2 CUSTOMIZATION STRATEGIES

As the configuration of production systems and thus products is dependent on the CDP which is placed on the continuum between forecast-driven market push and order-driven market pull, a distinction can be made between standardization and customization respectively. The product customization strategies which are present on this continuum vary based on the degree to which customers can customize products and the phases in which they are involved. These strategies consist of (1) pure customization, (2) tailored customization, (3) customized standardization, (4) segmented standardization and (5) pure standardization (Lampel & Mintzberg, 1996; Jonsson & Rudberg, 2014; Haug et el., 2009; Nahmens, 2007). These varying product customization strategies and associated phases are depicted in **Figure 7**.

On the aforementioned continuum the strategy which allows for the highest degree of customer involvement (individualization) is pure customization. Within this strategy the products design is created in accordance to customer specifications. Therefore, the stages of design, fabrication and assembly are all required to allow for a large degree of customization. Examples of pure customization are widely recognizable in the construction industry where the composition of a supply chain and production activities are often driven by customized designs. Within tailored customization a prototype (e.g. a base design) is presented to potential customers and adapted (tailored) based on individual requirements. Therefore, tailored customization influences the fabrication process while the standard components of the prototype (design) are not customized. Within customized standardization both the design and (off-site) fabrication process are not customizable whereas (on-site) assembly is. As the assembly processes is customized based on standardized options, customized standardization is often referred to as modularization or configuration (Jonsson & Rudberg, 2014). As generic designs are standardized, individual customers on the target market are presented with configurations of a product constrained by the range of options offered by a supplier. An example of customized standardization is the selection of interior finishes and functional extensions when ordering a car (Lampel & Mintzberg, 1996; Cavusoglu et al., 2007; Brun & Zorzini, 2009; Jonsson & Rudberg, 2014; Nahmens, 2007)

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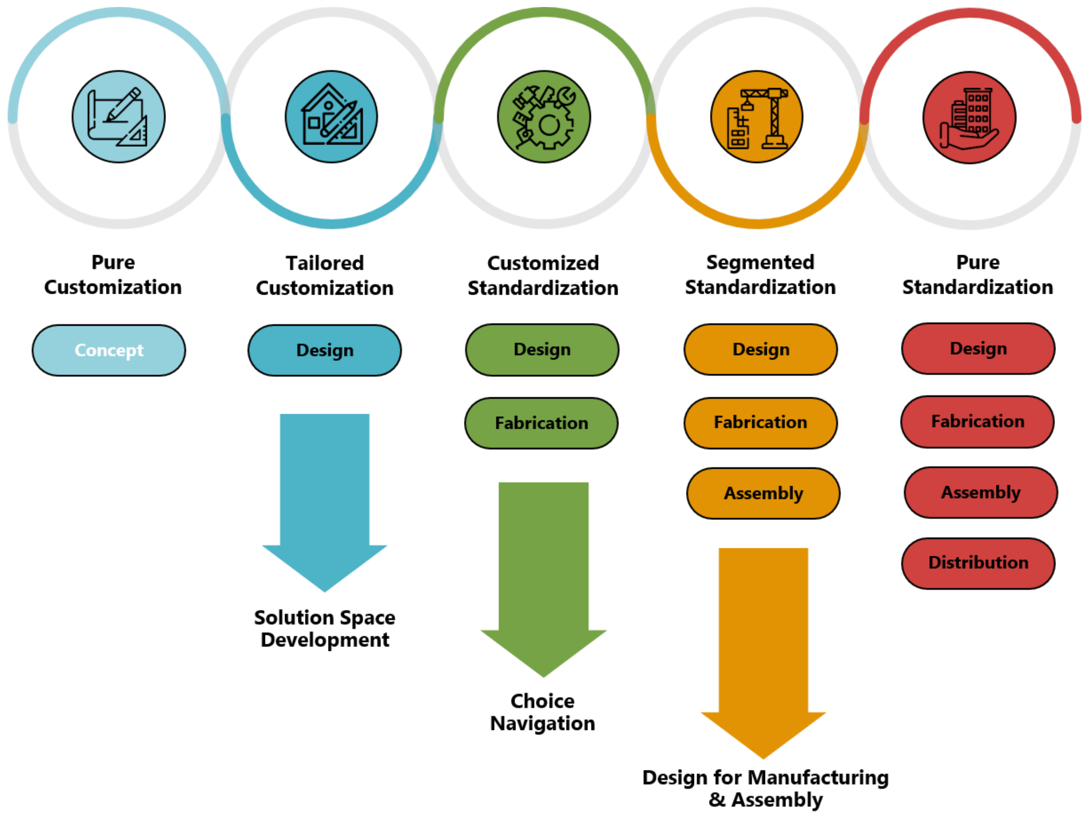


Figure 7 Product Customization Strategies adopted from: Lampel & Mintzberg, (1996)

Within the segmented standardization strategy, companies respond to the needs of clusters of customers by means of standardized offers including a restricted set of futures. Therefore, a standardized design is replicated and adapted to cover the requirements of aggregated sets of customer groups without allowing for the choices of individuals. Hence, customers are only enabled to exercise an indirect influence on the output of manufacturing and assembly processes while directly influencing the distribution of products by means of customization. Examples of segmented standardization are identifiable in the automotive industry where model types are distributed to shop floors based on customer demand. Pure standardization is on the extreme opposite of pure customization and effectively eliminates all customization options by customers. Within the pure standardization strategy the emphasis in on the creation of volumes, broadcasted to the largest potential group of customers. Companies which have incorporated the pure standardization strategy are organized to push products throughout the phases and are able to achieve significant price reductions through forecast-driven mass-production (Lampel & Mintzberg, 1996; Cavusoglu et al., 2007; Nahmens, 2007; Jonsson & Rudberg, 2014).

2.3.3 SOLUTION SPACE DEVELOPMENT

The goal of positioning products or services on a specific market is to achieve profit through sales by means of fulfilling the requirements and needs of customers. Within core customization strategies customer value is captured in a single product based on the needs of an individual customer whereas in purely standardized products the central tendencies of large groups of customers are captured in a single product. When progressing from pursuing a core customization strategy towards a pure standardization strategy, customization options for individuals and thus product flexibility is decreased. Therefore, the importance of aligning product properties or configurations to idiosyncratic customer needs becomes more apparent when standardizing product properties. In order to capture the idiosyncratic needs of groups of customers in a product or its configurations, insights are required into the attributes along which the requirements and needs of customer mostly diverge. The importance of obtaining insight into these attributes is captured in the term of Solution Space Development (SSD). The solution space can be defined as the configurations which are embedded in offered products on the market. Therefore, the solution space can be envisioned as a boundary which dictates what will be offered and what will not be offered (Piller, 2004; Salvador et al., 2009; Brunoe et al., 2012)

The importance of solution space scope can be emphasized as a narrow scope might incur lost sales due to misalignment with perceived customer value, whereas a too broad solution space might cause misalignment with requirements related to cost and delivery reliability. SSD is therefore considered to be one of the three essential capabilities companies need to possess in order to successfully achieve mass customization (Salvador et al., 2009). In order to encompass customization value in products, three distinct design dimensions can be identified consisting of (1) product fit, (2) product functionality and (3) product form (Salvador et al., 2009; Brunoe et al., 2012). When developing a solution space, heterogeneities along these aforementioned dimensions should be determined. The fit dimension involves the alignment of physical object dimensions to fit the proportions required by a customer. Fit is often indicated as the strongest component within mass customization while simultaneously the most difficult to achieve as it requires parametric designs and flexible product architectures (Salvador et al., 2009; Di Giuda et al., 2019; Cao & Hall, 2020). The functionality dimension involves the alignment of technical product attributes (e.g. upgradability or insulation value) to customer requirements. Finally the dimension of form regards modifications of a products outer appearance aiming at visual senses (e.g. colors & styles). Customization capabilities related to form are easily embeddable in manufacturing processes (e.g. by means of printing technology).

To enable companies developing a solution space to identify idiosyncratic customer needs, research conducted by Salvador et al., (2009) resulted in the identification of three distinct approaches in order to do so. These approaches consist of (1) innovation toolkits, (2) virtual concept testing and (3) customer experience intelligence. The application of innovation toolkits encompasses the deployment of software applications which enable large samples of customers to translate their preferences into unique product variants. Virtual concept testing considers the distribution and evaluation of prototypes based upon the submission of scores by prospective customers. Customer experience intelligence involves the analysis of past customer transactions and behavior to identify preferences. Brunoe et al. (2012) elaborated on these approaches by identifying measures to assess the solution space attributed to existing products. These measures consist of (1) profitability, (2) utilization, (3) variety demand satisfaction, (4) architecture and (5) responsiveness (Salvador et al., 2009; Brunoe et al., 2012).

2.3.4 CHOICE NAVIGATION

Whereas solution space development aims for the identification and capturing of customer needs within products and the offered assortment, the capability to support customers with selecting the most appropriate solution for their problems is essential to successfully demonstrate perceived value by aligning required and offered value. This ability is captured in the term of Choice Navigation (CN) and is considered to be the second of three core capabilities for mass customization. CN involves the reduction of the complexity and difficulty of choices associated with the alignment of identified customer problems and solutions within the offered assortment. The importance of CN is justified by the phenomenon of the “paradox of choices” and is signified by customers which are presented with a vast solution space without assistance. Within these circumstances, the perceived effort of solution space evaluation prevails over the utility attributed to the number of offered options. Therefore, demonstration of the paradox of choices can result in a reduction of perceived value attributed to solution space size instead of increasing it (Salvador et al., 2009; Nielsen, Brunoe & Storbjerg, 2013).

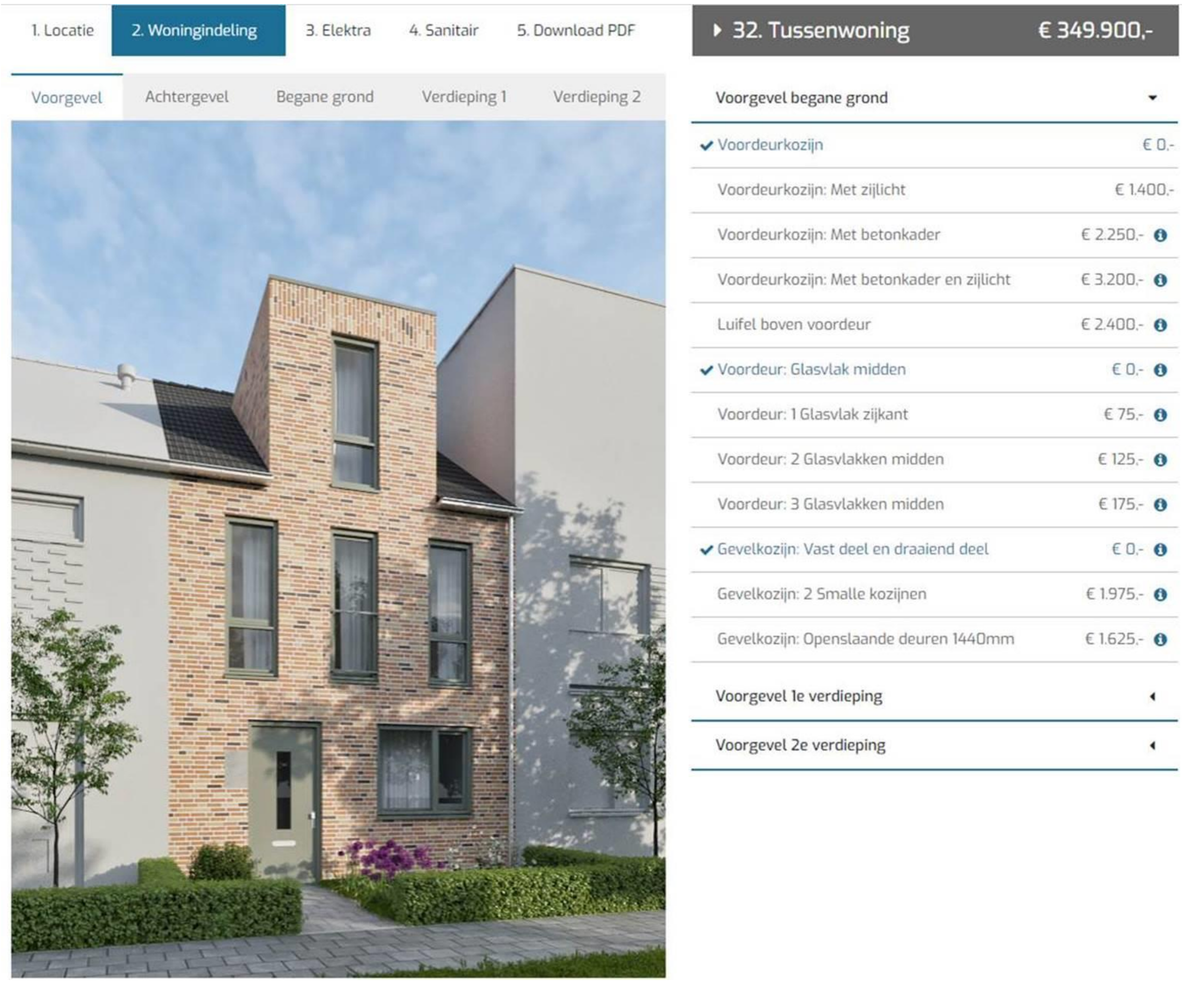


Figure 8 VolkerWessels Plus Wonen Configurator

Three identified approaches which aid in developing choice navigation capabilities consist of (1) assortment matching, (2) fast-cycle trail-and-error learning and (3) embedded configurations: Salvador et al., 2009). Assortment matching regards the automated generation of recommended configurations to evaluate, based on a match between the solution space model and customer requirements model. Therefore, a customer is presented with a set of configurations which fits their requirement model reducing the perceived effort of evaluation. Fast-cycle trail-and-error learning is complementary to assortment matching and enables customers to interactively construct models based on their individual needs. Hence, it allows customers to test matches between their individual models and available options (e.g. product configurators). An example of a product configurator deployed by the VolkerWessels[4] is depicted in **Figure 8**. Embedded configurations are embedded in standardized products and enable certain (functional) customizations to be executed by customers themselves after a product has been purchased (Salvador et al., 2009; Nielsen, Brunoe & Storbjerg, 2013). An example of a product with embedded configurations can be a façade component in which customers can change the pattern post-installation by means of an application.

2.3.5 DESIGN FOR MANUFACTURING & ASSEMBLY (DFMA)

When the reduction of time-to-market and cumulative production costs are prioritized over product diversification during design and development, Design for Manufacturing and Assembly (DFMA) is often indicated as an appropriate engineering methodology. Within DFMA the focus is on reducing the complexity of manufacturing and assembly processes by means of capturing DFMA principles in a product design. DFMA is a hybrid methodology which is composed of (1) Design for Manufacturing (DFM) and (2) Design for Assembly (DFA). DFM involves the reduction of time and costs associated with the production of components whereas DFA focusses on a reduction of time and costs attributed to assembly of manufactured components. DFMA originated in the publication "Product Design for Manufacture and Assembly" by Boothroyd (1994). Early adopters of the DFMA engineering methodology are recognizable in the automotive industry which aimed to efficiently produce large numbers of products without compromising quality. In the construction industry, DFMA is utilized in off-site manufacturing plants where ease of manufacturing and assembly is embedded in the product design of prefabricated components (e.g. floors). Advantages which are often attributed to the application of DFMA include (1) increased construction speed, (2) lower construction costs, (3) increased reliability and (4) more efficiency. As a consequence, product flexibility is reduced (Boothroyd, 1994; Bayoumi, 2000; Kremer, 2018; Lu et al., 2020).

Examples of an inexhaustible selection of principles utilized in DFMA consist of (1) minimization of parts, (2) standardization of parts/materials, (3) creation of modular assemblies, (4) designing for efficient joining, (5) minimizing product reorientations and (6) reducing the number of operations (Bayoumi, 2000; Lu et al., 2020). Considering these principles within the built environment, a distinction should be made between off-site manufacturing and on-site assembly as they are separated. The balance between manufacturing and assembly can be reflected in four distinct systems. Gibb (2001) proposed a distinction between (1) component manufacturing & sub-assembly, (2) non-volumetric pre-assembly, (3) volumetric pre-assembly and (4) modular building. Non-volumetric assemblies (e.g. façade elements) differ from volumetric assemblies (e.g. bathroom units) as they do not encompass usable space. In turn, modular buildings are fully composed of pre-assembled volumetric units. When the aforementioned systems are considered as a balance between off-site and on-site production intensity, it should be noted that manageability in off-site production facilities is higher compared to on-site production. Therefore, a shift towards more off-site production and less on-site (assembly) activities is often proposed (Gibb, 2001; Bayoumi, 2000).

2.4 VALUE CHAIN CONFIGURATION

Considering the identified construction phases, the CDP or stock point can be placed at multiple stages. The position of the stock point indicates the balance between forecast driven market push (what companies push to the market) and demand driven market pull (what customers purchase on

[4] https://www.pluswonen.nl/

a market). Furthermore, the position of the CDP directly dictates what companies are able to stock and indirectly influence the degree of customization provided to the customer. Based on the relative position of the CDP, the phases in which the customer is able to exercise influence on the output of a production system is established. These phases consist of (1) design, (2) purchase, (3) fabrication, (4) assembly and (5) distribution (Yang & Burns, 2003; Rudberg & Wilkner, 2004). Based on the position of the CDP, various production strategies can be pursued. These strategies or configurations consist of (1) engineer to order (ETO), (2) buy to order (BTO), (3) make to order (MTO), (4) assemble to order (ATO) and (5) make to forecast (MTF). Based on the pursued production system the customer is allowed to (1) purchase a unique design, (2) configure a unique product based on an existing design, (3) configure a standard design from a large range of options, (4) configure a standard design from a limited range of options or (5) take the product as-is (Gosling et al., 2017; Ivanov et al., 2019). The various production strategies, attributable CDP positions and thus balance between market push and pull are depicted in **Figure 9**.

