

Flow Dimensions at Swedish Construction Contractors

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Abstract

Research Question: How do different flow dimensions and their interrelations appear in Swedish construction settings?

Purpose: To contribute to the ongoing discussion on flow in construction by providing empirical data to a proposed flow model and widening the current understanding within Lean Construction with theory from industrialized construction and operations management.

Research Design: Transcriptions of nine in-depth interviews with managers at different Swedish contractors were utilized to identify different flow dimensions.

Findings: Results show different patterns which describe contractors' focus on different flow dimensions.

Limitations: The study is performed in Swedish construction companies with limited generalizability to construction in general. Data collection based on interviews might struggle with objectivity and multi-case studies do not coincide with in-depth research in each single case.

Implications: Different flow dimensions are relevant within construction contractors and should be addressed by either management activities or an operations strategy.

Value for practitioners: Increased understanding of flow in construction based on empirical data enables management of different flow dimensions to evolve contractors' operations strategies towards Lean Construction or industrialized construction.

Keywords: Industrialized construction, Lean Construction, operations management, operations strategy

Paper type: Full paper

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Introduction

Many things flow in business - material, information, manpower, money, and equipment (Forrester 1958). Ford's manufacturing system and Toyota's production system (TPS) are two approaches from the car industry to improve production flow (Krafcik 1988). Lean principles as a result from TPS (Womack and Jones 2003, Liker 2004) have influenced the construction industry through Lean Construction (Koskela 2000). However, the concept of production flow is not well understood in the construction context (Sacks 2016).

Construction is production organized in projects (Ballard 2000). Construction contractors are project-based organizations managing a portfolio of projects (Lessing 2015). All construction projects contain a series of operations that create a flow (Lidelöw and Simu 2016). Shingo and Dillon (1989) suggested a two-dimensional structure of production, which consists of process and operations flow. Sacks (2016) presented the portfolios-processes-operations model (PPO) and identified the need to understand distinct flows of projects, locations and trades. The PPO-model is based on the common understanding of production theory in Lean Construction (Ballard 2000, Koskela 2000), but is not empirically tested. In contrast to general construction settings, the Swedish construction context (Lessing et al. 2015, Lidelöw et al. 2015) can contain empirical data due to an ongoing industrialization process that offers the possibility to study portfolios, processes, and operations in empirical multi-case data.

The concept of flow is applied in areas as operations management (OM, Slack et al. 2016), Lean production (LP, Womack and Jones 2003, Liker 2004), Lean Construction (LC, Koskela 2000), and supply chain management (SCM, Mentzer et al. 2001). Nevertheless, its understanding is subjective and personal (Sacks 2016) and not easily defined due to its use in different operational conditions (Kalsaas and Bølviken 2010). So far, the concept of flow is generally used in industrialized construction publications (e.g. Jansson 2013, Erikshamar 2014, Lessing 2015) often combined with other words, e.g., material, information, or production but not defined in terms of clarifying whether the context implicates movement, transformation or value creation. Additionally, the portfolio flow dimension as termed by Sacks (2016) is not mentioned, even though projects flowing through industrialized construction companies portfolios are described in the field by, e.g., Lessing (2015) and Jansson et al. (2014). The Swedish construction settings can create theoretical and practical knowledge because industrialized construction companies have a need to improve the flow of projects in their portfolio to utilize their investments in standardization, long-term relations, and production systems as well as their niche market specializations (Lessing et al. 2015).

Traditional construction practices are criticized for supporting activity centered operating systems with specialized sub-contractors (Howell et al. 2011), which potentially lead to a strong operations flow focused business (Bertelsen and Sacks 2007) without creating reliable work flow in the complex and chaotic construction environments (Abdelhamid 2004). In contrast, a lean or industrialized construction based business approach would even address process and portfolio flows. To address this assumption, the aim of this study is to investigate the traceability of different flow dimensions exemplified in Swedish construction settings. This research contributes to the understanding of flow in construction, which is necessary for evolving contractors' operations strategies towards Lean Construction or industrialized construction.

Theoretical framework

The concept of flow in business processes is not new. Already Forrester (1958) stated: “*Management is on the verge of a major breakthrough in understanding how industrial company success depends on the interactions between the flows of information, materials, money, manpower, and capital equipment. The way these five flow systems interlock to amplify one another and to cause change and fluctuation will form the basis for anticipating the effects of decisions, policies, organizational forms, and investment choices.*” Flow is applied in areas as OM (Slack et al. 2016), LP (Womack and Jones 2003, Liker 2004), LC (Koskela 2000), and SCM (Mentzer et al. 2001), often without clear definition but combined with other words to create a term in a specific context. Pfohl and Gomm (2009) for example, distinguish between flow of goods, flow of information and financial flow. Mentzer et al. (2001) differentiate flow of goods to be products or services and flow of information to be separated in forecast, demand and information. Even though both sources frequently use flow, the authors do not exactly define it. Their focus seems to be on the movement of things (products, services, finances, and/or information) between different organizations (e.g. company, supplier, and customer) involved in a network of upstream and/or downstream institutions.

Flow in operations management

Every organization uses resources to maintain a process of creating something with the objective of making profit or serving the society (Slack et al. 2016). To let items flow rapidly and smoothly through the process is one of the main objectives of Lean (Slack et al. 2016). Schmenner and Swink (1998, p. 102) theorized this in OM as the theory of swift and even flow and stated that: “*the more swift and even the flow of material through a process, the more productive that process is.*” Schmenner (2001) empirically validated the theory with historical data, and showed that the theory was grounded far before Ford’s manufacturing system or LP, i.e., during the 1st industrial revolution (Crystal Palace) or at the Arsenal in Venice, where the galleys for the powerful Venetian navy were built and equipped between the 12th and 18th centuries.