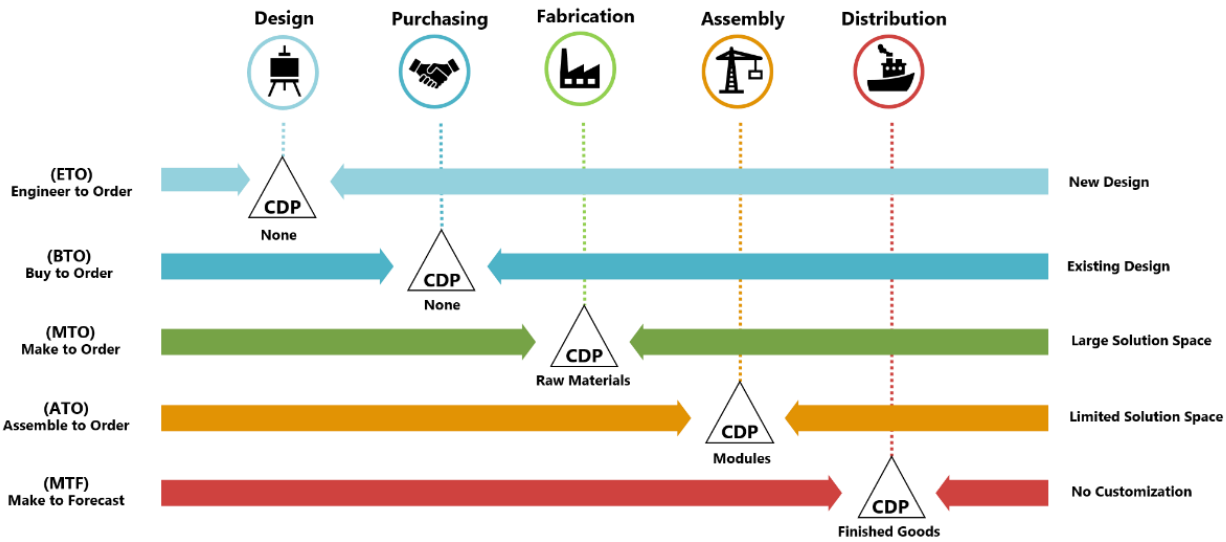


Figure 9 Value Chain Configurations based on the work of: Gosling et al., (2017)

2.4.1 ENGINEER TO ORDER (ETO)

Companies which utilize the so-called “concept to order” and “design to order” production strategies, aim for the production of unique products based on the requirements of individual customers. Both aforementioned strategies are driven purely by market pull based on customer orders. As the properties of products realized by means of these systems are unknown before customer requirements have been acquired and processed into a design, the realization of stocks is impeded significantly. This is mainly due to absence of fixed collaborations in supply chains as the supply chain is typically established after a design had been created to fit the order which has been received. Due to the creation of unique end-products the concept-to-order and design-to-order strategies are more commonly referred to as Engineer to Order (ETO) strategies. Due to the customers’ ability to determine **what** is produced by influencing the core properties of a design, purchasing (selection of suppliers), manufacturing specifications and assembly processes are influenced as well. Hence, ETO products can be most appropriately attributed to core customization product strategies. Within production systems which are designed to produce in accordance to this customization strategy, very low quantities (one or a couple) of a large variety of products are created. The variety of final products which can be created due to the allowed level of customization results in virtually limitless flexibility. Due to a low forecasting accuracy which is caused by the uniqueness of products and thus uniqueness of the production system, the variability of costs, lead times and quality associated with products created by means of an ETO production system can be considered extremely high (Haug & Edwards, 2009; Winch, 2003; Gosling et al., 2017; Ivanov et al., 2019). The ETO production systems has been widely applied in the construction industry where companies realize a large diversity of products (e.g. schools, houses & bridges) based on unique designs.

2.4.2 BUY TO ORDER (BTO)

The buy to order production strategy relates to products which are based on an existing design which is tailored to fit individual customer requirements. Products attributed to the BTO production strategy are based on a base design encompassing materials/components provided by various fixed suppliers. After significant design-reworks have been conducted to tailor a design to fit individual customer requirements, the selection from a set of fixed suppliers which should be involved in subsequent phases and the quantities of required materials are determined. Hence, the customer is able to influence **where** components are ordered within the boundaries created in the base design. Therefore, the CDP within BTO strategies is placed in the purchasing phase as customers do not influence supplier procurement. The retainment of stocks for products which are created by means of a BTO strategy are impeded by the allowed degree of freedom in design modifications. Within BTO production systems a large variety of products (dependent on the base design) are created in low volumes. Therefore, products created by means of the BTO production strategy corresponds to the tailored customization strategy. As the possible variety of final products which can be created is restricted by the offered options in a base design, flexibility is lower in comparison to ETO-based products. Forecasting accuracy and thus the variability of costs, lead limes and quality are high but can be considered to be lower when compared to ETO-based products as supplier procurement has been typically completed (Winch, 2003; Gosling et al., 2017; Ivanov et al., 2019).

2.4.3 MAKE TO ORDER (MTO)

Companies and value chains which are based on a make to order production system decouple the customer during the fabrication phase. Therefore, a design with fixed core components which are not customizable by customers is pushed to market. Products produced by means of the MTO strategy are fabricated after a customer order has been received. Therefore, the MTO strategy can be classified as a pull-based system. Although customers are not able to influence the core aspects of the design and thus design/purchasing phases, the customer is enabled to customize the end-products based on a large variety of options which are offered within a developed solution space. Therefore, customers are not able to influence where components are purchased, but are able to determine **which** components are fabricated with respect to the provided solution space. As the options are constrained by the developed solution space, value chains utilizing the MTO strategy are able to stock raw materials. The stocking of raw materials instead of semi-finished products renders the MTO strategy appropriate for industries which offer configurable products and in which the costs associated with stocking are significant (e.g. aircraft industry). Due to a restriction of options within the developed solution space, the most appropriate customization strategy which is attributable to an MTO-based production system is customized standardization. Application of the MTO strategy enables the realization of many products in medium volumes with moderate-high variability in costs, lead limes and quality (Winch, 2003; Gosling et al., 2017; Ivanov et al., 2019).

2.4.4 ASSEMBLE TO ORDER (ATO)

The assemble to order production strategy can be regarded as similar to the make to order strategy as it can be classified as a pull-based system. Within the ATO strategy customers are decoupled in the assembly phase instead of the fabrication phase, implying that they are able to exercise influence on the assembly (configuration) of modules from pre-fabricated components in the fabrication phase. Therefore, ATO is alternately referred to as configure to order or modular assembly. In an ATO-based production system pre-fabricated components or pre-configured modules are stocked and assembled into a final product after a customer order has been received. Due to the establishment of the CDP in the assembly phase, a customer is not able to influence which components or modules are fabricated but is able to determine the configuration of modules in a final product (Gosling et al., 2017; Ivanov et al., 2019).

Similar products which are created by means of an MTO system, the options for final product configurations are constrained by the provided solution space. Due to a dependency of the provided solution space on modules which are bought or stocked, the size of the provided solution space and thus flexibility of end-product configurations are smaller compared to MTO-based products. ATO production systems aim for the realization of a small number of products in high volumes (Gibb 2001; Ivanov et al., 2019). As the forecasting accuracy in ATO systems is higher and the variety of products/processes is lower, moderate variability in costs, lead limes and quality can be achieved (Gosling et al., 2017). Therefore, the most appropriate product customization strategies attributable to ATO production systems are customized standardization or segmented standardization depending on the size of the provided solution space.

2.4.5 MAKE TO FORECAST (MASS-PRODUCTION)

Companies which pursue a make to forecast (MTF) production strategy retain stocks of finished products either centrally (make to stock) or locally (ship to stock) dependent on their market. As the customer is decoupled at distribution and thus does not influence the design, purchase, fabrication and assembly, MTF is a purely forecast-based production system driven by market push. Customers are able to indirectly influence distribution, as forecasts are based on the demand requirements of clusters of customers on local markets. Therefore, products which are realized by means of an MTF production system are typically not customizable by individuals but can be customized based on forecasted requirements of aggregated markets (e.g. color of the product). As products which are created by means of MTF systems are cosmetically customizable at the most, the related product customization strategies are segmented standardization and pure standardization. As MTF systems aim for the production of several or a single product in high volumes, the variety of products, processes and flexibility are reduced to a minimum. As products and processes are fully standardized, attributed costs, lead times and quality rarely vary (Lampel & Mintzberg, 1996; Ivanov et al., 2019).

2.5 PRODUCTION SYSTEM

A production system can be defined as: "*any of the methods used in industry to create goods and services from various resources*" (Tanenbaum & Holstein, 2020; Ohno, 1988). Within the aforementioned definition of production systems, a clear distinction can be made between inputted resources, executed throughput processes and generated output goods or services as depicted in **Figure 10**. Hence, when considering a production system on the abstract level of a conducted process, production systems can be defined as transformation processes which consume or utilize resources in order to convert them into usable goods or services which are offered to internal or external customers (Meerkov, 2008). Resources which can be considered as the input for processes or production systems typically consist of (1) resources, (2) raw materials/parts and (3) demand information. The outputs of a production system typically consist of (1) intermediate/finished products and (2) defective products (error states).

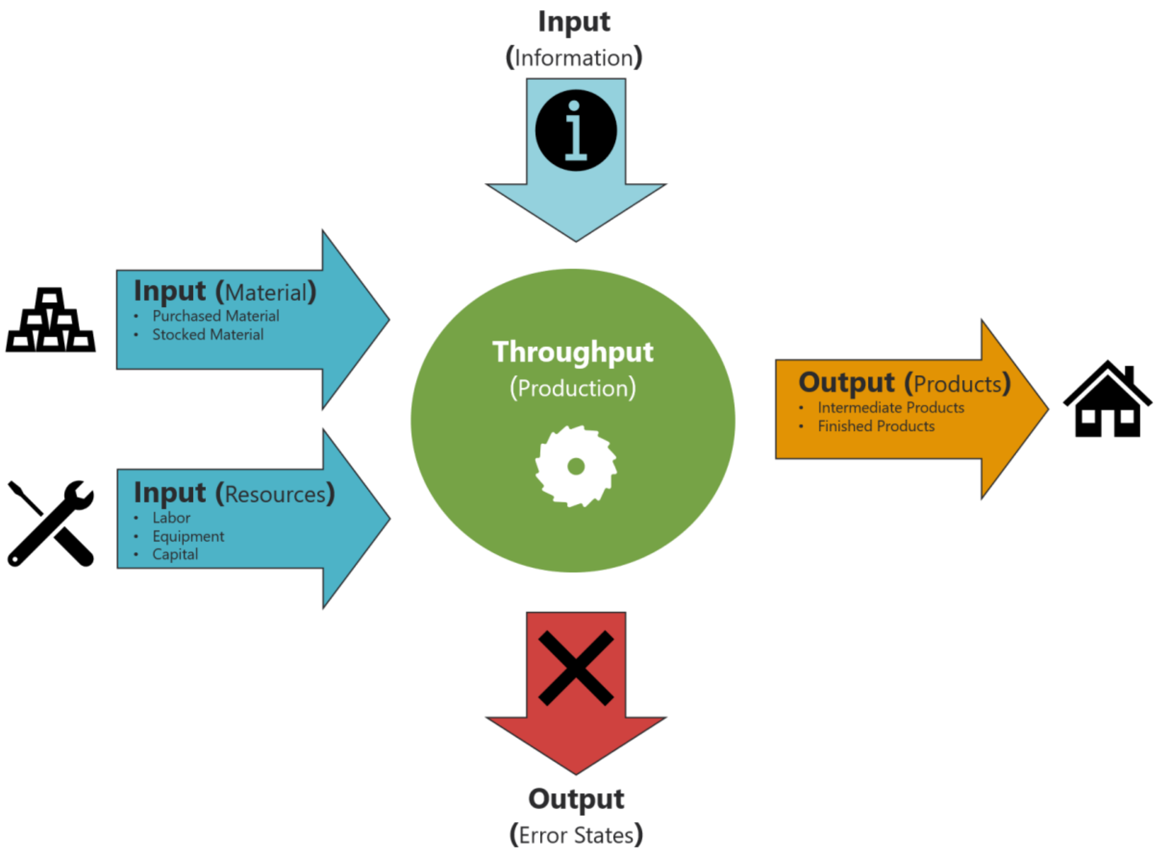
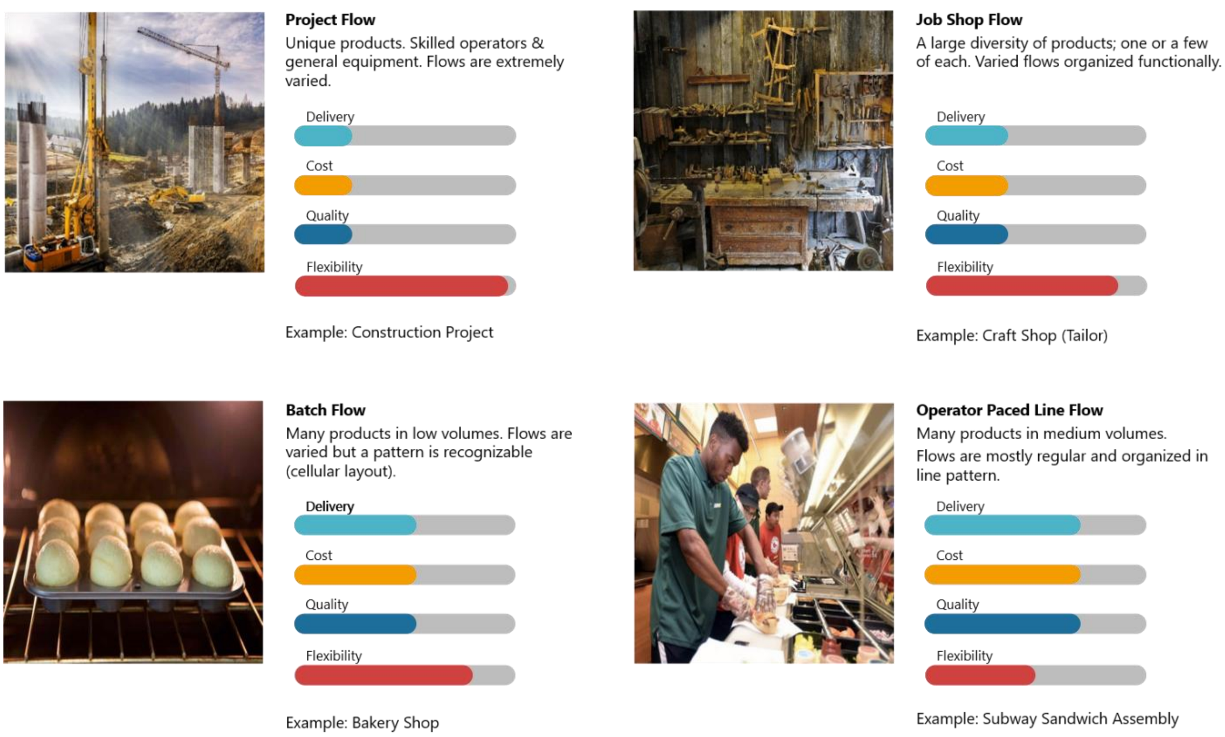


Figure 10 Depiction of a production system

The resources which are consumed by a production system can be further specified by (1) labour, (2) capital (machinery & materials), (3) space (e.g. land & production facility) and (4) required information for production. In the field of economy these input resources are defined as the factors of production whereas in industry these production factors are often specified into (1) men, (2) machinery, (3) materials, (4) methods and (5) money. In the construction industry inputted resources or factors of production are for example recognizable in the so-called bill of quantities. This bill is created and utilized during tendering procedures and contains an itemized description of (1) materials, (2) labour hours, (3) machinery and (4) sub-contracting. The direct costs associated with a component included on the bill of quantity is embedded into these factors. Indirect overhead costs are included separately. Hence, the production factors which are clearly established in economics are identifiable in transformation processes and thus production systems in the built environment.

2.6 PRODUCTION FLOWS

When considering the production system as a transformation process, flows within the system or process are categorizable between (1) physical (material) flows and (2) information flows. The physical flows regard the channel, movement and direction of inputted materials/resources, materials/resources contained in the (intermediate) manufacturing (throughput) stages of a process (work in progress) and (3) finalized outputted (intermediate) products. The information flows are often embedded in information systems and are required for the execution of the transition process by means of its physical flows. Hence, the direction of information flows is often opposite to the direction of material flows (Kaipia, 2009; Miltenburg, 2005; Ballard, 2005). As products are rarely created by means of a single (transformation) process in a value chain, physical material flows span multiple transformative activities in multiple companies linked in a supply chain. Therefore, financial flows (payments) in inter-company transactions flow in the opposite direction of material flows as well. With regard to material flows in production systems, the organization of production facilities and encompassed throughput activities depends on the adopted value chain configuration (**Section 2.4**). The organization of processes or flows in production systems can be classified as (1) project, (2) job shop, (3) batch, (4) operator paced line, (5) equipment paced line and (6) continuous. Each type of system differs based on (1) the variety of offered products, (2) yieldable production volumes, (3) process flexibility, (4) speed/reliability of delivery, (5) height/reliability of costs and (6) product quality (Miltenburg, 2005; Jonsson & Rudberg, 2014; Slack & Lewis 2014; Leong et al. 1990). The varying types of processes, attributable properties and examples are depicted in **Figure 11**.



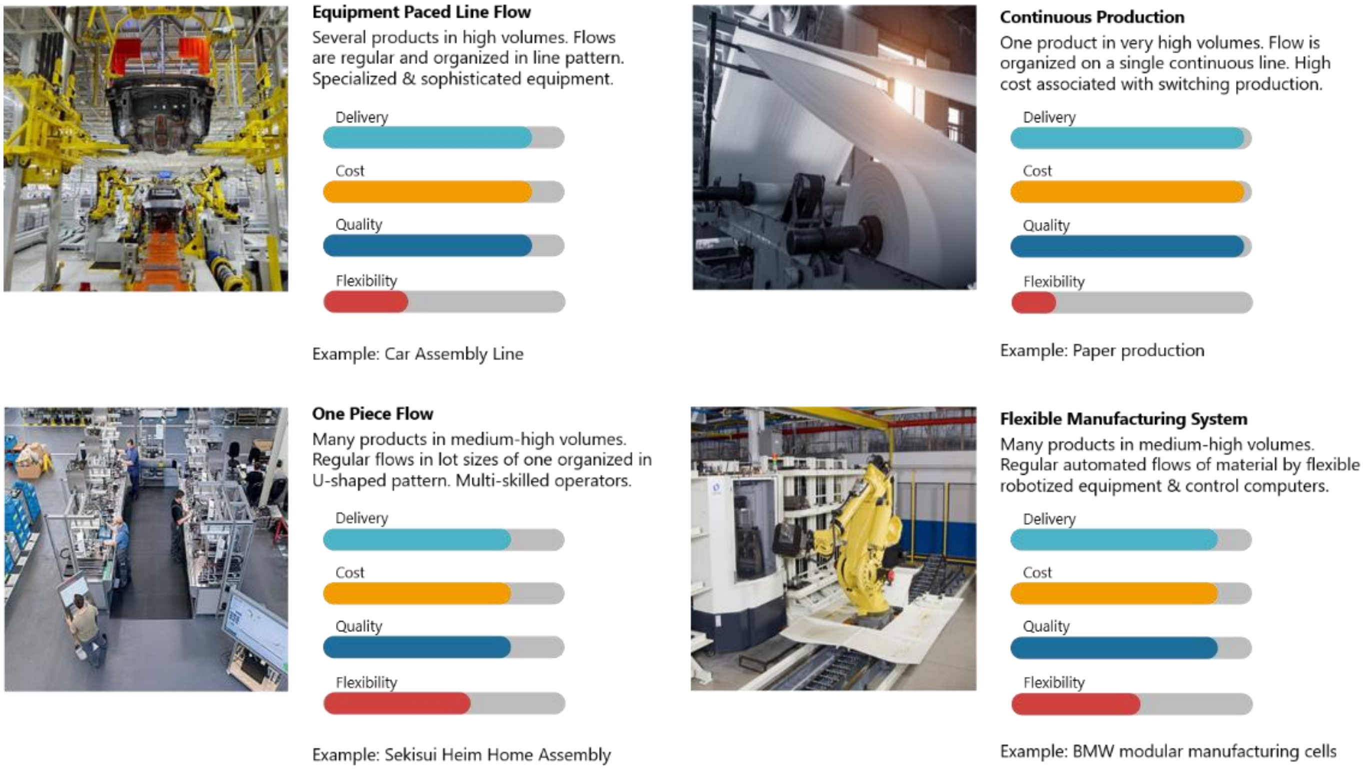


Figure 11 Types of production and attributed properties based on the work of Miltenburg, (2005).