Later on, Liker (2004) defined 14 fundamental management principles behind TPS. His second principle refers to creating a continuous process flow to bring problems to the surface. The process flow within this principle is different from the material flow of movement as it refers to overall transformation from raw material to finished goods or services - and has been termed production flow by Rother and Shook (2009), who use production and manufacturing synonymously and state that “*Toyota people learn about three flows in manufacturing: the flows of material, information, and people*”. Their value-stream mapping method focuses on measuring and visualizing the flows of material and information in a production system. Using value-stream mapping, flow is identified as all actions required to bring: 1) the product from raw material to the customer in the production flow or 2) a concept to launch in a design flow. The focus is on visualizing the value-creating flow to improve the whole instead of individual single-processes as a part of the value-stream (Rother and Shook 2009). The value-stream (production flow) in this method consists of processes, which implies that the process dimension is on a different level compared to Liker (2004) who focuses on overall processes.

The importance of jointly considering flow and value is emphasized in the Lean principles defined by Womack and Jones (2003) as they point out that continuous flow of the value-creating steps from the product point of view is the objective for efficiency instead of internal focus on organization or equipment. Flow is defined as “*the progressive achievement of tasks along the value stream so that a product proceeds from the design to launch, order to delivery, and raw material into the hands of the customer with no stoppages, scrap, or backflows*” (Womack and Jones 2003, p. 348).

Modig and Åhlström (2015) define flow units to be the critical element in processes because they are the units to be processed. Even though the word process comes from the Latin word *processus* or *procedere* and means ‘*to move forward*’, Modig and Åhlström (2015) point out the importance of moving forward in the transformation process by activities e.g. machines and assembly or analysis in healthcare, which is something different from movement in terms of transport, which they classify as waste.

Flow in construction

In construction, the concept of flow has been widely discussed during the last two decades e.g. within the ‘*International Group of Lean Construction*’ (Rooke et al. 2007, Kalsaas and Bølviken 2010, Lidelöw and Simu 2016). Koskela (2000, p. 90) introduced ‘*flow*’ to the construction context by defining the transformation-flow-value generation model, termed the TFV theory of production and argued that all three parts in the model should be operated simultaneously in production management, product design and development, to extend “*attention to modelling, designing, controlling, and improving production from all these three points of view*”. The distinction of the three parts of the TFV theory lies in their main objectives. While task management focuses on transformation and related costs, the main objective for flow management is to minimize the non-value-adding activities between the transformation activities while the customer-related goals are captured by value management. Flow in the TFV theory are the non-transformational parts of production; waiting, inspection, and moving stages, a definition contrasting the ideas from Lean literature who see the main objective of flow to be the transforming or value-adding activities as discussed above (Womack and Jones 2003, Liker 2004, Rother and Shook 2009, Modig and Åhlström 2015).

According to Sacks (2016), the flow in manufacturing “*is understood as a path through which a product progresses as it is processed from raw material to finished product (taking flow as a noun) or as the physical movement of the product along the path (as a verb).*” Kalsaas and Bølviken (2010) stated that the term flow is popular among both practitioners and academics but not precisely defined - “*to flow*” as verb means to “*move freely and continuously*” and “*flow*” as noun is “*the flowing movement/ continuous stream of something*”. They conclude however, that value should be included in the concept of flow and moreover extended with “*Shingo’s flow concept with the dimensions of process and operation, which include processing, inspection, delay, transport/movement and supportive work*”. Shingo and Dillon (1989) suggested a two-dimensional structure of production which consist of processes to be “*a flow of material in time and space; its transformation from raw material to semi-processed component to finished product*” on one hand, and on the other hand operations to be “*the interaction [with the flow of material] and flow of equipment and operators in time and space*”.

Shingo and Dillon's two-dimensional structure is formulated for manufacturing settings within TPS.

Kalsaas and Bølviken (2010) applied Shingo and Dillon's structure of production to construction and concluded *"that the process can be conceived of as the progress of the project, while the work undertaken by the different trades constitutes the operations. A construction project is seen as a process of aggregated sub-processes; however, not primarily comprising sequential but also reciprocal interdependencies. Operations in construction can be split into more or less aggregated work-packages, each of which has its own internal flow that includes processing, inspection, transport/movement and delay."* The process dimension describes the product flow (Sacks 2016) while the operations dimension refers to the work flow (Kalsaas and Bølviken 2010) of workers and machines. The differentiation in two dimensions leads to the conclusion that improvements in operations do not automatically improve the process flow of the products (Shingo and Dillon 1989). The value-stream mapping method as mentioned above do not include the flow of people (operations dimension) which Rother and Shook (2009) referred to be on a lower *"vantage point to see"*.

To fit Shingo and Dillon's model to construction settings, Sacks (2016) applied the concept of location flow (as introduced by Koskela 2000) to be part of the process dimension (comparable to products in a manufacturing line) while trade flow refers to operations. This definition is in line with Bølviken et al. (2014) who distinguished product flow to represent the production process and work flow, which refers to the flow of work to be carried out by the workers (operations). In addition, Sacks (2016) noted, that the *"term construction work flow appears to be used by different authors, and presumably also by practitioners, for what are two distinct flows: 'work' as product and 'work' as task. A preferable approach is to define work flow distinctly according to the two axes of operations and process as location flow (process) and trade flow (operations), respectively"*. Locations in this contexts are not only geographical places, they refer to divided sections of the construction objects, e.g., building (Jongeling and Olofsson 2007) resulting in a project's location breakdown structure for labor flow planning to minimize waiting times both for work to wait for workers and workers wait for work (Seppänen et al. 2010).

Construction is generally seen as project-based production with a high degree of subcontracting (Sacks 2016), which forces project management to use contractual techniques to manage the risk (Howell and Koskela 2000). This contracting practice towards trade contractors pushes project management to mainly focus operations and project managers primarily towards contracts instead of projects (Bertelsen and Sacks 2007). Following Shingo and Dillon (1989), construction is managed as a series of operations with low focus on the process dimension and risks to overlook the flow perspective of the products and projects. Variability in the production capacity of upstream trades impacts negatively the productivity of downstream trades and the performance of entire system in terms of project duration, lost capacity, and inventory buffers (Javanmardi et al. 2016). To prevent this, the line-of-balance chart as a two-dimensional representation of processes and operations of single projects can be utilized in construction (Jongeling and Olofsson 2007; Seppänen et al. 2010; Sacks 2016). Alternatively, the Last Planner System (Ballard 2000) has been suggested to improve productivity by creating a predictable work flow (Liu et al. 2011).

Sacks (2016) proposed to extend the two-dimensional structure of production as suggested by Shingo and Dillon (1989) with a third dimension, representing the “flow of work from project to project in a portfolio” (Figure 1).

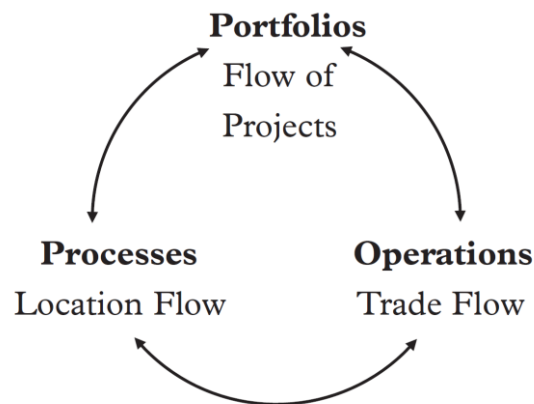


Figure 1: Cyclical view of the PPO-model (Sacks 2016)

The project portfolio dimension in the PPO-model is crucial to explain the peculiarity between construction and manufacturing in addition to size and immobility of the product with workforce and equipment executing different operations at diverse locations around the product (Bertelsen et al. 2007). Sacks (2016) summarized his three-dimensional model by stating that: “*construction work flow can be understood as functioning on three interrelated axes: portfolio, process and operation. In this model, trade crews are considered to flow not only from location to location within a project, but also from location to location across projects. Operations can extend across projects, reflecting an interdependence between projects.*” The logic of the “*project portfolio axis reflects the fact that design and construction occur simultaneously across many projects in any given regional economy*” and “*subcontractors balance their workload across projects, creating a flow of labor between the operations of different projects*”.

Flow in industrialized house-building

Beside the presence of LC, flow related issues have been driven in the Swedish construction by what we refer to as industrialized house-building (IHB). Lessing (2006) describes IHB in his licentiate thesis as “*a thoroughly developed building process with a well-suited organization for efficient management, preparation and control of the included activities, flows, resources and results for which highly developed components are used in order to create maximum customer value.*” The frame of his concept consists of characteristic areas that are linkable to different flow concepts. Information flow is represented through the areas ‘*Use of information and communication technology*’ or ‘*Performance measurement and re-use of experience*’ while material flow is characterized through ‘*Off-site manufacture*’ and ‘*Logistics integrated in the building process*’ (Lessing 2006). Lidelöw et al. (2015) further developed the IHB-concept by connecting the characteristic areas to a business model construct and to the platform concept (Figure 2). They define the logic of IHB companies to make money as the main target of the business model by utilizing a platform referred to as the resource base in the business model. The platform consists of four parts - technology, process, suppliers and knowledge - with continuous improvements of all parts around the central business model.

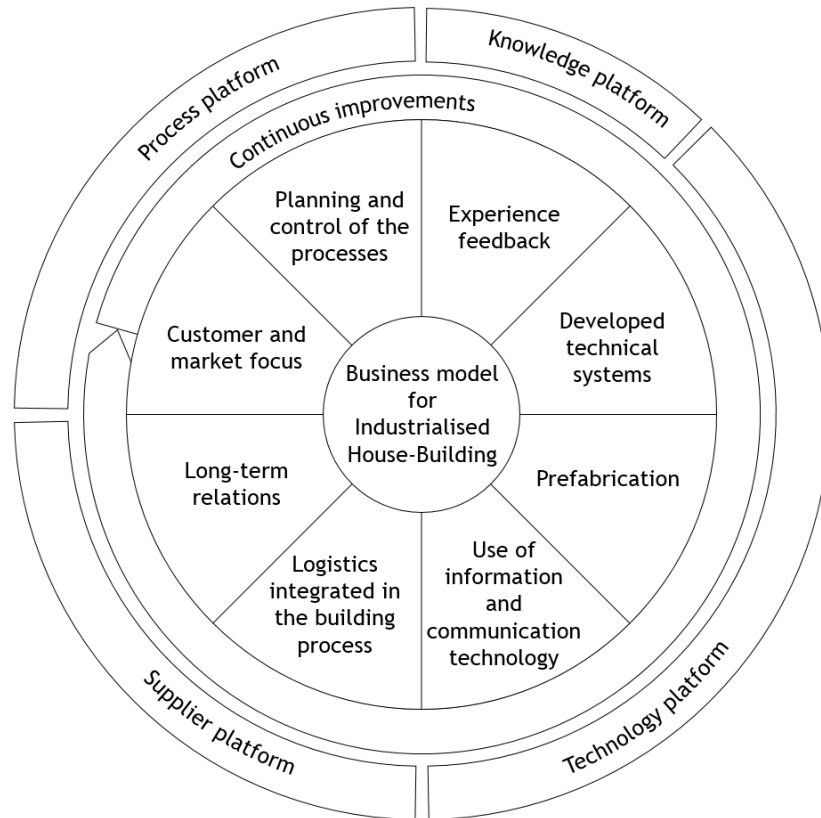


Figure 2: Definition of industrialized house-building (adapted by Lidelöw et al. 2015 from Lessing et al. 2015)

Lessing (2015) connected the platform concept that supports the execution of building projects with a structured flow of information from the platform level to the individual projects in the portfolio and from the individual projects back to platform development process (Figure 3). Both the platform development process and the portfolio of projects are visualized as flowing objects.