2.6.1 PROJECT FLOW

Project-based systems allow for the creation of low volumes of a large variety of unique products based on individual customer requirements. Projects allow for a high degree of flexibility and are thus suitable for products with a high degree of complexity and expertise. The variety of products which are created by means of the project system, cause variances in process flows and required resources as well. Based on a project's complexity, resources are often converged on a temporary basis to realize a project within a pre-determined time-frame. These variances cause the accuracy and thus reliability of estimations regarding speed, costs and quality attributed to outputted products to be reduced significantly (Miltenburg, 2005; Jonsson & Rudberg, 2014; Slack & Lewis 2014). Examples of the application of project-based systems are recognizable in the construction industry where specific and specialistic projects (e.g. airports or dams) are created. Due to the variety and flexibility associated with created products, the customization strategy attributed to project-based systems is core customization. Establishment of a supply chain based on a unique design relates project-based systems with an ETO production system configuration.

2.6.2 JOB SHOP FLOW

The job shop system is similar to the project-based system in terms that it enables companies to create a large variety of products in relatively low volumes. In job shop systems resources are often converged at a specific manufacturing location with a functional layout, containing general purpose equipment. Due to the variety of created products and related processes, flows within a job shop are varied, irregular and often lack a specific pattern. Parts are moved between workstations based on specific operations which are required to be conducted on the product. Due to the variety and uniqueness of products, the required skill level of operators in order to conduct varying processes is significant. As job shop flows allow for relatively easy product adaptations, the flexibility attributed to the job shop system is similar to project-based systems constrained by the size and encompassed equipment in a production facility. As a consequence, the job shop system enables the execution of (partially) unique creation processes which significantly decreases the reliability of delivery speed, cost estimations and quality (Miltenburg, 2005; Jonsson & Rudberg, 2014; Slack & Lewis 2014). Examples of the application of job shop systems are recognizable in craft shops or garages in which individual products (e.g. clothing or cars) are being fabricated. Job shop systems therefore align with core customization, tailored customization and ETO/BTO strategies.

2.6.3 BATCH FLOW

In batch systems, higher volumes of specific sets of repeated orders are manufactured in comparison to project-based and job shop systems. Batch flow systems are similar to job shop systems with regards to their execution in production facilities containing mostly general purpose equipment. However, batch flows differ from job shop systems with regard to the randomness of required operations on products as a (cellular) pattern is recognizable. A pattern is recognizable as multiple products or orders can be merged based upon a shared set of characteristics and thus requiring similar operations. Due to the presence of a pattern, the repetition of specific operations within a batch flow system are higher. Therefore, more specialized equipment is present and the variety of required skills in order to conduct operations with this equipment can be lower in comparison to job shop systems (Miltenburg, 2005; Miltenburg, 2008; Ballard, 2005).

Due to the flow of batched products through specific common operations, the flexibility within the system is constrained by the capabilities and capacity attributed to the corresponding workstations. Therefore, large quantities of work in progress (WIP) are often recognizable within these type of systems. Large quantities of WIP caused by specific workstations or operations are attributable to so-called bottlenecks in the process and are characterized by an accumulating stock of intermediate products. Products which are manufactured in a batch system might include a combination of product-specific and batched operations. Therefore, the delivery speed, costs and quality associated with products manufactured in a batch system can vary per batch (Miltenburg, 2005; Jonsson & Rudberg, 2014; Swamidass & Darlow, 2000). Examples of the application of batch system are recognizable in bakeries and chemical plants in which a batch of products (e.g. loafs of bread) move through common operations (oven process). Customization strategies which correspond with batch-based products vary between core customization and customized standardization whereas the most appropriate system configurations can be considered to be BTO/MTO.

2.6.4 LINE FLOWS

Line flow systems can be divided into two distinct categories based upon the factor which determines the processing pace or flow of products in a production line. Line flow systems therefore consist of (1) operator paced line flows and (2) equipment paced line flows. In contrast to batch flows, products within a line flow system are moved between a fixed set and sequence of operations encompassed within a production line. As the sequence of operations through which products flow is fixed, the flows within both of the aforementioned systems rarely varies and are mostly regular. As the operations within a line are fixed, line-based production systems enable the production of a specific set of products in high volumes. Furthermore, homogeneity of operations within line-based systems requires the deployment of more specialized equipment and thus operators. Therefore, the initial capital investments associated with setting-up or switching to a line-based system are high. Because committed line-based systems include specialized equipment to produce a confined set of products, product flexibility is significantly decreased (Swamidass & Darlow, 2000; Miltenburg, 2005).

The flexibility of product adaptations in line-based production systems is low as switching between the production of various products incurs delays and additional costs. However, producing similar products within a line-based system significantly reduces lead-times, costs and increases the reliability of provided quality. Similar to batch systems, a line-based system is constrained by the capabilities and capacity attributed to weakest workstation (bottleneck) in a line, characterized by accumulated WIP. Flows in line-based systems are extremely suitable for process optimizations and automations due to its standardized product and process aspects (Miltenburg, 2005; Jonsson & Rudberg, 2014; Slack & Lewis 2014; Swamidass & Darlow, 2000). A operator paced line flow can be exemplified as the process in which a Subway sandwich is created. Operators organized in a line subsequently add value to the sandwich. Two examples of an equipment paced line flow are recognizable in the automotive industry and food packing industry. In the first example car parts are moved through workstations by means of overhead conveyor belts on which specialized robots perform operations. In the latter example, food trays are moved and filled on a conveyor belt by specialized operators before they are vacuumed by a specific machine. Customization strategies which correspond with line-based products vary between customized standardization and pure standardization whereas the most appropriate system configurations range between MTO and MTF.

2.6.5 CONTINUOUS FLOW

In continuous production systems, material flows are organized to pass a single or multiple products through a set of fixed operations by means of an uninterrupted continuous flow. The continuous production system is typically deployed to efficiently achieve large output quantities by means of product-specific equipment/methods to achieve short lead times and low production costs. The continuous system is alternatively referred to as an assembly system and is recognizable in industries which aim for mass-production. Production systems which aim for continuous flows are fully automated and do not encompass flexibility of produced products and executed processes. As the products, executed processes and incorporated equipment are fully standardized, costs, lead times and provided quality remain constant. Examples of continuous production are recognizable in the production of paper or float glass. Pure standardization and MTF are the most suitable customization and configuration strategies respectively (Slack & Lewis 2014; Swamidass & Darlow, 2000; Miltenburg, 2005).

2.6.6 JUST IN TIME & ONE PIECE FLOW

An alternative to the previously discussed flow systems is identified within management and production techniques such as the Toyota Production System (TSP). TSP is often used as a synonym of LEAN manufacturing, Just-in-Time (JIT) manufacturing or Kanban. However, LEAN manufacturing is but a part of the entire LEAN philosophy which was produced based upon TSP. Furthermore, JIT manufacturing is a part of LEAN manufacturing encompassing various production techniques and tools whereas Kanban is a substitute of JIT manufacturing dealing with balancing demand with available capacity (Womack et al., 2007). Kanban and the characterizing Kanban board have been increasingly used within the construction industry to manage internal demand between contractors. JIT deliveries have been applied to manage the delivery of prefabricated components on construction sites with limited storage space and thus, to reduce stocks. Application of both techniques have unlocked previously hidden efficiency and capabilities within the construction process (Pheng & Shang, 2011; Gao & Low, 2014). Successful application of one-piece flows and JIT replenishment in the construction industry was identified at the Japanese company Sekisui Heim. Sekisui produces various customizable modules in lot sizes of one (one module per time) on U-shaped production lines. Operators within these lines are multiskilled, receive sub-assemblies JIT and are responsible for the production of the entire module in accordance to the cycle time (Barlow et al., 2004). Regardless of the aforementioned example, Kanban and JIT replenishment have been rarely used in a complementary manner with other JIT techniques. Examples of a selection of JIT techniques which are often jointly propagated and utilized to reduce stocks, shorten lead times and reduce costs include (1) elimination of defects, (2) one piece (lot) flow, (3) balancing flows, (4) worker skill diversification, (5) design product for process, (6) compact plant layout, (7) cellular (U-shaped) manufacturing and (8) the Kanban replenishment & supply system (Miltenburg, 2001; Womack et al., 2007; Nyhuis & Vogel, 2006).

Equation 1 – Cycle Time adopted from the work of: Miltenburg, (2001)

$$CT = \frac{T_a}{D}$$

$CT = Assembly\ time\ to\ meet\ demand\ (Takt\ Time)$

$T_a\ = Net\ time\ available\ to\ work$

$D = Customer\ demand$

The application of one piece flow aims for the creation of individual products by multi-skilled workers in U-shaped production lines. As the lot size is one and stocks are reduced by means of Kanban replenishment, (intermediate) stock (WIP) is effectively reduced. Production is driven by Cycle Time (CT) or Takt Time (TT). CT (equation 1) refers to the maximum time which can be attributed to the creation process of a single unit without compromising the ability of an organization to meet quantifiable internal or external demand (Miltenburg, 2001). Therefore, the production configuration which is attributable to one piece flow application corresponds with MTO/ATO. Although the pace of the flow is ultimately dictated by demand through CT, the actual pace of the flow is determined by operators. As operations are conducted in U-shaped cells which are committed to certain products, the pace is determined by operators and the lot size, JIT manufacturing could be considered similar to batch or operator paced line flows. If applied correctly, JIT manufacturing could yield the speed/cost benefits associated with line systems while simultaneously encompassing the flexibility attributed to job shop systems. However, application of one piece flow is considered to be appropriate if the produced diversity of product is $(5 \leq n\ \leq 100)$ and production quantity is $(1 \leq n\ \leq 50)$ per hour. Furthermore, machine up-time should be near 100%, the number of defects (disturbances) should be low and supplier reliability should be high (Miltenburg, 2001; Miltenburg, 2008; Womack et al., 2007; Pheng & Shang, 2011; Gao & Low, 2014). A comment on the latter can be made as the recent development associated with the COVID pandemic demonstrated the gaps in JIT replenishment and importance of safety stock. Additionally, it is often argued that LEAN techniques are not directly suitable for all industries and thus further investigation is required to determine if JIT can be viewed as a potential solution for the construction industry an large-scale renovation.

2.6.7 ROBUST PROCESS DESIGN

In order to increase the capability of value chains, organizations, their production systems and attributed processes to adapt to and fulfill differentiated customer requirements, encompassed resources should be recombined and reused. The capability of organizations to do so is embedded in the term Robust Process Design (RPD) and is considered to be the third of three key capabilities to successfully achieve mass customization. The aim of RPD is to produce and deliver customized products with near mass production efficiency. In order to achieve this aim, a value chain needs to be able to simultaneously guarantee production flexibility without compromising the reliability (speed, costs & quality) attributed to its operations. Three distinct mutually inclusive approaches which are embedded in RPD consist of (1) flexible automation, (2) process modularity and (3) adaptive human capital (Salvador et al., 2009).

Although automation and process rigidity are often considered as intertwined principles, the application of advanced robotics, additive manufacturing and automated IT solutions nowadays enables flexibility instead of causing rigidity. Flexible automation is therefore often recognizable in industries with equipment paced line flows, which are progressing towards mass customization on the rebound of mass production (e.g. automotive). Process modularity regards the reutilization and reorganization of existing capital resources embedded within a value chain in order to adapt to deviating customer requirements. Salvador et al. (2009) discusses that process modularity can be achieved by means of thinking of operational processes as segments (e.g. painting cell) which are each coupled with a source of variability in customer needs (e.g. color). Furthermore, it is argued that both of the aforementioned RPD approaches should be accompanied by adaptive human capital as they possess capabilities to account for any redundant rigidness which might be embedded in deployed technology (Salvador et al., 2009; Jensen et al., 2018; Boer et al., 2018).

2.6.8 FLEXIBLE MANUFACTURING SYSTEMS (FMS)

The two RPD approaches of flexible automation and process modularity are recognizable in Flexible Manufacturing Systems (FMS). These systems are often composed of (1) production machines, (2) physical flow systems and (3) digital flow systems. Production machines (e.g. CNC's, robots & sensors) are embedded in production cells and conduct transformative operations. Physical flow systems or material handling systems (e.g. conveyor belts) transport materials between production machines. A digital flow system (central control system) controls the physical operations and flows executed by production machines and physical flow systems. FMS are attributed to line flow systems which are equipment paced and allow for routing flexibility and machine flexibility. Routing flexibility enables systems to adapt to the production of new product types and to change the order of conducted operations. Machine flexibility involves adaptations related to changes in capacity or volume and includes the capability to deploy multiple machines for identical operations (Terkaj et al., 2009; Kostal & Velisek, 2010; Gania et al., 2017; Petersen et al., 2019). An example of the application of modular flexible manufacturing systems at the BMW company is provided by Salvador et al. (2009). Within the BMW factory, standardized movable platforms are deployed in a line on which manufacturing equipment is mounted. To enable switching to production of various product families in accordance to demand, platforms can be interchanged between lines or the configuration of the required equipment on these platforms can be changed conform a standardized configuration.

2.7 OUTPUT INDICATORS

Performance measures on multiple levels should be established to enable comparison of value chains with respect to market requirements. Comparisons of value chains, companies, production systems and processes subsequently enable a competitive analysis to determine respective industry positions. Furthermore, analysis of individual systems enables the identification of gaps between current performance on multiple attributes (status-quo) and the required performance on these attributes (desired) dictated by customer requirements. Thus, establishment of output measures on multiple attributes and a comparison with market requirements aids in the clarification of where customer value can be achieved. Therefore, business, functional and/or operational strategies can be adapted in order to provide customers with the required value and to gain a competitive advantage. Hence, required transitions in customization strategies, production configurations and the organization of flows can be identified and executed.

2.7.1 KEY PERFORMANCE INDICATORS (KPI'S)

Performance measures are often intertwined with a company's Key Performance Indicators (KPI's). KPI's are measurable values which indicate how effectively companies are achieving their key business objectives in line with their strategy. These objectives can be related to internal or external effectiveness and efficiency. KPI's should be regularly assessed and are often coupled with target values in order to do so. Various methods which enable establishment and assessment of company performance (e.g. Balance Score Card) are available (Miltenburg, 2005; Jonsson & Rudberg, 2014). However, it should be noted that KPI's rarely transcend the company level and due to differences in objectives, KPI's of various value chain parties can differ. As a value chain in composed of various parties which add value to a product until the end-user had been reached, common performance measures should be established. These measures of performance can be considered as competitive priorities. These priority measures should be based on the value and product/service attributes which are ultimately provided to the final customer. Therefore, measures which relate to performance of a value chain should be related to measures associated with the performance of value chain links (companies) and their production systems. Measures which are often indicated to do so consist of (1) quality, (2) delivery, (3) costs, (4) flexibility and (5) reliability (Leong et al., 1990).

2.7.2 COMPETITIVE PRIORITIES

Miltenburg (2005) captured these measures which encompass the competitive priorities of companies in (1) cost, (2) quality, (3) delivery time & reliability, (4) flexibility, (5) performance and (6) innovativeness. These measures involve product as well as process measures and have been included in a strategy assessment configurator. Jonsonn & Rudberg (2014) conducted research on a strategy reference configurator for the industrial realization of multi-family residences. In order to do so, they tailored the configurator provided by Miltenburg (2005) to fit this purpose and aligned the aforementioned performance indicators with KPI's in the construction industry. In order to do so, a literature review was conducted and empirical evidence was established. This ultimately resulted in the performance measurements listed in **Table 1**.

Table 1 List of quantified performance measures adopted from: Jonsonn & Rudberg (2014)

Performance Measure	Qualitative Definition
Quality	Project quality based on the costs for rework & total production costs
Delivery Speed	Delivery speed of a project based on total production time & gross floor area
Delivery Dependability	Delivery precision based on actual & planned production time (delays)
Cost Level	Project cost level based on total production cost & gross floor area
Cost Dependability	Cost precision of the project based on actual & budgeted costs (cost overrun)
Flexibility (Volume)	Expansion capability (projects) based on maximum capacity & break-even volume
Flexibility (Mix)	Stability and the mobility of a production system
Flexibility (Expansion)	Ability to increase capacity based on target capacity & new break-even volume

Although the measures established by Jonsonn & Rudberg (2014) are similar to the measures provided by Miltenburg (2005), Slack & Lewis (2014) and Leong et al. (1990), their measures are grounded in both theory and more specifically construction industry practice. Furthermore, their study on the development of a strategy configurator for industrial multi-family residence execution is similar to the purpose of the conducted study on industrial renovations. However, the focus of their study mainly focused on the establishment or alignment of the strategy of individual main contractor companies to the market. More specifically, the strategy configurator provided by Jonsonn & Rudberg (2014) combined the customization strategy attributed to products and degree of on-and-off-site manufacturing with each other and attributed performance indicators to these combined strategies. Therefore, the established performance indicators between value chain parties are indirectly but not directly aligned. In order to enable analysis on the renovation value chain level and thus incorporating customization strategy, configuration strategy and flow organization, the performance indicators provided by Jonsonn & Rudberg (2014) were compared to the Supply Chain Operations Reference (SCOR) model. The SCOR model does establish a direct alignment of performance indicators between various levels and has been constructed by APICS in collaboration with industry[5]. Therefore, the SCOR performance indicators are also grounded in practice and their application has been widely covered in academic research (Render & Klünder, 2017; Nasir et al., 2017; Ahoa et al., 2018; Xun et al., 2019).