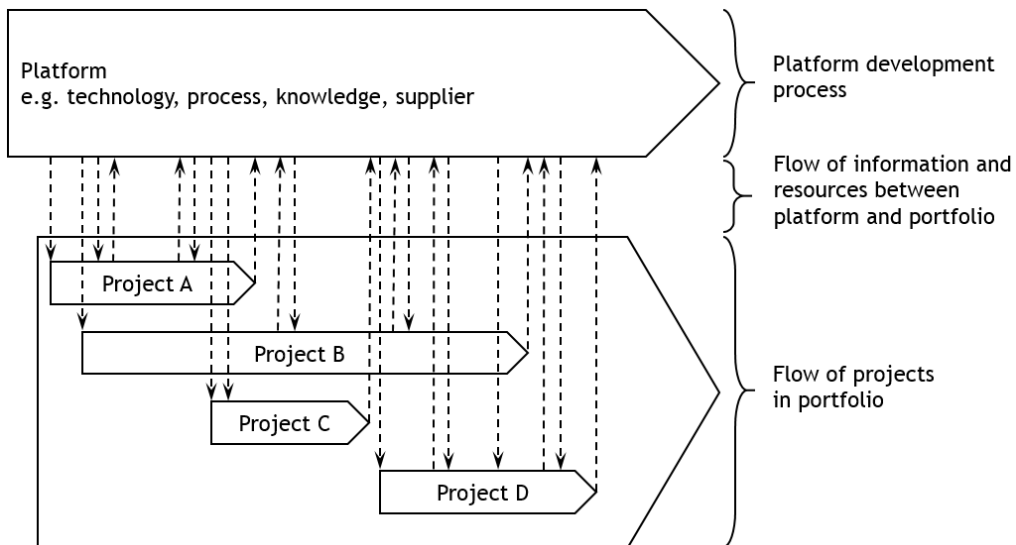


Figure 3: Platform development process that supports the flow of projects in the portfolio (adapted from Lessing 2015 and Jansson et al. 2014)

IHB companies utilize a platform to re-use experience and knowledge between projects (Lidelöw et al. 2015). Platform initiated standardization intended to reduce the costs in the design phase, in the procurement work, and in the production phase by narrowing down the number of possible choices while at the same time allowing for local variation and individual creativity (Styhre and Gluch 2010). The intention of the platform is to create a continuous flow of output from the portfolio by an effective flow of resources and information back and forth from the platform to the single projects.

The continuous improvement process that includes all parts of the platform (Figure 2) is organized to enable an ongoing flow of individual housing projects and simultaneously a flow of continuous improvement of the platform (figure 3, Lessing 2015, Meiling et al. 2014). The parallel processes makes IHB an interesting research subject for the PPO-model because IHB companies invest in their platforms, off-site production systems, long-term relationships with suppliers and customers, integrated logistics, and focus on niche market specialization (Lessing 2015). These investments must be utilized in a project portfolio; otherwise, the IHB-companies find themselves in an economical risk situation of higher costs compared to traditional competitors due to their investments and with a low utilization of self-owned resources. To summarize, IHB companies should have methods, tools or processes to control the flow of projects in their portfolio, making the Swedish construction context an interesting research objective for the PPO-model.

Summary of literature review

Even though this paper is not aimed to be a complete literature review about flow, we summarize our most relevant findings in Table 1 ordered by their year of publication.

Table 1: Summary of relevant flow definitions

Flow concept	Definition	Reference
Flows of information, materials, money, manpower, and capital equipment	Movement of flow objectives in industrial systems	Forrester 1958
Process flow	Flow of material in time and space; its transformation from raw material to components or finished product	Shingo and Dillon 1989
Operations flow	Interaction with the process flow and flow of equipment and operators in time and space	Shingo and Dillon 1989
Flow of material	Process of material to product through value-adding (transforming) work	Schmenner and Swink 1998
Flow	Non-transformational parts of production (waiting, inspection, and moving)	Koskela 2000
Flow of products, services, information, financial resources, demand, and forecast	Movement of flow objectives in supply chains	Mentzer et al. 2001
Flow	Progressive achievement of tasks along the value stream so that a product proceeds from the design to launch, order to delivery, and raw material into the hands of the customer	Womack and Jones 2003
Process flow	Overall transformation from raw material to finished goods or services	Liker 2004
Production flow, design flow	All actions required to bring a product from raw material to the customer or a concept to launch	Rother and Shook 2009
Flow	Flow as verb means to move freely and continuously and flow as noun is the flowing movement/ continuous stream of something; chain of events to add value	Kalsaas and Bølviken 2010
Work flow	Carried out by the workers (operations)	Bølviken et al. 2014
Flow unit	Critical element in processes to move forward by the transformation activities	Modig and Åhlström 2015
Flow in manufacturing	Path through which a product progresses as it is processed from raw material to finished product (taking flow as a noun) or as the physical movement of the product along the path (as a verb)	Sacks 2016
Location flow	Represents the process flow in construction	Sacks 2016
Trade flow	Represents the operations flow in construction	Sacks 2016
Flow of projects	Representing the flow of work from project to project in a portfolio because design and construction occur simultaneously across many projects	Sacks 2016

Model of analysis

The PPO-model (Figure 1) consists of the three main flows - portfolio, process, and operations and the arrows in between. Shingo and Dillon introduced the distinction between processes and operations to production theory, which has been adopted in LC by e.g. Sacks (2016), Bertelsen and Bonke (2011), and Koskela (2000). Even though many researchers in LC seem to agree on this distinction between processes and operations, the authors choose a terminology from OM theory instead (Slack et al. 2016). This allows a distinction of transformed and transforming resources. The flow of a project in a portfolio from customer request to delivery is a process as well as the transport of equipment or the movement of an operator from one location to the next, but both are not classified as 'Processes' in the PPO-model as they are parts of 'Portfolio' and 'Operations' respectively.

The distinction between transformed and transforming resources (Slack et al. 2016) does not contradict the TFV Theory (Koskela 2000), as we include flow and value in the analysis constructs in the relevant construct definitions. Our terminology allows for inclusion of the flow of material, resources (equipment and labor), and information in the analysis model, even though Sacks (2016) exclude these from the original PPO-model. Additionally, we consider the portfolio dimension to allow both a single company portfolio interpretation as well as a regional construction economy understanding.

To the authors, flow refers to the evenness and speed of processes within OM, either in transforming events to create a continuous value transmission from transforming resources to transformed resources or in movement events to create a continuous transport of the resources to the transforming events or to the customer.