[5] SCOR Supply Chain Operations Reference Model | SCOR Configurator | APICS

2.7.3 SCOR PROCESS LEVELS

Within SCOR a distinction is made between (1) top level, (2) configuration level, (3) element level and (4) implementation level. These levels correspond to the (1) value chain, (2) company, (3) production system and (4) activity (flow) levels respectively[6] as depicted in **Figure 12**. Within the SCOR model, practices, human capital and performance indicators are related to each level and interrelated with each other. The practices include established and proven techniques which are considered to enhance supply chain performance and consist of standard practices, best practices and emerging practices. Various bottom-up performance indicators on lower levels are merged into five main performance attributes consisting of (1) reliability, (2) responsiveness, (3) agility, (4) costs and (5) assets (Ahoa et al., 2018; Xun et al., 2019). These main performance attributes are further discussed in **Section 2.6.4**.

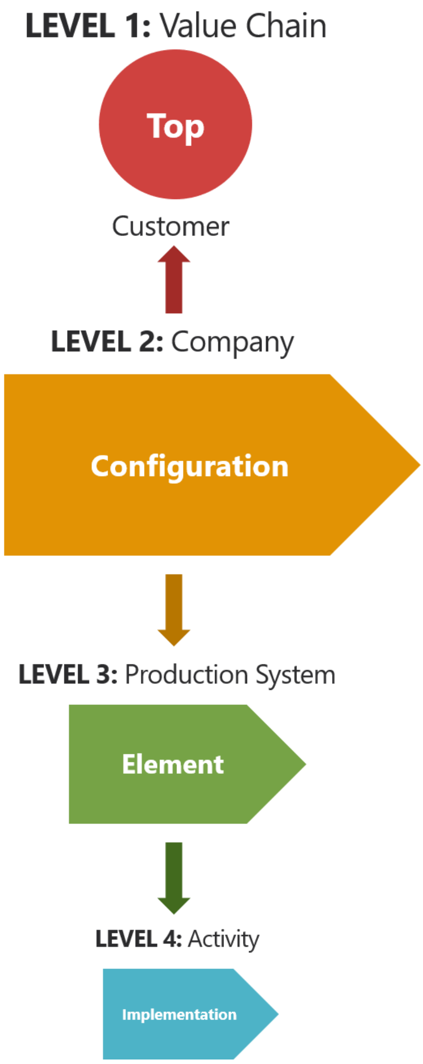


Figure 12 SCOR Levels

2.7.4 SCOR PERFORMANCE INDICATORS

Considering the five main performance attributes which are embedded in the SCOR model, each individual attribute is composed of several lower level attributes which enable measurement on the production system level. Therefore, the main performance attributes can be utilized to define the

[6] Supply Chain Metrics | SCOR Metrics | APICS

performance on a value chain level and thus are relatable to the competitive priorities required by the market. As an example, delivery reliability, cost reliability and quality reliability are all embedded in overall reliability as a main attribute. Therefore, the main attribute of reliability is not merely based on rework cost but rather depends on on-time delivery, on-budget costs and the absence of rework (Render & Klünder, 2017; Ahoa et al., 2018; Xun et al., 2019). The five identified performance attributes, their definition and examples of attributable lower level metrics are depicted in **Figure 13**.

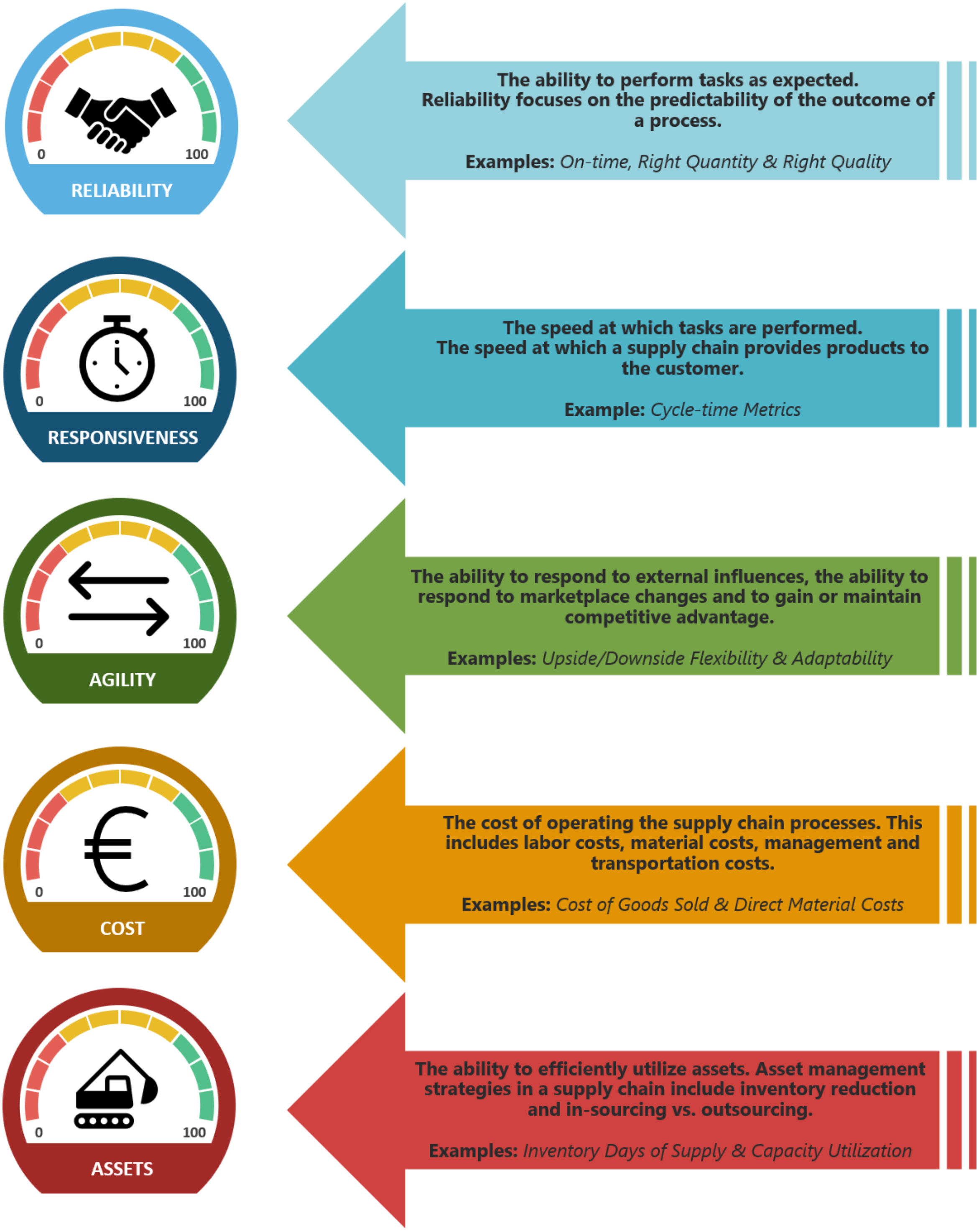


Figure 13 SCOR Performance Indicators

2.8 RENOVATION STRATEGY & ASSESSMENT CONFIGURATOR

To enable addressing a deficiency in renovation capacity, strategies in construction industry value chains need to be established first. Because individual companies and collaboration of companies in value chains pursue varying goals on similar markets, a variety of interdependent strategies can be utilized on the (1) corporate, (2) business and (3) functional level. A company's competitive and growth strategies involve the determination of markets on which products will be deployed as well as the identification of the competitive priorities which will be pursued in these respective markets. In order to gain a competitive advantage by means of existing/new products on existing/new markets, product differentiation, cost leadership or a hybrid strategy can be pursued. Dependent on the requirements of a market, associated competitive priories and functional strategies have to be organized accordingly to capture these priorities in a product or service. The customization strategies which can be used to do so consist of (1) pure customization, (2) tailored customization, (3) customized standardization, (4) segmented standardization and (5) pure standardization.

In order to provide these products with customer value on a market, value chains are required to be configured accordingly. The configuration strategies which can be pursued in order to do so consist of (1) ETO, (2) BTO, (3) MTO, (4) ATO and (5) MTS. A value chain's configuration is dependent on the relative position of the Costumer Decoupling Point (CDP) with respect to the phases of (1) design, (2) purchasing, (3) fabrication, (4) assembly and (5) distribution. In order to efficiently adhere to established competitive priorities on a market, product customization strategies and value chain configurations need to be in line. To align both of the aforementioned functional strategies, the material and information flows (processes) in production systems on the operational level have to be organized accordingly. By doing so, value can be provided on a market by means of required competitive priorities (e.g. quality & price). Successful realization of these priorities depends on the alignment between the customization strategy, value chain configuration and organization of flows in the production system. Misalignment of these aspects might invalidate the achievement of desired competitive priorities.

2.8.1 ASSESSMENT CONFIGURATOR

To capture and align pursuable strategies in renovation value chains, a strategy configurator which encompasses customization, configuration and production system strategies is required. In order to enable the realization of such a configurator, matrices and configurators produced based on the work of Hayes & Wheelwright (1997), Swamidass & Darlow (2000), Miltenburg (2005) and Jonsonn & Rudberg (2014) were studied extensively. Based on these established configurators, identified strategies, attributable principles and their relations, a new configurator was created. Initial product-process matrices created by Hayes & Wheelwright (1997) and Swamidass & Darlow (2000) use the diversity/volumes of outputted products and related them to various production system structures to capture their feasibility. Miltenburg (2005) elaborated on these product-process matrices and established a configurator which enables the assessment of manufacturing strategies including attributable performance indicators. Jonsonn & Rudberg (2014) tailored the aforementioned configurators for the assessment of multi-story construction strategies. In order to do so, the latter adapted the product customization strategies established by Lampel & Mintzberg (1996) to capture product diversity/quality and degree of off-site assembly by Gibbs (2001) in favor of previously used process structures.

In the realized renovation strategy configurator, the customization strategies will be used as they better reflect the degree of product standardization, while the varying process structures are better equipped to reflect the organization of flows in various production systems. Process structures are thus adapted instead of the degree of off-site assembly. **Due to the incorporation of value chain configurations to additionally enable the establishment of supply chain strategies instead of manufacturing strategies only, the created configurator differs from the aforementioned configurators.** For the same reason, the created configurator encompasses differing performance indicators and associated metrics on multiple (SCOR) levels. These performance indicators consist of (1) reliability, (2) responsiveness, (3) agility, (4) cost and (5) asset management. As the effective realization of competitive priorities through these indicators depends on the alignment of product customization, value chain configuration and production system organization, feasibility boundaries based on the work of Jonsonn & Rudberg (2014) are established in the created configurator as well. The proposed configurator for renovation strategy assessment is depicted in **Figure 14.**

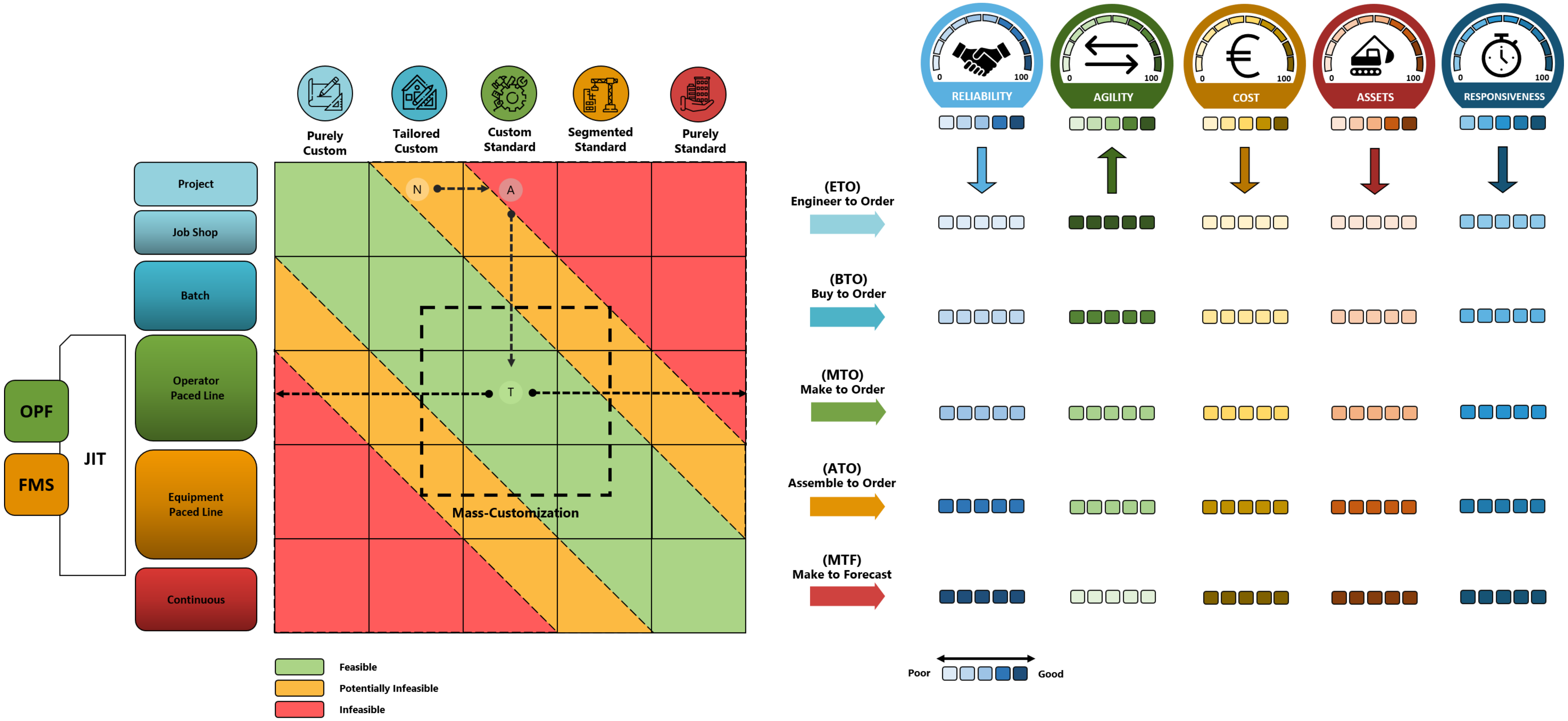


Figure 14 Initial Strategy Assessment Configurator

Because mass customization focusses on the creation of a variety of products with near mass production efficiency, the agility (flexibility) associated with personalization is combined with the reliability and cost efficiency associated with mass production. Therefore, differentiation is pursued through personalization of components and cost leadership through mass production components resulting in a hybrid strategy. As mass customization can be associated with a hybrid competitive strategy, the importance of addressing risks associated with “getting stuck in the middle” should be addressed sufficiently when aligning varying strategies. The most appropriate product customization strategies which are usable to achieve mass customization consist of (1) tailored customization, (2) customized standardization and (3) segmented standardization. The value chain configurations which correspond to the pursuit of mass customization consist of (1) BTO, (2) MTO and (3) ATO. The flows in production systems which match with these customization strategies and value chain configurations consist of (1) batch flows, (2) operator paced line flows and (3) equipment paced line flows. The proposed area of mass customization is depicted in the center of the configurator in which varying combinations are possible. Selection of the most appropriate combination of strategies and configurations depends on the competitive priorities which are pursued by value chains and reflected in the incorporated performance indicators. Although varying combinations are possible, the areas which are indicated to be infeasible should be avoided.

2.8.2 APPLICATON OF CONFIGURATOR & FURTHER RESEARCH

To illustrate the application of the presented configurator, a fictive case is drafted similarly to the cases presented by Jonsonn & Rudberg (2014). Company X as depicted in **Figure 14**, currently offers customers a basic renovation design which is tailored to fit individual customer needs. Therefore, the variety of offered products by Company X is high while the volume of output (finished renovations) is low. As a direct consequence of the number of permitted customizations (solution space), an ETO, BTO or MTO value chain configuration is used. The solution space offered by Company X is high to account for the variances in required expertise and materials by individual customers. As the design varieties and thus, supplier selection is not restricted, an ETO value chain configuration is identified. Processes and thus flows are organized in projects in which design adaptations, supplier selection, fabrication and assembly are executed subsequently. Although the current position of Company X which is depicted as (N) in **Figure 14**, enables agile responses to individual requirements by customers, research conducted by marketing revealed dissatisfaction on the market associated with reliability, responsiveness, costs and scale.

To capture the product customization options which are most desired on the target market, Company X is aiming for customized standardization through solution space development. Due to a sole focus on product customization strategy, flexibility is reduced while reliability, responsiveness and lower prices are not realized. Based on the aim (A) of Company X as indicated in the proposed configurator (**Figure 14**), the utilization of the ETO value chain configuration and organization of flows in projects are not feasible. To successfully achieve desired competitive priorities by means of customized standardized products, the value chain configuration and organizations of flows should be re-engineered accordingly.

- In order to achieve the desired feasible situation indicated as (T) in **Figure 14**, Company X should focus first on solution space development and choice navigation to enable efficient product customizations by customers.
- Company X should establish MTO/ATO value chains by means of supply chain partnering and/or integration.
- Robust process designs should be developed for production and information systems within these value chains to achieve operator paced, equipment paced or JIT flows.
- After achieving the desired situation (T), the competitive priorities associated with reliability, responsiveness and asset utilization are expected to increase while agility and costs are expected to decrease.

Provided prices, delivery times and quality are aligned to the required competitive priorities associated with the market Company X operates on. Based on the application of the proposed configurator in the discussed case of Company X, the presented configurator can be suitable for renovation strategy assessments based on competitive priorities. Although the configurator was demonstrated to be applicable in a fictive case, the suitability for cases in practice should be investigated in further research. In order to do so, the relations between competitive priorities, performance indicators and the combination of applicable strategies in individual situations should be verified as well. As the main goal of the presented research is to increase renovation capacity, the configurator should be used to determine the (1) current position, (2) desired position and (3) most appropriate position for various companies in the construction industry. After verification of the proposed configurator, assessment outputs can be used to support strategy and production system transitions. To establish an initial overview of the aforementioned positions of various construction industry companies on the proposed configurator, semi-structured interviews have been conducted. The methods, composition and results of these interviews are presented in **Chapter 3**.