Sacks (2016) does not explicitly define the arrows in the PPO-model; he uses 'interdependency' as an explanation and states that the "interdependence of the flows means that improving location flow can positively affect both project flow and trade flow." Dubois and Gadde (2002) point out that "every single industrial activity is to some extent interdependent with a number of other activities: they are coupled in various ways" with some of these "couplings are 'tight' while others are 'loose'". A rigid sequence between operations of a production process in construction is a classic case of sequential interdependence of work (Winch 1989). The degree of coupling between two units depends on the activity that the two units share and how they influence each other i.e. a weak coupling results in strong independence of two units (Dubois and Gadde 2002). We follow Sacks' (2016) interdependence terminology for further use in the model of analysis which in summary consists of six constructs based on the PPO-model as described in detail in Table 2.

Table 2: Model of analysis

Analysis model construct	Main indicator for construct	Main references for construct
Portfolio flow	Multiple project management Flow of projects in portfolio	Sacks (2016) Lessing (2015) Bertelsen and Bonke (2011)
Process flow	Transformed resources as materials, information, locations, or single projects move, wait, or receive value	Shingo and Dillon (1989) Womack and Jones (2003) Bertelsen and Sacks (2007) Sacks (2016)
Operations flow	Transforming resources as trades, operators, or equipment move, wait, or add value to transformed resources	Shingo and Dillon (1989) Sacks (2016) Slack et al. (2016)
Interdependency between portfolio and process flow	Transformed resources (e.g. material, information, location, single project and product) within the multiple project management	Sacks (2016) Modig and Åhlström (2015)
Interdependency between portfolio and operations flow	Transforming resources (e.g. operators and equipment) management within multiple project management	Bertelsen and Sacks (2007) Sacks (2016)
Interdependency between process and operations flow	Interaction of transforming resources (e.g. operators and equipment) with transformed resources (e.g. material, information, location, single project and product)	Shingo and Dillon (1989) Rother and Shook (2009) Seppänen et al. (2010) Sacks et al. (2013) Modig and Åhlström (2015) Slack et al. (2016)

Method

Data collection

Nine managers on top or middle level from different construction contractors in Sweden were interviewed for about one hour. The selection of respondents was based on their position in the contractor and due to their long-term experience in construction (Table 3). The interviews were semi-structured and refer to the contractors' organization, standardization and variation within and between projects and processes, relations to subcontractors, experience feedback, competitive advantage, and how resources are balanced between projects. All interviews were recorded, fully transcribed and sent to the respondents for approval. The contractors inherit the same abbreviation as the respondents in the following chapters. Their business varies from apartment house-building, commercial house-building, and infrastructure.

Table 3: Respondents

Respondent	Respondent's position at contractor
A	Platform manager, part of top management, joint liable for a turnover of 45 M€
B	Middle manager, reporting directly to top management, liable for a turnover of 50 M€
C	CEO and cofounder, liable for a turnover of 3.5 M€
D	Top manager, responsible for one third of the total business, liable for a turnover of 35 M€
E	Platform manager, part of top management, joint liable for a turnover of 1,300 M€
F	Lean manager, reporting directly to top management, liable for improvements of 10 M€
G	Middle manager, reporting directly to top management, liable for a turnover of 100 M€
H	CEO, liable for a turnover of 110 M€
I	Middle manager, reporting directly to top management, liable for a turnover of 30 M€

Data analysis

The unit of analysis in this research are the contractors, the appearance and importance of different flows and their potential interdependencies. The analysis was performed according to the following procedure:

A) Coding

The analysis model constructs (portfolio, process, and operations flows and the three interdependencies portfolio-process, portfolio-operations, and process-operations) are utilized as labels in the coding. The interview raw data transcribed in nine different word-files (one per contractor) has been read and findings in the text have been colored (each label a different color) when identifying one of the labels according to their definitions as described in the model of analysis (Table 2). The identification of the labels follows the logic of coding as described by Miles and Huberman (1994) i.e. the raw data is tagged with the label when the respondent express something meaningful relatable to a label's definition. All interviews have been coded in sequence in randomized order by the first author of this research.

B) Grouping

In this step, all identified findings have been copied to an excel-file (one sheet per contractor) and compiled within the different labels. Miles and Huberman (1994) refer to this step as data reduction and clustering to abstract and group relevant data out of a larger amount of raw data before further analysis.

C) Positioning of contractors in model of analysis

The grouped findings have been reread, further reduced to remove doublets and vague findings, counted, and compiled in a spreadsheet (Table 4) with the intention to assess prioritized flow dimensions at each contractor. Table 4 might lead to the assumption that the grouped findings have been quantified and the contractors' position in the model of analysis is mathematically calculated as the center of all six quantities representing the constructs. This would be possible, but undermine the depth of the

qualitative data. Instead, all authors read the reduced findings, weighted against each other and concluded in individually suggested contractor positions in the model of analysis. A more central position implicates a balance between the flow dimensions. With increased distance from the center, one or two flow dimensions or their interdependencies increase in significance. In a final analysis meeting with all authors participating, the findings have been discussed and resulted in an agreed position of the contractors in the model of analysis as visualized in Figure 4. Consequently, the quantities as presented in Table 4 are one assessment aspect for the contractor positions in the model of analysis beside the reduced findings' judgment of all authors based on the model of analysis (Table 2). Additionally, the final analysis meeting led to the grouping of contractors in three groups with comparable flow appearances.

Reliability and validity

To create knowledge, research needs a logical set of statements and its quality must be controllable for readers. Yin (2009) suggests four criteria for empirical social research quality assessment: construct validity, internal validity, external validity, and reliability.

Construct validity refers to identifying correct operational measures for the concepts and one possible tactic within case study research is the use of multiple sources of evidence (ibid). Within this research's analysis, most of the constructs have been identified in several empirical findings within the coding process (Table 4). The researchers individually positioned the same contractor differently in the model of analysis. This is reasonable, due to the large amount of qualitative data. Additionally, the model of analysis has not been chosen for its mathematical accuracy, e.g., it lacks orthogonality and quantification precision. It has been chosen to visualize qualitative data, i.e., differences in appearances of flow dimensions between diverse contractors. Consequently, the exact position of contractors in the model of analysis is not purpose of this research and the quantification is not meant to be in exact figures.

The internal validity in terms of establishing a causal relationship between observations and researchers interpretation can be reached by a transparent and logical data analysis tactic (Yin 2009). The methodology of this study has been setup to create this relationship through a theory-based analysis model and an objective analysis approach. However, the multi-case approach causes weaknesses because the number of cases limits the possibility of deep research in each single case. One must respect that the results might depend on interviewee's background, experience, and role at the contractor. The selection of interviewees was based on their position in the contractor firm (top or middle management level) and due to their long-term experience in construction, but must be seen in its temporary context as always in qualitative case study research (ibid). Therefore, interviewees' opinions might be unstable over time. To increase internal validity, the interviews were semi-structured with questions regarding contractors' organization, project and process management, and their relations to subcontractors to assess company level but limit personnel opinions.

The external validity which refers to the domain of generalizability of the results can be increased by the use of theory and/or replication logic in multi-case studies (Yin 2009). Both opportunities have been utilized in this research; it has been based on previous theory and the high number of cases creates a potential for generalizability in the Swedish context, e.g., all contractor groups consist of several cases.



Reliability in terms of a research process to be consistent, reasonable, stable over time and across researchers (Miles and Huberman 1994) has been accomplished by data protocols and detailed descriptions of the methodology (Yin 2009). The goal of reliability is to minimize a study’s errors and biases (ibid). A confirmation bias risk to find certain labels in the empirical findings is present and has been decreased with cross analysis by multiple researchers. The empirical findings have been analyzed by all authors independently and jointly discussed before the final positioning of the contractors in the model of analysis was accomplished. This analysis steps create higher objectivity within the analysis process and consequently higher reliability compared to single researcher analysis (ibid). Additionally, the aim of this research has not been to trace all labels in the data material, discussions and conclusions have been independent on the exact number of labels to be traced in the empirical data.

Empirical findings and analysis

Table 4 visualizes the quantities of traced analysis model constructs (Table 2) for each contractor. Empty fields indicate that the respective construct could not be traced at the contractor. This might not be critically because flow dimensions could be represented through related interdependencies instead.

Table 4: Quantities of traced analysis model constructs per contractor

Analysis model construct \ Contractor	A	B	C	D	E	F	G	H	I
Portfolio flow	2		2		1	5		2	1
Process flow	1		2			4	2		
Operations flow			3						3
Interdependency between portfolio and process flow	3	1			5	1	2		
Interdependency between portfolio and operations flow	6	13	2	4			1	2	3
Interdependency between process and operations flow	3	3	7	5	3	10	4	3	3

Figure 4 visualizes the results of the data analysis as a position of the contractors in the model of analysis. They can be interpreted as a pattern which describes the contractors’ focus on different flow dimensions. A more central position implicates a balance between the flow dimensions. With increased distance from the center, one or two flow dimensions or their interdependencies increase in significance. The contractors’ position allows grouping based on a similar pattern. This logic is utilized to describe the contractors in terms of their flow focus in three separate groups: a) Group AEF with the main focus on portfolios and processes; b) Group BDI with the main focus on operations; and c) Group CGH with a balanced flow focus.

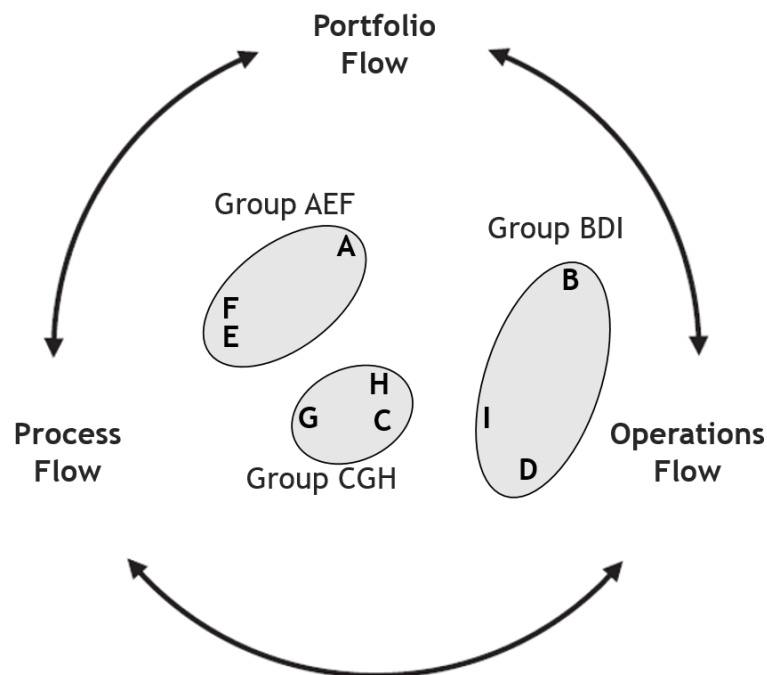


Figure 4: Contractors' position in model of analysis

Group AEF - Contractors focusing mainly on portfolios and processes

The general characteristics of this group are:

- Platform development process
- Product, process, and project management standardization
- Demand leveling or takt time planning
- Repetition in portfolio

In detail, contractor A established its business on the multi-family house market in 2005 in the Stockholm region by utilizing pre-engineered type houses with prepared production planning. To enable further growth in the following years, the product platform was extended but started to diverge in a negative sense. Consequently, contractor A streamlined its product platform by launching reference houses supported by standard design instructions. This finding symbolizes how the product platform develops during its use in the portfolio flow and can be exploited in single projects within the portfolio. To create a stable project flow within its portfolio, contractor A balances fluctuations in demand on the condominium market with rental house projects.

On the process dimension, contractor A divides its projects using stairwells as a unit of locations for planning purposes with repetitive character and combines them with different but repetitive apartment layouts depending on the project. Stairwells and apartments are repeated within the portfolio in terms of production processes, the houses are unique from a customer point of view.

Nevertheless, contractor A focuses mainly on portfolios and processes, the operations dimension is noticeable. Contractor A follows up how many hours are spent on each apartment, tries to build up long-term relations with architects and subcontractors or hire own design specialists instead of contracting them for each project.