3. INTERVIEWS

In order to determine the variety of strategies currently applied by best-practices in construction, semi-structured interviews were executed. Insights were obtained in the markets these practices operated on as well as indications of growth/competitive strategies. Moreover, the product customization, production system and value chain configuration strategies currently applied by these companies were established. Besides determining the current application of strategies individually, the combination of applied strategies, as encompassed in the proposed configurator (Section 2.8.1), was put through an initial verification iteration. Besides current strategic considerations, the views of best practices on the progress and process towards industrialized construction/renovation were discussed. Constraints and potential solutions associated with the transition towards industrialized construction and/or mass customization were embedded in the interviews as well. Insights into the current application of strategies, desired application of strategies, transition of strategies, constraints and potential solutions, aids in determining the prioritization of actions to scale up overall renovation capacity. In order to obtain these insights the second research question is formulated as follows: "*Which combination of strategies are companies in the construction industry currently using, what are they aiming for and which combination of strategies should therefore be pursued?*".

The first part of this chapter is dedicated to the sample associated with conducted interviews (Section 3.1). In the second part of this chapter the topics which have been included within the interview are briefly introduced (Section 3.2). Discussion of observations regarding markets, strategies, constraints and proposed solutions, yielded from data analysis are included in the third part of this chapter. (Section 3.3). The chapter is concluded with a brief discussion and reflection involving the proposed configurations supplemented with yielded qualitative data, answering the aforementioned research question (Section 3.4).

3.1 SAMPLE

A total of eleven interviews were executed out of which ten interviews were processed and analyzed. In a single instance, the interview was not recorded at the request of the interviewee and thus observations were made by means of notes instead of a full transcription. The recording of one interview is still expected. From the ten processed interviews, one interview was conducted with the former chairman of a network association for industrialized construction, whereas the others related directly to industry companies. The sample at which semi-structured interviews were conducted consist of contractors and manufacturers which focus on new property development and renovations. The size of companies (based on employees) varies between small (-150), medium (-300) and large (x≥ 300). A profile of the sample is presented in **Table 2**.

Table 2 Interview Sample Profile

Company Role	Company Size	Primary Focus	Current Position	Experience
Contractor	Large	New	R&D	+ 10 Years
Contractor	Large	New	Commercial	+ 10 years
Contractor	Large	New	Corporate Strategy	- 10 Years
Contractor	Large	Renovation	Senior Manager	+ 10 Years
Contractor	Medium	New/Renovation	Director	+ 10 Years
Manufacturer	Large	Renovation	Director	+ 10 Years
Manufacturer	Medium	Renovation	Commercial	+ 10 Years

Manufacturer	Small	Renovation/New	Director	+ 10 Years
Manufacturer	Large	New	R&D	+ 10 Years
Manufacturer	Medium	New	Commercial	- 5 years
Association	-	Renovation	Former Chairman	+ 10 Years

3.2 TOPICS

In order to determine various aspects associated with the markets selected companies operate and focus on, various sub-topics were discussed during the interviews. These sub-topics included: (1) targeted customers/segments, (2) market requirements, (3) competition and (4) growth. By means of discussing these sub-topics, insights were gathered on competitive and growth strategies utilized by the selected companies. Due to the semi-structured nature of the interviews, questions encompassing these sub-topics varied slightly. These questions are similar to: *"could you tell something about the customers you are mainly focusing on?"* or *"could you tell something about how you distinguish yourselves from competition?"*.

In order to determine the current and desired product customization strategies associated with the concepts/products offered by selected companies, various sub-topics related to primary products were discussed. In order to do so, interviewee's were first asked to indicate and describe their primary concept/product. Based on this general description, questions were asked in the instances where clarification of the concept/product was required. Follow-up questions were directed towards (1) product components, (2) current/desired volumes, (3) offered product varieties and (4) product development. To gain insight into the organization of flows in production systems and the configuration of value chains, questions were focused on (1) the layout of production facilities, (2) global description of production processes, (3) presence of equipment, (4) variety of suppliers and (5) stocked components. If applicable, insights were gathered in on-site assembly as well. Examples of questions associated with the product, production system and value chain strategy topics are: *"could you tell something about the varieties offered to customers?"* and *"could you provide us with a global description of your off-site production process?"*.

Finally, insights were obtained in the desired future strategies by means of questions directed at the development of the production process, desired production volumes and desired collaboration with supply chain partners. At the end of each interview, questions were directed towards the biggest challenges associated with the transition of each individual company as well as challenges associated with scaling up capacity for large-scale renovations. Furthermore, interviewees were asked to participate in further research by means of an expert panel under construction which was pledged on all occasions. The expert panel can be consulted in future research by means of interviews, surveys, in workshops and during review sessions to practically verify designed artifacts and written reports.

3.3 RESULTS

Within the presented section, results obtained from the analysis of processed interviews are presented. All analyzed interviews were utilized to discuss the market and constraints associated with strategy transitions. Six conducted interviews which were directly related to companies were used to describe the various cases. The results are discussed hereafter.

3.3.1 MARKET

With respect to targeted customers on the current market, contractors focusing on renovations and new property construction indicated to be mainly focused on housing cooperations and larger property developers. The main motivations associated with the focus on these market segments can be attributed to the capabilities of these customers to simultaneously provide larger volumes of demand. The involvement of end-users was indicated to be encompassed in current renovation regulations and thus, mandatory. Considering new properties, end-user involvement in concept development was considered key and in a single instance desirable due to nature of a business model. Therefore, end-users can be considered as indirect customers of the contractors offering construction and renovation concepts.

Manufacturing parties indicated to primarily focus on contractors & installation companies as these companies carry the responsibilities and risks associated with on-site assembly. A secondary focus of manufacturers was observed on housing cooperations as end-users and prospective primary customers in the future. The majority of the manufacturers and contractors indicated a tendency towards future orientation on private individuals, aiming at a production size of one. However, the effort and costs associated with engineering, large-scale production and the management of value chains for single property development was indicated to render expansion towards this market segment currently unfeasible and undesirable. Therefore, the current market associated with industrialized construction & renovation can be considered as a B2B or B2B2C market in contracting and manufacturing instances respectively.

Besides a segmentation in terms of customers, a segmentation was observed which relates to the type of properties and in case of renovations, the year of construction attributed to existing properties. The majority of the concepts and products developed by respondents focused mainly on the construction or renovation of single-family dwellings with outliers towards multi-family residences. An overall tendency was observed towards buildings constructed after 1960 for renovations. This tendency was attributed to the technical and financial infeasibility associated with renovation of properties constructed before this range. The aforementioned tendency was recognized by some respondents associated with new property development which indicated that they were aiming to fill the gap of property shortages caused by demolishing these buildings. Properties with an architectural or monumental significance were indicated to be too complex to renovate on large-scales and were therefore attributed to specialized contractors. It should be noted however that the composition of the sample included in qualitative research did not incorporate specialized or smaller contractors. Contractors which aim for pure customization might focus on the renovation of properties and market segments which are currently dis-considered by larger contractors and manufacturers.

3.3.2 CASE A

In the interview with the company associated to case A, two distinct concepts for new property development were discussed. Both of these concepts focused on the realization of single-family residences. The first concept involved a (partially) standardized residence (two or three stories) which are configurable based on approximately 24 standardized modules. The second concept regarded a fully standardized loft residence in which the outer shell and the position of the toilet, bathroom and installation pods are not customizable. The interior however is fully customizable by means of standardized interior wall panels and floors post-realization. In the first concept, flexibility was thus offered to customers by means of the configuration of modules in a building. Variety within these modules (e.g. layout & dimensions) were indicated not to be offered whereas some customization of interior finishes is allowed. In the second concept, no flexibility in the composition (outer dimensions) of the building was offered, but (partial) interior flexibility by means of standardized components was offered.

In both concepts cosmetic customization of the exterior appearance of the building was provided to customers. In the first concept full flexibility was allowed whereas in the second concept (standardized) options were provided. Both concepts were indicated to be in the prototyping phase as less than 10 properties were realized to-date. In terms of solution space development, innovation toolkits and virtual concept testing were indicated to be applied via customer panels for both concepts. Embedded configurations, which is one of the approaches associated with choice navigation was identified in the second concept as interior configurations post-realization are enabled. Beside customization of interior and exterior finishes in the first concept, the composition of a product related to the combinability of modules is permitted. Therefore, the customer is able to influence the assembly of the product and the most appropriate product customization strategy is **customized standardization**. Although some exterior customization is permitted in the second concept, a single standardized product which can be interiorly customized by customers themselves after realization is produced. Thus, a single standardized product is fabricated and assembled based on the requirements of an aggregated group of customers. The second concept is attributed to the **pure standardization** strategy. The current/future configuration of both concepts in case A are depicted in Figure 15.

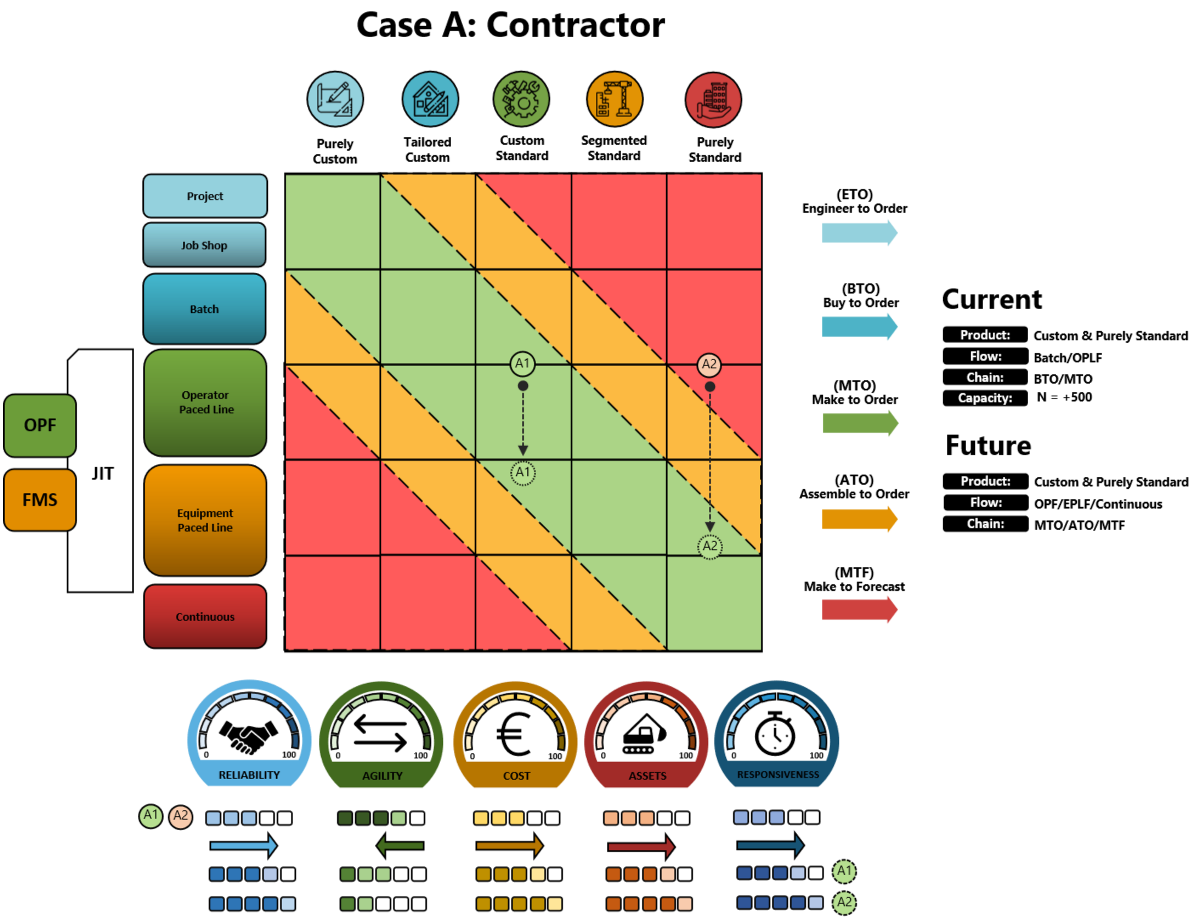


Figure 15 Case A: Configuration

In company A, modules and prefabricated segments are produced off-site and assembled on site respectively in the first and second concept. As both of the aforementioned concepts are currently in the prototyping stage, the production facility for these concepts has not been fully developed yet. However, a test facility had been utilized in order to create the first prototypes. During the interview and within commercial communication it is indicated that a series size of two is realizable without any additional costs compared to other concepts. Additionally it was indicated that the aim was to set up a line-based system in which ultimately a series size of one would be achievable. Within this line, a high degree of automation would be achievable, however, this was not directly considered to be feasible in the near future. Therefore, it is assumed that a **batch-based** or **operator paced line system** will be accommodated in the production facility of both concepts. The latter would be achievable if production lines are dedicated to a specific product (1 house type). The desired combined future output associated with both concepts relates to +500 residences. Because both concepts differ considering the degree of customization, the most appropriate organization of production systems and value chain configurations differs as well. Especially in the instance of concept A2 committed EPLF can be established to achieve a significant increase in scale and decrease of cost.

3.3.3 CASE B

The concept offered by the company attributed to case B focusses on the realization of standardized single-family residences with one-three floors consisting of (1) terraced houses, (2) semidetached houses and (3) corner houses. Three width dimensions are offered consisting of: 5,4, 5,7 and 6,9 meters. The offered product variants are composed of standardized prefabricated elements (walls, floors & roofs) and modules (e.g. staircase pods). The interior layout, kitchens, floors and finishes are fully standardized whereas various options are provided regarding exterior appearance in a fixed solution space. As customers are permitted to select a standardized product within the concept and are not able to influence the configuration of the product (exterior appearance excepted), the final assembly of the product is not influenced. Therefore, the most appropriate customization strategy attributed to this concept is **segmented standardization**.

The company associated with case B produces the variety of offered products within the concept in its own off-site facility. After off-site fabrication, non-volumetric prefabricated segments and volumetric pods (competed bathrooms & stairway modules) are assembled on site. External finishes are incorporated in the off-site prefabrications and prefabricated roofs are installed on-site. Assembly is executed by an assembly crew of five which is dedicated to the concept. Based on on-site and off-site capacity the current output was estimated to be 530 in which a series size of 10 was considered the minimum. Off-site production lines were indicated to be present, however, these production lines were not committed to specific products (housing types) or elements to permit flexibility. Reorganization towards dedicated operator based line flows and ultimately (flexible) equipment paced flows were indicated to be desirable if market demand rendered the investments associated with this transition feasible. Furthermore, it was indicated that a single robot was present in the production facility. Based on these details it is assumed that a **batch-based flow** is adapted on-site and off-site. The current/future configuration of the concept related to case B and the expected influence on performance indicators is depicted in Figure 16. A transfer towards an EPLF or FMS to accommodate fluctuations in demand for various product types would be most appropriate without incurring costs for switching the line between product types. Accurate forecast of demand for each of these product types would eventually enable the stocking of modules in line with ATO configurations.

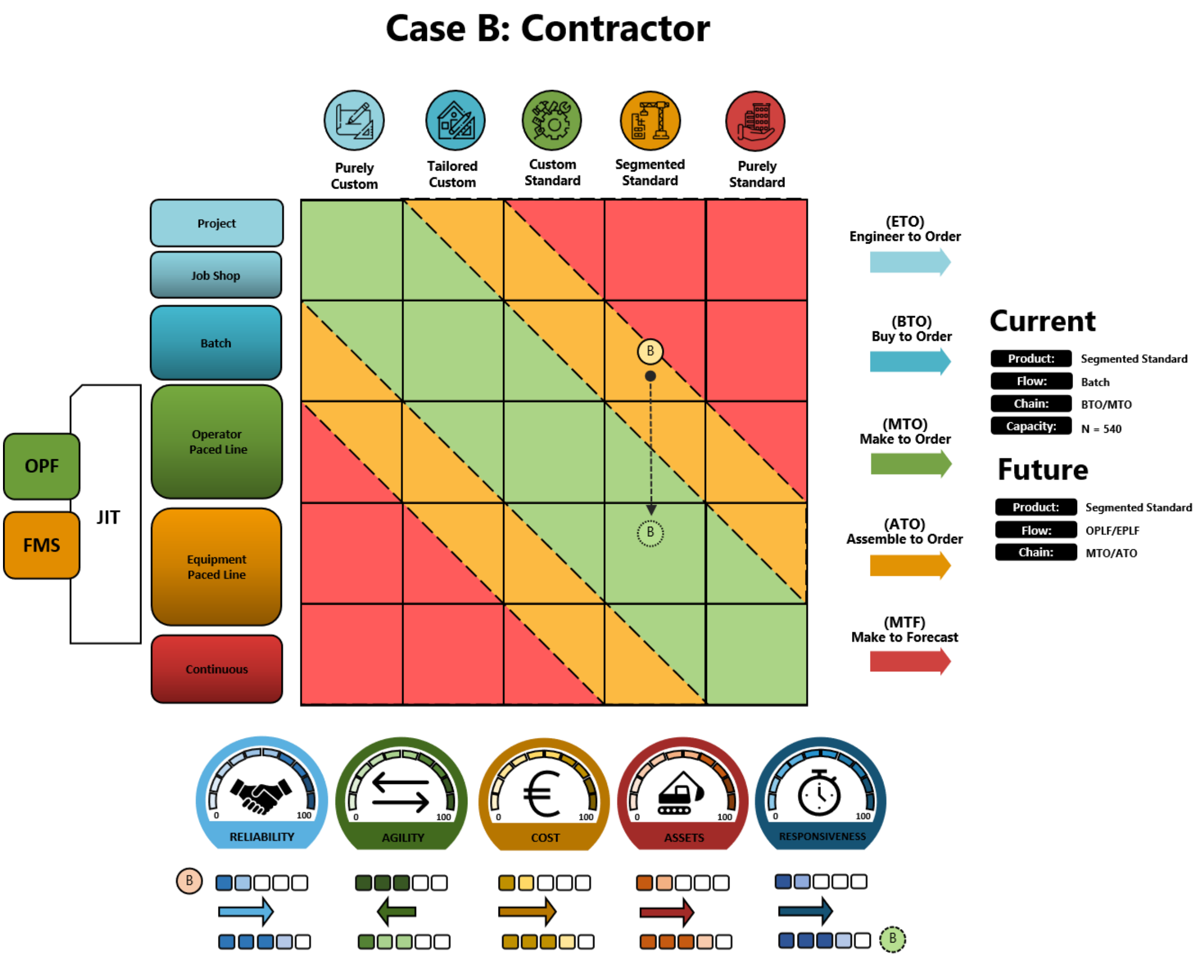


Figure 16 Case B: Configuration

3.3.4 CASE C

The concept related to case C focusses on the realization of studios, single-family residences and multiple-family residences by means of modules fabricated off-site. These modules are constructed based on either a steel/concrete-based or a wooden frame. The products which are realized in the concept are designed based on the requirements of individual customers. Therefore the dimensions, layout and exterior finishes of these modules and the building are customizable by the client. The dimensions of individual modules were indicated to be restricted by the permitted transport size of 4,50 meters. However, based on the constructed modules, virtually unlimited configurations were permitted. Although the customizability attributed to the concept is high, the design created by the client is required to be suitable for composition of prefabricated modules. Hence, the most appropriate product customization strategy is considered to be **tailored customization**.