Within its project portfolio, contractor E compares production costs to close the gap between the best and worst performing projects. This has decreased the number of unprofitable projects, increased customer satisfaction, and created an economic space to invest in project independent product development, e.g., low-energy houses, standardized working methods for production activities, purchase and project management. As a consequence, the freedom of how project leaders can run a single project has decreased to allow process management to be more equal between projects and how customers are met.

Within its multi-story house segment, contractor E does not offer catalogue houses. They run a standardization strategy for components and technical solutions as window fastenings, electrical installations, plumbing, wall and ceiling elements to enable process and method development while allowing customization choices for layout, claddings, or other local requirements. This platform is a solution range for alternatives available within single projects and the base for production planning in terms of steering takt times for predefined activities which consider local proportions and safety issues. The interviewee highlights that the main focus is on overall project process and not on pushing craftsmen to work faster on single activities.

The standardization strategy within contractor E impacts even the operations because it *“requires some kind of industrialized construction”* and asks for *“uniformity”* because it is *“easier to implement improvements in the entire group”*.

Contractor F offers customized architect-designed buildings produced with standardized components and work methods. On its portfolio dimension, contractor F focuses on repetition instead of uniqueness. Even though the market offer spreads from student apartments to hotels and multi-family houses to both commercial and private clients, 90 % of the work content is repetitive. This rate is connected to the companies building system which is based on prefabrication of volumetric elements in an off-site system and on-site assembly and finishing activities. The volumetric elements are utilized as the flow unit through the entire process to create a takt production from sales to the customer and the interviewee describes the overall portfolio performance in terms of their *“increased takt of 10 to 20 % this year”*. Even though the prefabrication degree is high, the main focus is on the work flow on-site due to the project unique site characteristics. The regional managers meet once a month to synchronize actual projects to define uniform requirements from the different projects towards the off-site system and to minimize the effect of personal experience and background of the site managers.

In recent years, the process flow has been improved by stock reduction as well as just in time activities (product flow) and involvement of design activities in improvements by visual planning and follow up of sub-deliveries (internal) and sub-contractors (external) to secure an on-time delivery to the customer.

Within contractor F, the process flow dimension is more important compared to operations flow. The interviewee explains that a forklift driver should not be utilized 100% because this situation most likely indicates that some operator or machine is waiting for material. Instead, the main focus is meant to be on the process dimension in terms of adding value to the volumetric elements which might result in some underutilized transforming resources. Another example is the role of group leaders who naturally work hard to support bottleneck operations while they should step out and try to overview the

overall process flow and ask questions of why the bottleneck emerged and how to secure operators utilization?

Although, contractor F focuses mainly on portfolios and processes, the operations dimension and the interdependency between operations and process dimension is noticeable. They follow up how many hours they spend on each volumetric element, maintain operation sheets that explain how operators proceed to create the process flow, and perform work studies to secure the takt and improve current methods.

Group BDI - Contractors focusing mainly on operations

The general characteristics of this group are:

- Unique projects
- Single-project sub-contracting and specialists
- Supply levelling

In depth, contractor B has divided its business in three divisions 1) housebuilding and industry, 2) infrastructure, and 3) landscaping. This separation is motivated because operators are supposed to have equal competences and can be easily moved between projects in each division. The divisions for landscaping and housebuilding and industry are subdivided in three different regions because operators are normally linked to a certain part of the total business region. In contrast, within infrastructure the operators are further specialized on, e.g., groundwork or concrete and work over the entire region due to the spread and number of projects. One subdivision within infrastructure is specialized on mining areas with smaller equipment compared to similar equipment for infrastructure projects as road work so the equipment is not shared between the subdivisions. The business managers, however, are in charge of regions as they do not need special competences for different products. They are in charge of what projects to bid for depending on the status of resources' utilization.

B sees itself as part of a regional construction process and do not want to tie potential sub-contractors with long-term agreements as this would risk increasing prices. To monitor prices consistently, B prefers project-oriented sub-contracting but opens up for an alternative strategy within its housebuilding division which partly offers standardized product solutions to customers. These concept houses increase efficiency because operators gain experience in repeating the same tasks during several years; a logic that could be transformed to sub-contractors. Within this subdivision, expert operators have been relocated between regions to share experiences to less experienced operators.

On the project management side, different administrative specialists (e.g. purchasers) are dedicated to single projects, their number and profession depends on the project size. The number of operators is agreed between regional and site manager for each project, both discuss even adjustments during project execution. The site manager is named to be an important factor for project success.

B focuses mainly on operations. One reason might be that the portfolio is very wide in terms of project spread which includes different contractor roles and uniqueness on the product. Just within housebuilding the portfolio-process-interdependency is noticeable due to a utilization of concept houses with partly pre-engineered solutions and reuse in the portfolio.

Historically, the three partners in Contractor D run the company both strategically in terms of what projects to work on and in daily operations on-site. This scenario has changed due to increased business and young white collar workers entering the company and demanding interesting working conditions with own tools and resources to create effective building sites. Both facts lead to a need for an alternative system of steering and controlling the company e.g. regional managers who overlook the market portfolio and cover project type, size, place, and suitable production engineers to estimate potential differences between operators demand and supply. The production engineers are central in project management as they follow the projects from calculation, planning, procurement all the way to the site and have often a better overview over the project compared to site managers. Depending on project size and work load, they work simultaneously with several projects.

Normally, D acts as either general or main contractor, but prefers design-build contracting to enable control over the design phase while design-bid-build projects often struggles in the interphase between sub-contractors for technical design solutions, e.g. electrical installations and plumbing. To improve overall construction performance, the interviewee at D highlights the importance of production planning to link design and calculation to the planning and steering of resources in the single project.

One example within D which shows some process flow dimension is a partnering project with shared risk logic with the customer. The project is performed in joint execution together with the client with more focus on product-related solutions instead of blaming each other for mistakes.