Case company C produces fully finished modules within three distinct off-site facilities. After fabrication of these modules including cladding and interior finishing, the modules are assembled on site. The overall lead time for a project was indicated to be 3-6 weeks if permitted by capacity. The organization of the off-site facilities was indicated to consist of a logistical compartment, a compartment for the prefabrication of wall/floor segments and a space were modules were assembled and finished before transport. Within this process it was indicated that for the creation of wall/floor segments various CNC and framing machines were used. It was indicated that the flows attributed to module assembly and finishing was considered to be rigid. Due to the presence of a pattern and rigidness, the flows which are attributed to the production system of company C were considered to be a combination of **batch/job shop**. No desire was expressed to advance towards equipment based or single piece flows. Orientation towards optimization of the current system and transition towards an operator paced line flow was discussed and is depicted in Figure 17.

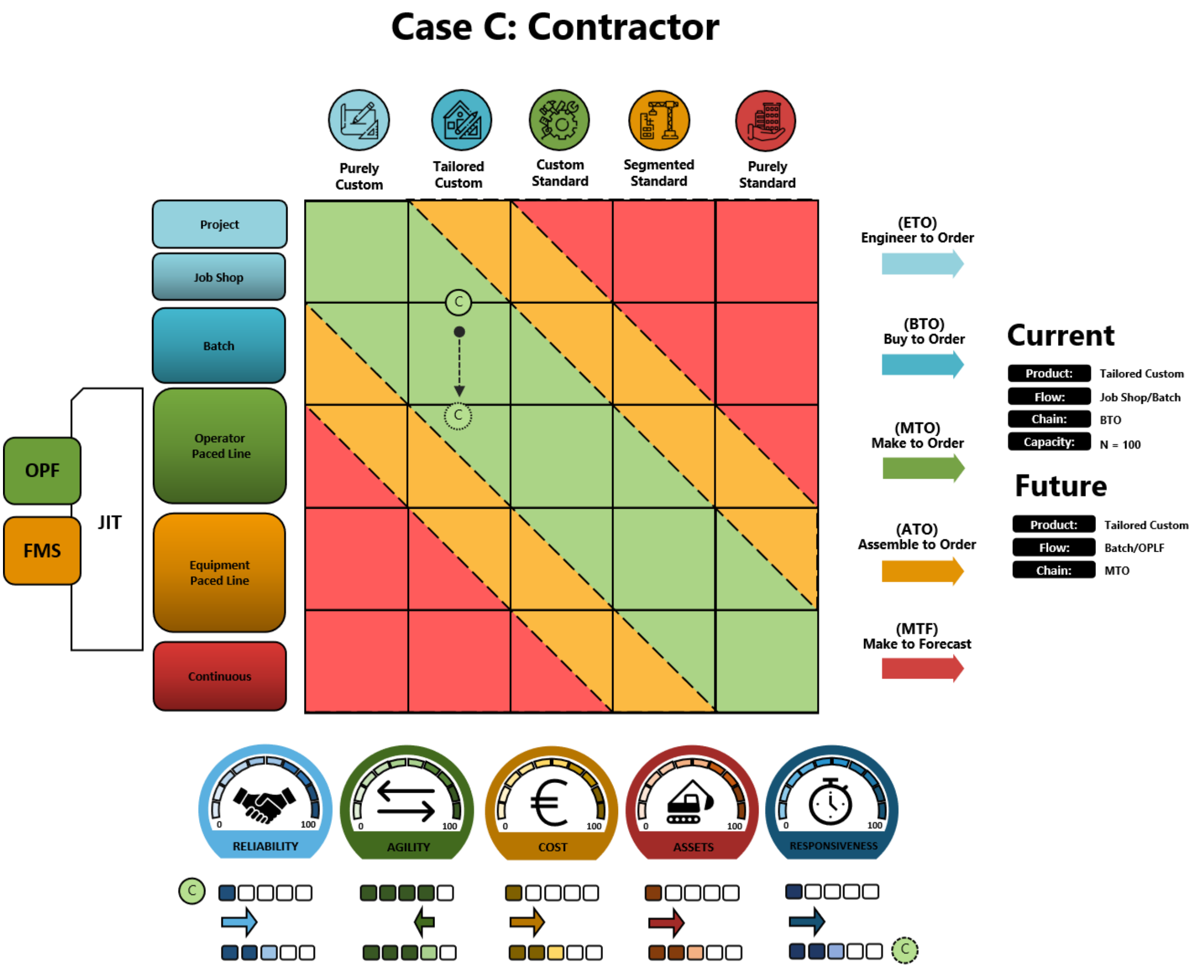


Figure 17 Case C: Configuration

3.3.5 CASE D

The concept related to case D focusses on executing renovations of mainly single-family residences. As the renovation of existing properties cannot be executed by means of full modular units, utilization of non-volumetric (e.g. wall panels) and volumetric pre-assemblies (mainly installation pods) were indicated. Within this concept a standardized variety of pre-assemblies fabricated by externals are offered, which can be jointly or individually installed by contractors on existing properties. Exteriorly these pre-assemblies consist of a selection of façade systems, tilted roof systems, gutters, heat pump and ventilation systems. Interiorly low temperature heating radiators and saving-taps are included in the concept. Within individual assemblies included in the concept (e.g. facades), various cosmetic customizations (exterior finishes) and functional options (e.g. insulation values & dimensions) are offered within the solution space of suppliers. The solution space of the concept attributed to case C is recognizable in the fixed selection of assemblies which are offered. Therefore, the contractor is enabled to standardize most joint interfaces between these assemblies. As customers are able to determine which mix of products are assembled on-site within the solution space the attributed customization strategy is **customized standardization**. However, it should be noted that some solutions or the mix was indicated to be tailored to accommodate for deviations in existing properties. Hence, a tendency towards **tailored customization** was observed as well.

Concept D does not directly possess an off-site production facility for the production of non-volumetric assemblies destined for renovation execution. Instead, most of the assortment of offered solutions were co-developed with external suppliers. A configurator was demonstrated which allowed potential customers to configure the required solutions and review a price based on heat demand or budget. This configurator is in line with the assortment matching approach related to the mass customization capability of choice navigation. After agreements have been reached, a project is scanned in 3D after which the selected components are produced to fit the existing situation. After production has been completed, a renovation contractor related to the same parent company assembles the prefabricated assemblies on site. Although concept D is related to a selection of suppliers, the company which executes the renovation can differ. Therefore, the flows attributable to concept D are not directly determinable and could differ. Based on an educated review of details it is assumed that flows vary between **project and batch**. In the future, an advance towards (internal or external) off-site equipment paced assembly lines and experienced assembly crews committed to concept D were indicated to be desired. Especially the latter combined with the organization of information/logistic flows was indicated to be important for increasing capacity. Therefore, one-piece-flows can be appropriate for on-site assembly whereas EPLF would be eventually appropriate for off-site manufacturing facilities as depicted in Figure 18.

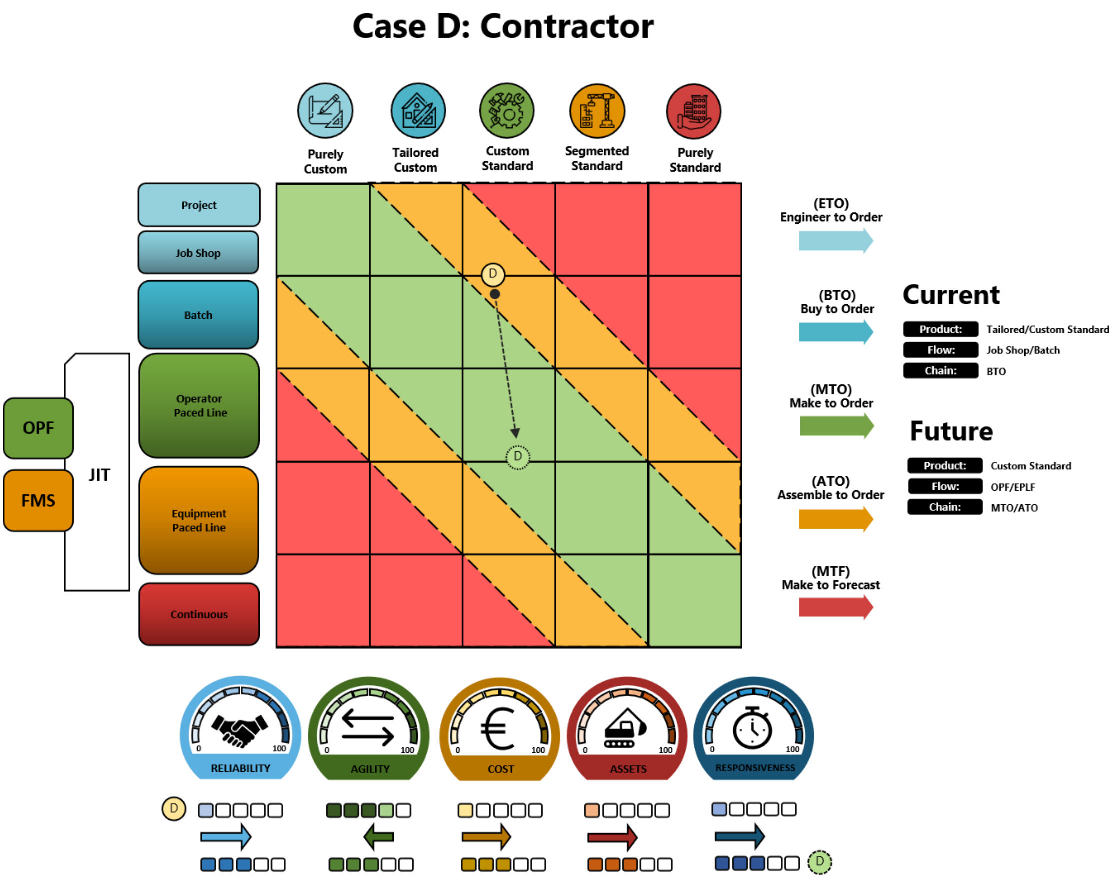


Figure 18 Case D: Configuration

3.3.6 CASE E

The product which is produced by the company attributed to case E is a standardized non-structural façade system. These facades are non-volumetric pre-assemblies which include window frames, door frames and exterior finishes. These facades are primarily manufactured for the renovation market and in some instances for new properties as well. The basic product is produced based on standardized components. The product is configurable based on required dimensions, required framing and exterior finishes with respect to a limited solution space dictated by the production process. Therefore, the customer is enabled to influence the assembly of the product (finished façade) but does not influence the core aspects of fabrication (façade core). Thus, **customized standardization** is associated with this product. The company attributed to case E produces their product in a highly industrialized off-site production facility. Within this production facility non-volumetric pre-assemblies are fabricated and in most instances assembled on-site by company E as well. Within the process of company E a specific line is dedicated to a specific product. Although parts of the process involve manual labor, the presence of automated CNC machines, robots and automated transportation devices is significant. Company E indicated to be able to achieve an output of sufficient components for the renovation of approximately 1000 residences per year. Although a capacity of 1000 residences can be considered high it is insufficient to cope with the expected demand. Furthermore, it was indicated that not all designed capacity was currently utilized. Installed assets on the production line attributed to concept E permitted a wide range of flexibility which was recognized in the wide diversity of permitted customizations. Based on the attributes of the production system described by company E, it is assumed that the organization of flows is bordering **EPL** flows or **FMS** as depicted in Figure 19. Therefore, further product diversification and process automation can be feasibly executed.

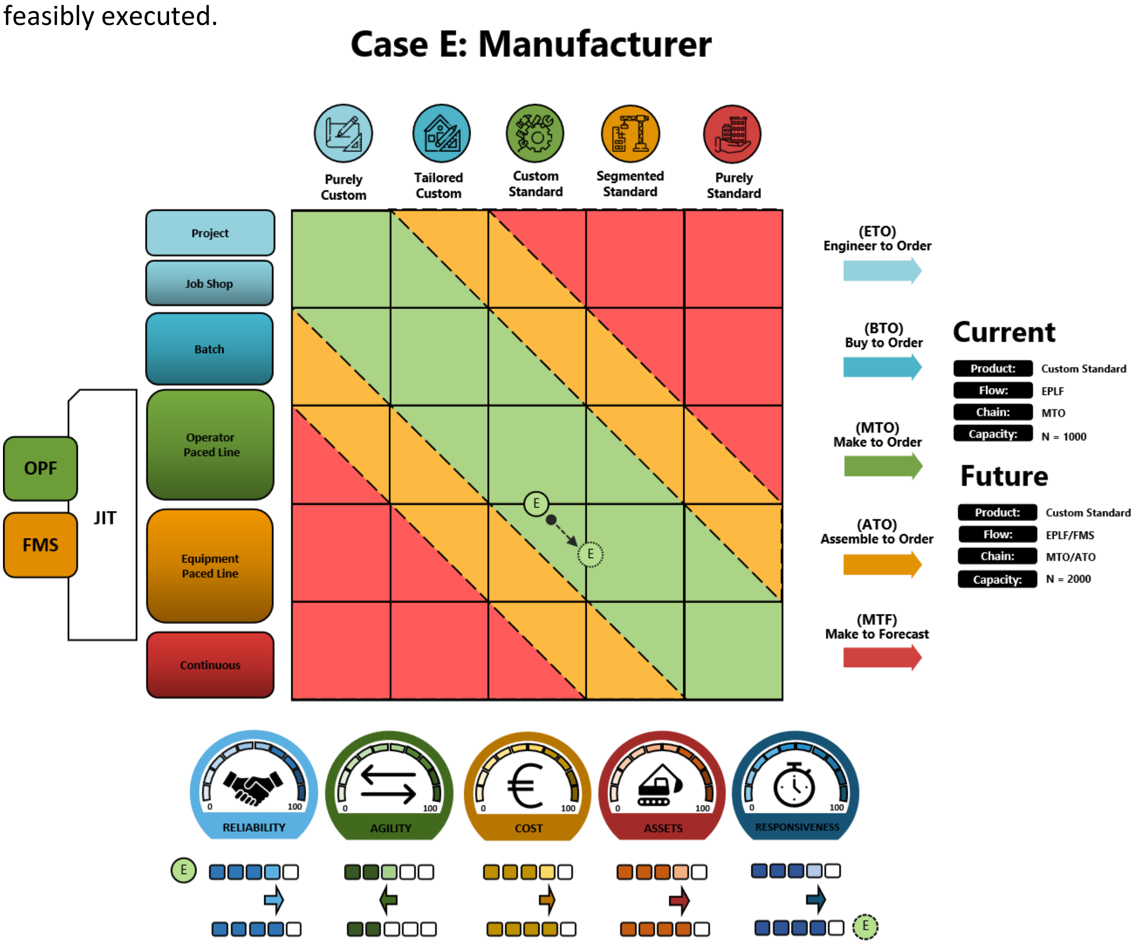


Figure 19 Case E: Configuration

3.3.7 CASE F

The product which is produced by the company related to case F is a standardized thermal solution. This thermal solution consists of several components and is offered on the renovation and new property market. However, in order to be able to apply the offered system, certain preconditions need to be met. These pre-conditions include (1) sufficient insulation, (2) low temperature heating and (3) space for the installation of a heat buffer. The primary product generates a specific heat demand and is offered as a standardized solution to a large segment of customers. The configuration of components within the primary product are adaptable in order to accommodate the requirements of other customer segments (e.g. with higher heating demand). However, the components used within the concept themselves are fully standardized. Therefore, the **segmented standardization** strategy is identified. The components attributed to concept F are pre-assembled in a small off-site facility and by various suppliers after which the final standardized assembly of the product is realized on site. The process of company F is dedicated to the aforementioned concept and rarely deviates from the basic variant. Furthermore, basic requirements are stated for the application of the product. Although the company currently operates at a smaller scale, the company utilizes a large network of verified installers which are able to realize final assembly. Due to the pattern in the process and the commitment to a single product an **operator paced line flow** is recognized. Potentially the product in concept C would be suitable for production in EPLF or even continuous flows if there would be sufficient demand. ATO or MTF configurations might thus be appropriate as depicted in Figure 20.