The interviewee at contractor I describes the company's portfolio as unique projects, which are almost always subject to change that needs to be handled. The involved resources are divided in material, machines and humans with the human factor struggling most calling for highest demand for planning. The regional management group meets regularly and check the process of all running projects and the available operators at the different sites to take reallocation decisions or suggestions of rescheduling of activities (dynamically for activities and blue collars while more static for white collars).

During the latest recession in 2008-2009, I reduced its own staff dramatically. In the following market recovery phase, I chose a higher share of subcontracting instead of rehiring own staff (e.g. bricklayers) even though the interviewee admits that this development is critical for the company in some competence areas and white collars cannot be hired in direct proportion to the company's turnover.

Focus on operations flow at I is exemplified by its attempt to separate moving zones for human workforces and equipment at the building sites. The portfolio and process flow dimensions are noticeable at I through the utilization of standard components and process descriptions as well as trade-off decisions between safety and productivity which are handled on the project portfolio level.

Group CGH - Contractors with a balanced flow focus

The general characteristics of this group are:

- Continuous improvements of site activities
- Long-term relations
- Demand and supply levelling



Thoroughly, contractor C is organized in three divisions: new-build, re-build, and facility services. To achieve portfolio flow, the execution of several projects is handled with a phase offset in between them, especially groundwork is concentrated on one construction site at the same time. The resource demand is smoothed out in the overall portfolio by starting maintenance projects when new-build projects do not ask for the total resource supply.

The process flow dimension is represented because C tries to integrate several elements of a construction process and building life-cycle: land development, design, production, and facility management.

The operations flow in C is concentrated on humans who are meant to have high resource utilization while machines have lower utilization in average. The operations flow outside the company is intended to create collaboration with external long-term partners (e.g. for architectural design) and sub-contractors who are integrated in planning and follow-up activities. Towards its clients, C prefers partnering contracts.

C is working with continuous improvement activities especially within the process-operations interdependency, e.g., standardization of technical solutions for electrical connectors, distinct structure off construction sites to create effective logistics, design phase locations with visual planning boards to integrate consultants and sub-contractors, and integrated BIM-GPS-solutions for groundwork applications. In addition, the facility service teams are setup with competences, material and tools to enable direct problem solving. Two mind-sets describe C's process-operations focus; there is a difference in operators' utilization and how much value they create within a project and problems within a project should be solved before construction instead of reacting on-site.

Contractor G has worked with standardization in two areas. Within production, three steps are necessary: 1) securing quality but not in terms good or bad because it must be seen digital in either meeting the standard or not, 2) utilize repetition within the project portfolio to generate learning curves, and 3) find solution to increase productivity, e.g., automation. The standardization is meant to decrease the direct dependency from individual's skill or ability and secure that knowledge is available in the company when people leave. Standardization has even been adopted on administrative processes to visualize ongoing work, systemize working procedures, and define outlines. One example is the design phase steering model mentioned to keep control over the design work and to create a taked design process. This standardization work has impact on operations as structural engineers who normally leave the projects after their design currently follow the project even under the building phase to get direct feedback on their drawings from the operators and the possibility to discuss alternative solutions with them for improvement in future projects. Even purchasers and calculation responsables do not leave their projects in advance.

Continuous improvement activities at G impacts the process-operations interdependency, exemplified in prefabricated walls to reduce setup times, transport and inventory achieving increased productivity in terms of spend operator working hours per square meter wall.

Within its project portfolio, Contractor H works with local experiences and product development and try to distribute the best solutions to the entire company through repetition, e.g., offering the same product type in locally adopted projects. The

distribution is affected by H's business structure consisting of local subsidiaries, so inter-organizational groups for different trades and administrative specialists are organized and the different subsidiaries are expected to cooperate with resources to balance regional demand peaks. Despite the standardization efforts, the interviewee at H highlights the importance of flexibility for unpredicted events and local requirements in single projects.

Notwithstanding that H tries to create long-term relations with clients, it does not have the ambition to become the client's only choice as this scenario would cause trouble when clients request for project delivery demands does not meet H's supply of resources. Towards its sub-contractors, H chooses to standardize only the material while leaving the production technique choice unspecified.

Conclusions

Different flow dimensions are traceable at contractors in the Swedish construction settings. Their appearance differ between contractors, verified as flow pattern in the PPO-model (Sacks 2016). Contractors in the same PPO-area focus and similar on the different flow dimensions were visualized as three distinct groups in the results. Single-project and sub-contracting oriented contractors focus more evident on operations flow, production oriented contractors focus on operations and process flow while industrialized contractors with implemented platforms, standardization approaches and stronger repetition between projects consider the portfolio flow.

Contractors who focus very strongly on just one flow dimension (portfolio, process, or operations) have not been found in this research. These kind of contractors might exist, but earlier research that distinguish between different flows (e.g. Sacks 2016, Lessing 2015, Rooke et al. 2007, Mentzer et al. 2001, Shingo and Dillon 1989) and findings from this research lead to the conclusion that different flow dimensions must be taken into consideration simultaneously for construction contractors. Thus, interdependencies between flow dimensions are important to consider and practitioners should ask how the different flow dimensions are addressed and balanced within their operations strategy.

Contractors with a balanced flow focus address all three flow dimensions simultaneously. However, conclusions about potential performance advantages cannot be drawn from this study and might be related to more complex business settings. This research is theoretically based on flow concepts from both LC, OM and IHB without causing direct conflicts between the concepts. Consequently, the understanding of flow within LC can be broadened with concepts outside the field.

Future research

Case studies with a reduced amount of contractors but a higher amount of interviewees within each company would enable conclusions about the impact of interviewee's role, their experience and position in the organization on their understandings and awareness of different flow perspectives. A very disparate flow perception of different interviewees in the same company could potentially rise questions about strategy implementation processes (Höök and Stehn 2008). Research could study the link between focus on different flow dimensions and companies' level of LC maturity (Nesensohn et al. 2016), their approaches to increase industrialization, e.g., prefabrication

(Lessing et al. 2015), or potential expressions in operations strategy (Lidelöw and Simu 2016). Moreover, future research might quantify a contractor's flow focus with achieved business performance and different approaches to act in its supply chain.

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