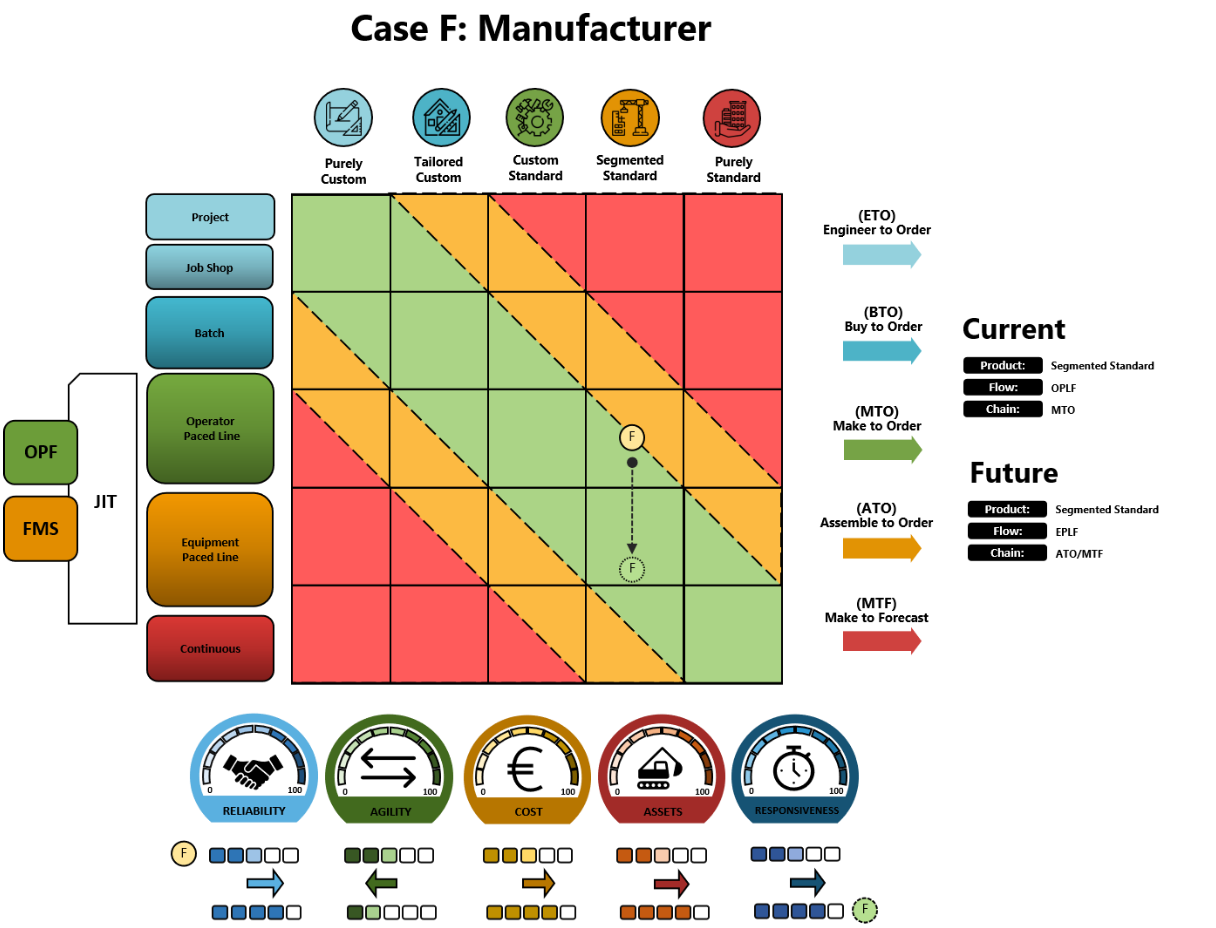


Figure 20 Case F: Configuration

3.3.8 CASE G

The concept offered by company G consist of twenty-two standardized new single family residences of one-three floors which are included in three separate series. Most of the options included in these series can be executed as detached or semi-detached properties with varying core dimensions (5,7, 5,4 & 5,1 meters). The focus of the provided concept is on reliability, delivery speed and affordability. The offered properties consist of a range of standardized non-volumetric and volumetric assemblies in which the majority of the layout is standardized. Various options with regard to extensions, interior finishes and exterior finishes are provided within a pre-determined solution space. Besides various concepts for new property development, company G offers a concept for the renovation of facades/roofs for single family detached dwellings of two floors with flat facades and a tilted roof. Because customers are permitted to select a pre-configuration within the three provided series developed based on the idiosyncratic needs of customers and due to confined customization options within each pre-configuration the most appropriate customization strategy ranges between **customized and segmented standardization**.

The company associated with case G produces all offered products within the aforementioned series in its own off-site facility. After off-site fabrication, the non-volumetric and volumetric assemblies are assembled on site. The external finishes are prefabricated off-site or are fully realized on site. On-site and off-site capacity was divided between two streams with a cumulative output of 400 houses in series size between 10-100. Off-site production was indicated to be organized on flexible lines which were not committed to specific output types. Therefore, the lines are adapted based on the requirements which are attributable to various batches. Ambitions were indicated to expand output capacity towards 1000 and 2400 properties on the short-term in order to cope with speculated required capacity. A transition towards committed operator paced and eventually equipment paced lines was indicated to be desirable if sufficient market demand for specific products within the concept justifies decreasing the diversity of produced batches (project portfolio). Based on the information obtained regarding the organization of flows in the production system, a **batch-based flow organized in a line pattern** is established. Because company G indicated the intention to scale capacity without significant changes to the production system, this is reflected on the configurator as depicted in Figure 21. Although the optimal solution to achieve significant increases in scale would orient towards EPLF or FMS, the incurred loss of product flexibility and thus agility were considered to be undesirable by company G.

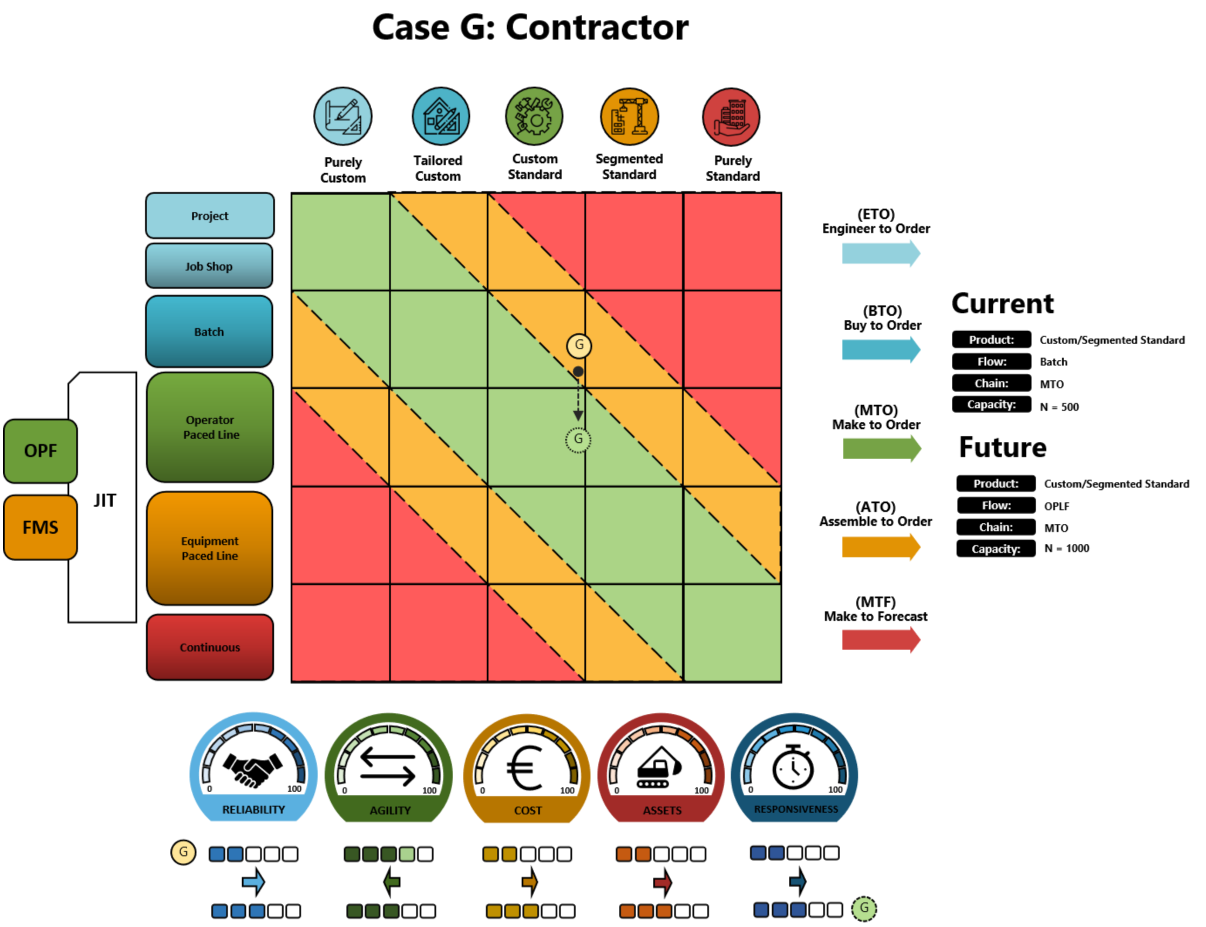


Figure 21 Case G: Configuration

3.3.9 CASE H

In the instance of case H, non-volumetric pre-casted facades, floors and interior walls are produced. The produced façades include non-volumetric pre-assemblies like window frames and electrical appliances. However, these facades do not include interior or exterior finishes and thus, these need to be applied in on-site processes. Produced elements are mainly pre-fabricated to be applied in the construction of new property. In some occasions the façade system has also been applied in renovation projects when facades required replacement as a whole. The sole group of customers targeted by company H consist of contractors and competition was indicated to consist of other manufacturers offering (pre-casted) non-volumetric elements. Considering the degree of permitted customization of façades in case H, the customer is able to influence the dimensions and embedded pre-assemblies (e.g. window frames). As customers are able to influence the dimensions and the embedment of pre-assemblies/sub-assemblies in the offered product, **customized standardization** was identified.

Company H produces their products in an off-site factory which is organized as a so-called carrousel plant. Within this plant individual elements are created on a movable platform which is navigated incrementally throughout the production process. The flow of these elements was indicated to be organized in a cellular pattern in which individual elements were merged for specific operation (e.g. casting). The utilization of labor force was indicated to be prevalent in the production process whereas specialized equipment pieces (e.g. adaptable molds & overhead cranes) are used to simplify the production process. On-site installation of the produced assemblies was offered by company H as well. Based on the presented details a **batch-based flow** of the production system was identified. Because company H indicated that further standardization was considered to be undesirable by their clients and due to the intention to transfer towards a more sophisticated production system, the expected position of company H on the configurator is reflected in Figure 22. If the clients of company H (contractors) would for example desire further reduction of costs, standardization of specific product aspects (e.g. window frames) is required. This would ultimately enable EPLF and ATO value chain configurations.

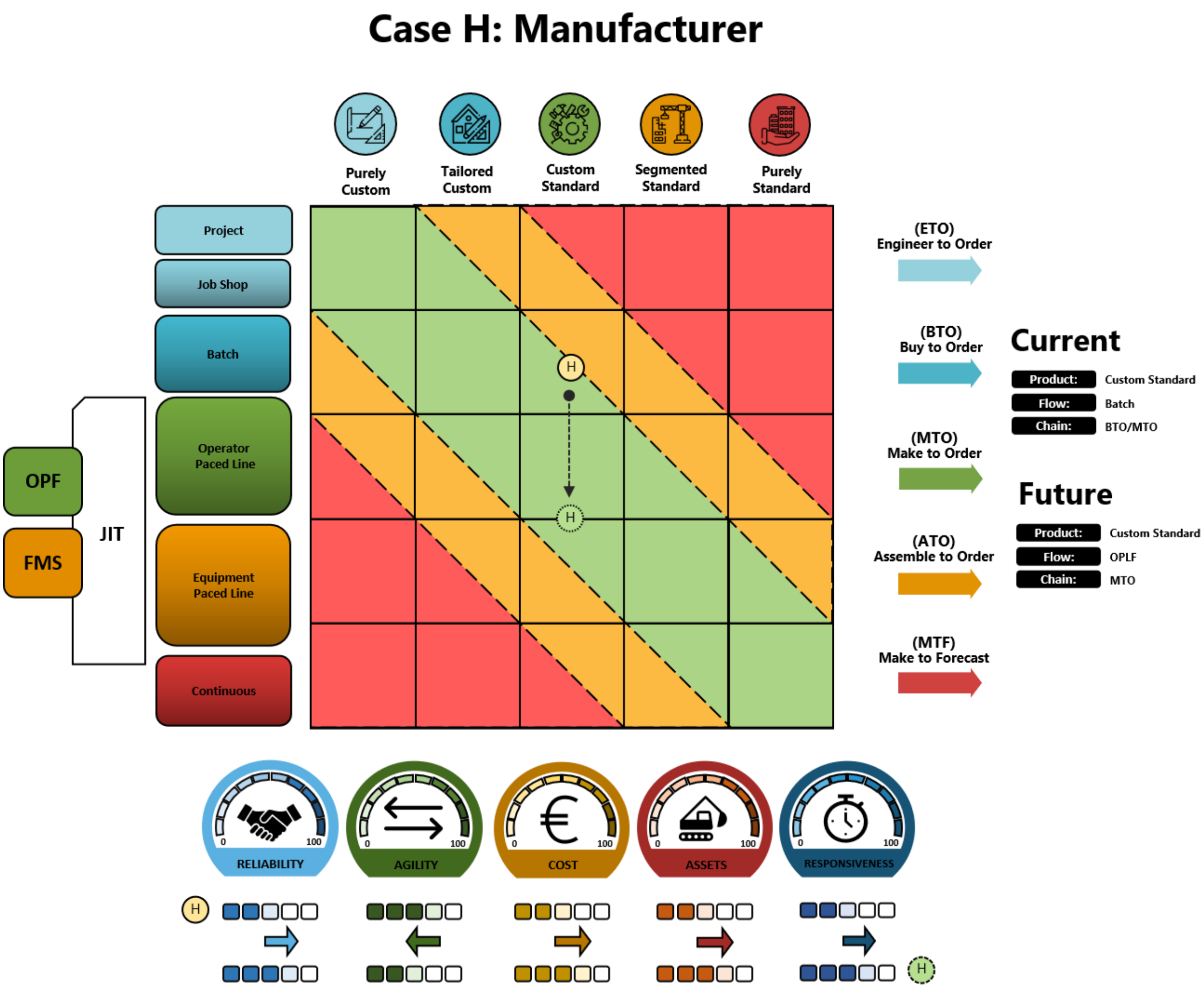


Figure 22 Case H: Configuration

3.3.10 CASE I

The products produced in case I are similar to the products produced in case H. However, discrepancies were indicated with regard to permitted customization. Besides customization of the dimensions and included assemblies within the produced non-volumetric assemblies, the form of products and the type of products was indicated to be customizable as well within a pre-determined solution space. Therefore, the most appropriate customization strategy ranges **between tailored customization** and **customized standardization**. Production of the products created by company I is executed in an off-site factory whereas on-site assembly was offered by company I as well. In contrast to company H, company I produces the formworks for pre-casted elements based on the requirements of individual customers. Furthermore, the workstations within the factory are organized functionally in order to enable product flexibility. It was indicated that the functional organization of the manufacturing plant and attributed product flexibility was considered as one of the competitive distinctions which were actively perused by company I. Therefore, the attributable flow typology ranges between **job-shop** and **batch flows**. Because company I indicated to aim for optimization of the current production system and product development instead of strategic transformations, their expected position and results are depicted in Figure 23. Due to this intention, company I can only aim for achievement of becoming best-in-class but risks being outpaced price-wise by competitors offering more standardized products by means of line-oriented production systems.

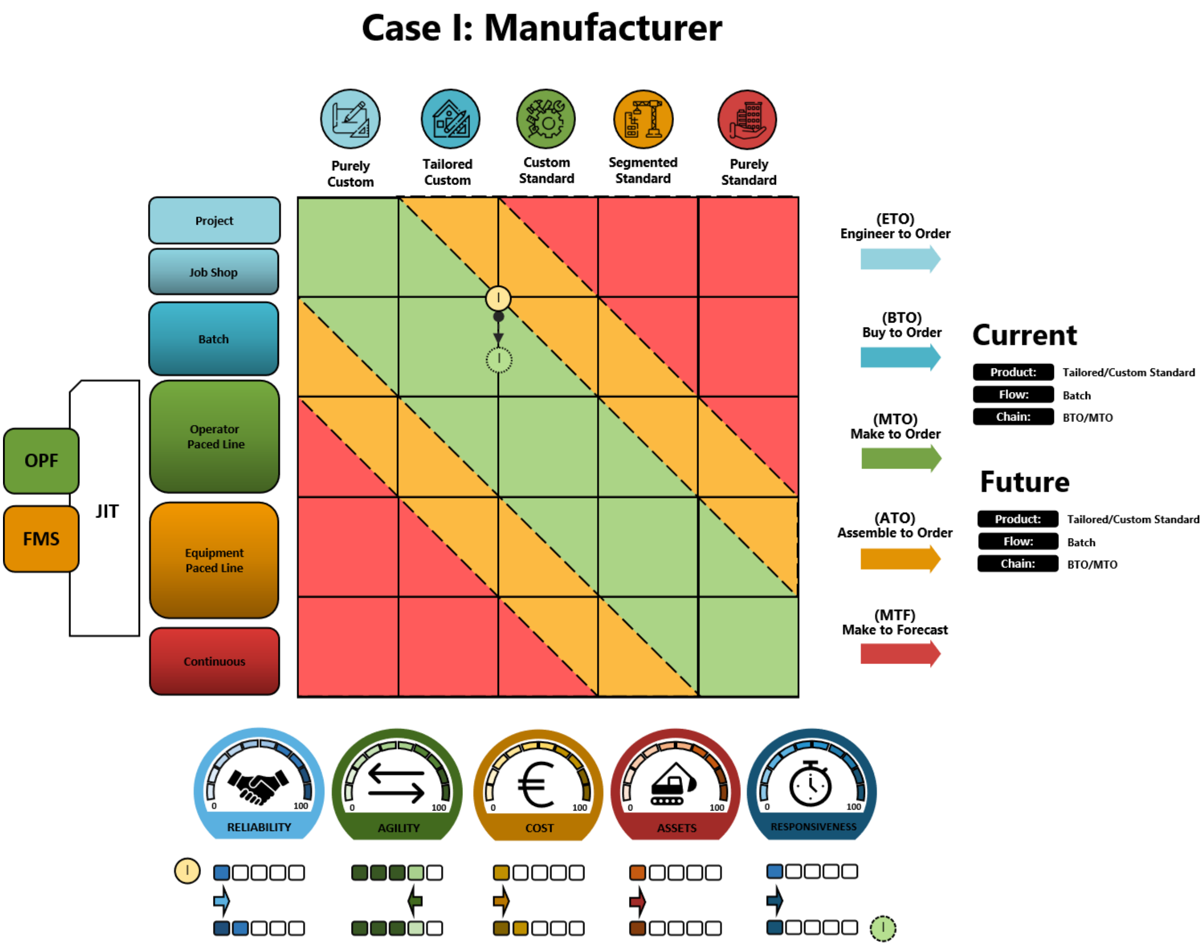


Figure 23 Case I: Configuration

3.4 CONSTRAINTS & POTENTIAL SOLUTIONS

Based on the conducted interviews, various internal and external barriers related to increasing production capacity and switching towards mass-customization strategies were identified. Insight into these barriers were indicated to be present in new property development as well as renovation. Indicated solutions have been supplemented based on previous conversations with interviewees and are provided hereafter.

Constraints

1. Inability of architects and developers to utilize standardized concepts or modules in unique designs or to configure designs based on customization permitted in concepts
2. Lack of capacity at regulatory institutions and government bodies associated with required permits for construction and renovation
3. Regulations which are mainly project-based and are not aligned with the application of standardized concepts
4. Regulations which require housing cooperations to obtain assent from end-users in properties which require renovation
5. The risk of decreased asset utilization when creating industrialized production lines
6. Reduction in flexibility of product mixes produced on a industrialized and committed line without significant costs associated with line changes.
7. Risks associated with investments in fixed capital (equipment) for the transformation towards industrial production lines (strategy adaptations)
8. Too much offered variety in products and customization options which impede standardization of products, processes and the development of joint interfaces between them
9. Required effort, costs and duration of engineering activities required in order to prepare production and abide by regulations. This is also indicated to impede progress towards single piece flows
10. Magnitude and diversity of the number of properties which are considered to require renovation
11. Fragmentation of suppliers and customers on the real estate market
12. Lacking actual demand for renovations and fluctuations in demand which does not justify significant investments by single parties.

Potential solutions

1. Development of a product platform which allows architects and developers to configure designs based on compatible modules or components
2. Guaranteed demand by government bodies and cooperations for the execution of renovations and production of required components. Guaranteed demand results in guaranteed capacity, less market fluctuations and is considered to justify investments in further industrialization of production systems
3. Abolition or adaptation of regulations which relates to required permits for standardized products
4. Abolition or adaptation of regulation which regard the required ascent of end-users in renovations if rent increases are waved
5. Automation of engineering and the application of interchangeable flexible manufacturing systems (cells)

6. Single piece flow renovations on-site by means of mobile factories with sophisticated equipment (e.g. printers).
7. Renovation contractors as retailers and installers of specific combinations of renovation components
8. Horizontal supply chain integration by both manufacturers as well as contractors
9. Joint investments by suppliers in a industrialized production facility/hub which enables industrialized production and rapid assembly.
10. Diversifying the focus on segments within the renovation market based on ownership and required energetic transformations which is indirectly related to construction year
11. Dis-considering renovation of non-monumental property before 1950-1960 and preparation of standardized new property producers to fill the gap
12. Focus on energetic renovations only: facades, windows and roofs. Immediately or later supplemented with prefabricated or custom installations for ventilation and thermal.

3.5 REFLECTION ON CONFIGURATOR

Based on the interviews and observations regarding the combination of strategies applied in various cases (Section 3.3), the position of these cases on the presented configurator are indicated in Figure 24. Although initial positioning of these companies had been executed, these positions are based on a single round of interviews and therefore not fully reliable. Furthermore, due to the dis-commonality of some companies included in the sample, not all positions are comparable. However, a comparison between various concepts related to new property development and a sample of manufacturers was enabled. As these companies aim for large output quantities by means of standardization and industrialization, insights into the development of products, process and configurations of their value chains are obtained. These insights can be valuable for the development of industrialized products, processes and value chains applicable on renovation as well.

Based on the relative position of various concepts on the configurator, it can be observed that a single concept is positioned within the area which is indicated to be infeasible. This is mainly due to the high degree of product standardization whereas the absence of a committed operator paced or equipment paced line flow does not enable the company to fully capitalize on the benefits associated with this customization strategy. Therefore, the organization of the current production system and value chain unnecessarily increase lead times and costs while being constrained by the standardized nature of the product. However, realization of a sophisticated line committed to such a product might include significant investments in fixed assets. Therefore, it might be appropriate to increasingly make a transition toward a committed production line when market demand permits to do so. If sufficient market demand is reached, stocking of pre-assemblies, modules or even finished product might be possible in this concept. The risk of underutilization of captured capital within these assets however increases with the level of completion of components in stock.

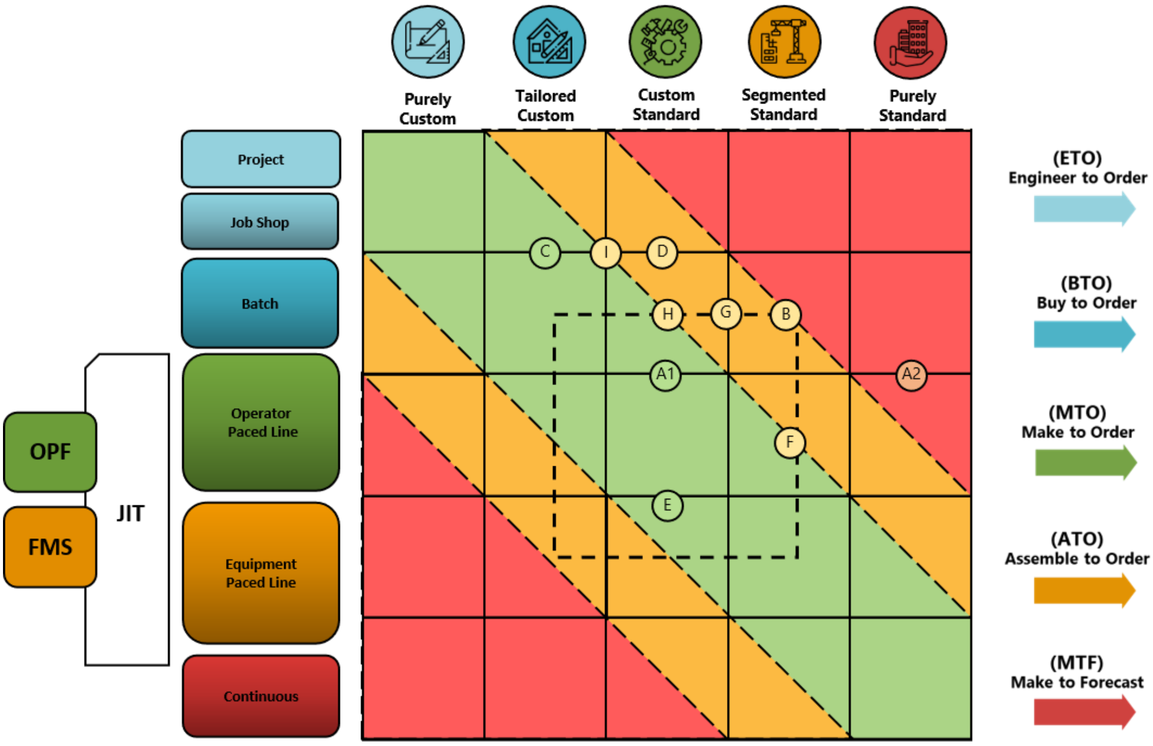


Figure 24 Strategy Assessment Configurator including cases

Besides a single concept in the infeasible space, six concepts are indicated to utilize a potentially infeasible combination of strategies. Two of these strategies produce segmented standard products in which the customer is permitted to make changes within a restricted solution space without directly affecting the on-site assembly of these concepts. Furthermore, four concepts were identified to utilize a customization strategy ranging between tailored customization and segmented standardization. The aforementioned concepts mainly utilize a job shop-based or batch-based flow while a single concept was identified to use an operator paced flow. To illustrate difficulties in adapting the organization of flows, the variety of products produced by companies G and B within a concept are produced at shared workstations in lots of 10. With regards to production systems, lower costs/shorter cycle times can be achieved by the organization of operator paced or single piece flows. Reduction of the lot size however might be undesirable due to the absence of a committed line (thus switching is required) or associated engineering costs (distributed over 10 lots instead of 1). Insufficient demand for specific product variants might cause companies to merge product lines whereas increased demand for a specific variant might enable the establishment of a committed line. Although the products produced in the concept of company H differ from the aforementioned products, issues related to the required flexibility through portfolio diversification are similar.

In the case of concept F, insufficient scale and/or demand has been achieved to justify progress towards EPL flows. The offered concept however is extremely suitable for large-scale production and assembled components can be stocked if sufficient demand is reached. In the case of concept D a large quantity of varying renovation solutions and options were offered and partially tailored to customers. However, the attributed workflow seemed to indicate a job-shop/batch-based flows. As the overall goal is to increase capacity and reduce costs, adaptation of an operator paced or one-piece flow during on site assembly might be appropriate. However, further research on the application of these flows in on-site processes should be conducted. In the instance of company I a large variety of customization is permitted in a partially standardized concept. In order to enable the pursuit of flexibility instead of cost-leadership of delivery speed as a competitive priority, a job-shop-based flow is utilized. To enable company I to reduce costs and increase delivery speed while retaining a large degree of flexibility, the pursuit of batch-based or one piece flows might be appropriate. However, optimization and eventually replication of the current production system might be appropriate if larger instantaneous investments are undesirable.

Finally, various concepts were identified to be present in the indicated feasible space. In the instance of concept C, the company considered flexibility to be essential to its competitive stance. It was indicated that although the company was satisfied with its current position, more progression towards line-based flows was desired to enable costs and delivery time reductions. In order to do so, advances should be made towards the organization of lines dedicated to multiple or single products. However, the variability in products which is offered within concept C might impede the organization of lines without losses due to changeover times. A gradual balance between product standardization and line organization can be combined with current system optimization. A focus on these aspects is expected to slightly reduce costs and minorly increase capacity. Finally concept A1 and E were considered to be present in the space of mass-customization. For both concepts a progression towards an operator paced and equipment paced line could be considered feasible if market pre-conditions are met. Furthermore, raw materials or components could be stocked in cases more downside flexibility is required or if up-site reliability is low in the supply chain. Both parties are enabled to safely diversify products and to effectively achieve cost leadership if current production stability can be maintained.

4. CONCLUSION

Due to the large quantity of buildings which require renovation as well as the need for lower-cost renovations adaptations of strategies utilized by construction value chains are required. In order to achieve large output quantities (finished renovations) and to account for variations in individual requirements a balance between the output indicators of (1) flexibility, (2) reliability, (3) responsiveness and (4) cost should be perused. In order to do so, the overall production strategy of mass-customization can be perused. Within mass-customization restricted flexibility is perused through product customization whereas cost and cycle time reductions are achieved through standardization of product and process components. However, it should be noted that a transition towards mass-customization requires the adaptation of various strategies simultaneously instead of individual strategies. Combining appropriate strategies is required to ensure achievement of desired output indicators and hence, market competitiveness and growth of companies operating within the construction industry. As a balance between customization-related and standardization-related properties should be perused to achieve mass-customization, these companies should aim for a hybrid competitive strategy consisting of product differentiation and cost-leadership. As mass-production and mass-customization requires a relatively stable and sufficient demand of buildings with similar properties, buildings owned by housing cooperations should be considered first to achieve economies of scale. As the hybrid competitive strategy regards a business strategy, several functional and operation strategies should be adapted in order to successfully fulfill the aforementioned hybrid strategy. These strategies encompass (1) the degree of product standardization (customization strategy), (2) the configuration of the value chain and (3) the strategy associated with the organization of flows in production systems. To achieve mass-customization and required output indicators by the market, the most appropriate combination of functional/operational strategies consist of (1) customized standardization of products, (2) MTO/ATO value chain configurations and (3) line flows which are either operator paced, equipment paced, one piece flows or flexible manufacturing systems.

If sufficient scale and stability of market demand can be achieved to justify investments associated with the aforementioned transitions, application of these combined strategies can contributed to unlock additional renovation capacity in the construction industry. Furthermore, the cost reductions through standardization (replication) realized by means of these strategies can contribute to scalable and payable renovations which are required by the market. The presented configurator and reflection on the configurator thus contributes to the body of knowledge required for increasing renovation capacity by means of industrialized mass customization. As the configurator involves various strategies and combines them, it enables organizations to identify possible changes of construction processes and logistics top down. Top-down changes are vital as the appropriate levels of strategy need to be assessed and adapted to enable sustainable progression towards designing or realizing the **most appropriate** production system and desired attributed outputs. Therefore, the initial configurator was first developed, its usability was tested by means of a fictive case after which initial verification in practice was sought. In future research the aspects of the configurator will be further verified, extended and/or adapted if required. After realization, verification and extension of the configurator it can be utilized by varying companies on the renovation market to determine the most appropriate strategy and to re-design production systems accordingly.

4.1 DISCUSSION

Initial practical verification is mainly based on the interviews which have been conducted till date. Additional interviews focusing on a more homogeneous sample of manufacturers and contractors associated with renovations should be conducted. A more homogeneous sample is required to enable comparison between individual companies. Such a comparison and deeper insights into the renovation market was not fully possible within the current sample. However, it should be noted that inclusion of best-practice contractors associated with (modular) new property development enabled the extraction of valuable insights. These insights can aid in the determination of appropriate strategies associated with renovation as well. Therefore, it could be valuable to conduct additional interviews and attend conferences which include best-practice companies within and outside of the Netherlands. Although initial positioning of various companies on the presented configurator was enabled, further investigation of their products, production system and value chain configuration strategies can be conducted. These investigations could involve product analysis, factory visits and additional interviews when Covid-19 restrictions permit so. Furthermore, various market segments, investments associated with navigation over the configurator and simulation of achievable outputs can potentially be added to the presented configurator.

Within the presented deliverable an emphasis was placed on achieving mass-customization whereas consideration of achieving other strategies (e.g. personalization) were not extensively discussed. Pure customization, ETO value chain configurations and project based flows could for example be considered appropriate for buildings or clients requiring a purely customized approach (e.g. monumental structures). The associated costs, lead times and overall output capacity related to companies which focus on such an approach are not in line with the overall goal to significantly increase renovation capacity and decrease associated costs. However, a portion of the buildings which require renovation will never be suitable for renovation by means of mass-customization. Therefore, the combination of other strategies by companies aiming for deviating market output indicators (e.g. more flexibility) is required to successfully renovate 7.8 million properties as well.

Besides a significant part of existing buildings which are potentially not suitable for renovation by means of mass-customization, demolition and reconstruction of a part of these buildings, as indicated by a majority of the interviewees, might be the most feasible solution. Most of the dwellings which might not be directly suitable for mass-customized renovations have been constructed before 1950. Therefore, the focus should be mainly on buildings constructed after 1950 which are mostly owned by housing cooperations . These buildings consists of both single-family as well as multi-family buildings and require insulation of (1) floors, (2) facades, (3) roofs and (4) the application of energy efficient installations. Due to the complexity related to multi-family buildings, the initial focus should be on the renovation of façades and roofs for single-family dwellings. After these buildings have been sufficiently isolated, the application of energy efficient installations is enabled. Application of these installations without additional insulation can be appropriate for buildings which have been constructed relatively recent (2000-2021).

Although the aforementioned strategies are considered to be most appropriate to realize a balance between flexibility, cost and cycle time, several transitions should be made in order to do so. To achieve a customized standardization strategy, product standardization is required whereas customization of product aspects along which customer requirements diverge the most should be permitted. This can be achieve through solution space development based on extensive market research. Successful establishment of upstream MTO/ATO value chain configurations enables companies to stock material and/or semi-finished products required for renovation. Hence, cost and lead times can be significantly reduced while product flexibility permitted to clients (downstream) is confined to the selection of standardized and stocked materials/semi-finished products. To successfully establish (upstream) MTO/ATO value chains supply chain integration or partnering should be realized whereas downstream MTO/ATO configurations can be achieved by means of postponement of customer involvement towards the renovation phases of fabrication or assembly respectively. To successfully establish operator or equipment paced line flows in production systems, the realization of lines which are committed to a selection or a single product is required. By doing so, the flexibility of the process, outputted product(s), associated costs and cycle times are significantly reduced. Furthermore, the establishment of committed lines required significant investments in specialized human and equipment capital. Hence, the importance of stable and sufficient market demand for product produced on these committed lines can be underlined due to a reduction of a company's product portfolio and requirement of significant investments. To provide companies operating in the construction industry insights into potentially achievable output parameters and by comparing them with required investments, a transition towards industrialized mass-customization can be aided. To prevent disruptions of current production systems and attributed operations in companies, digital simulations can be desirable.

4.2 ADDITIONAL RESEARCH

To further simplify the utilization of the developed strategy configurator and to aid transition towards the desired combination of strategies aligned with desired output parameters, further research should be conducted. First, additional research is required to enable companies to conduct an analysis of current state products and production systems. This can be achieved by means of the development of a quick scan or workshop which enables companies to plot their relative current position on the presented configurator. Furthermore, such a quick scan can be expanded to determine their desired future state position and to provide insights into the required transitions. Plotting their current and desired position on the configurator and providing insights into the required transitions can provide companies with insights into the required adaptations of their strategies. By means of establishing observations regarding the current position and the desired position through a quick scan or workshop, specific problems can be formulated which are aligned with the required transitions associated with strategy adaptations (e.g. lowering production costs).

After specific problems have been formulated for individual companies, appropriate data can be collected (e.g. throughput times, utilization rates & process design) which enables the construction of a digital model of the current and desired processes. After both of the models are sufficiently verified (e.g. by an expert panel), production simulations can be executed digitally instead of physically. These simulations can yield specific output values related to desired market performance indictors (e.g. total cycle time & costs). Analysis of the yielded output values in multiple scenarios enables the identification of the most appropriate scenario and would thus enable insights into feasible strategic transitions. For the execution of these complex simulations, dynamic agent-based simulation models such as discrete event simulations (DES) might be most appropriate. DES is a method which can be suitable for the simulation of complex systems such as construction industry value chains. DES is utilize to obtain insights into complex relationships between components, resources and the manner in which the are used in a production system or process. The usage of DES in manufacturing industries for the assessment of exiting processes and for the development of new processes is widespread while the application of DES in the construction industry has been rare (Birgisson, 2009). For the execution of DES experiments, a variety of free-to-use and commercial software is available such as (1) AnyLogic[7], (2) Arena[8] (3) Siemens Plant Simulation[9] and SimPy[10]. The nominal process sequence attributed to DES is depicted in **Figure 16**. If DES is the most appropriate method for further research and thus will be applied, has to be established in subsequent deliverables.

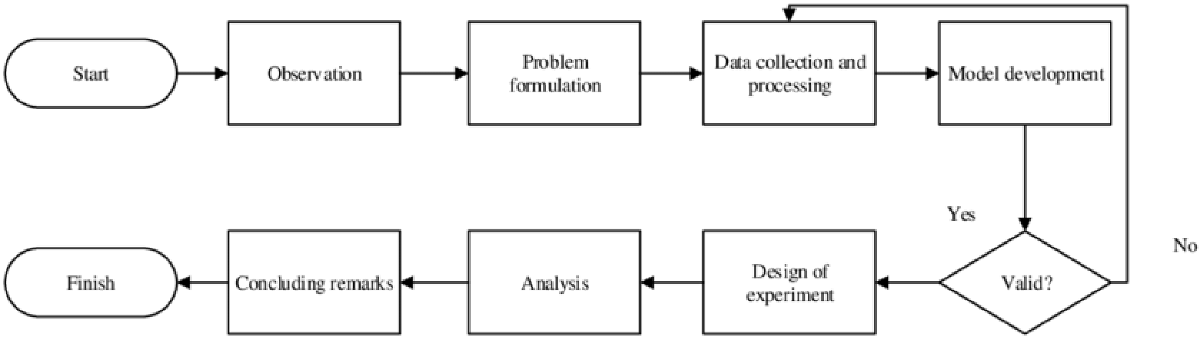


Figure 25 Discrete event system simulation steps adopted from Sulistio & Hidayah, (2017)

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[7] https://www.anylogic.com/
[8] https://www.arenasimulation.com/
[9] http://www.plm.automation.siemens.com/en_us/products/tecnomatix/plant_design/plant_simulation.shtml
[10] http://simpy.readthedocs.org/

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