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SO MANY FLOWS!

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ABSTRACT

Flow is one of three perspectives in the Transformation-Flow-Value (TFV) conceptualization of project production systems. Accordingly, many papers published in the IGLC proceedings and elsewhere have addressed flow on a theoretical or practical basis. This notwithstanding, quite a few of these papers describe various flows only loosely without defining them formally. For example, a term such as workflow is widely used in the Lean Construction literature, but what exactly does it refer to? This paper poses the question: What kinds of flow can be distinguished? In response, different kinds of flow are listed, some already well-described and others (e.g., assembly flow) seemingly overlooked in the Lean Construction literature. The contribution of this paper is distinguishing and defining a certain number of flows in construction, using a vocabulary that is internally consistent. Flows need comprehensive attention in the design and execution of Lean Construction systems, so it is important to be clear on terminology. The goal of providing definitions regarding flows in Lean Construction is to facilitate research and communication of ideas with scholars and practitioners around the world.

KEYWORDS

Flow, assembly flow, equipment flow, location flow, material flow, operation flow, process flow, product flow, resource flow, service flow, tool flow, trade flow, value flow, worker flow, workflow

INTRODUCTION

Koskela (1992, 2000) presented flow as one of three perspectives in the Transformation-Flow-Value (TFV) conceptualization of project production systems. Whereas the traditional view on construction is focused predominantly on transformation and correspondingly the efficiency of conversion processes, the flow view sheds light on the management of handoffs between and within conversions (Ballard and Howell 1994).

Focusing on the point of handoff between supply and demand, namely the start of an activity, Koskela (1999) identified seven flows as the preconditions for work. So, are there only seven flows in construction? Koskela (2000 p. 187) hints at more. "[O]ne may

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argue that [the concept of seven flows] is not based on a structured analysis of the nature of the process and its flows" (Bertelsen et al. 2006 p. 35); these "are just put forward as an example of the impact of a relatively small uncertainty in each of the flows on the soundness of the whole process" (Bertelsen et al. 2006 footnote 6). This raises the question: What shape and form do various flows take on before they reach a handoff?

Terms such as workflow are not new (e.g., Birrell 1980) and have been used widely in the Lean Construction literature. However, taking a closer look at that literature reveals that, for example, the term workflow appears to mean different things to different people (as Tommelein et al. (1999 p. 304), Kenley (2004), Kalsaas and Bølviken (2010), Sacks (2016), and others noted) and the term does not appear to have a generally accepted definition. The same can be said of several other construction flows. Even among the members of our P2SL research group, achieving agreement and consistency in use of terminology is an ongoing challenge. We therefore set out to identify flows in construction and define them to the best of our ability, not only for conceptual clarity to facilitate our own research work but also to be able to share ideas clearly with others. It is unrealistic to expect that this terminology will be universally adopted, however it seems reasonable to highlight that there is a need for everyone to strive for consistency in their own word use and to define the terminology they use as clearly as possible.

The methodology followed to arrive at the terms in this paper stemmed, first, from our long-standing attempt to use words consistently while teaching Lean Construction concepts and methods. Clear definitions are necessary to make sense of the literature (e.g., what one calls lead time, another calls cycle time, and vice versa) and crucial when communicating ideas. For that reason, over the last 20-some years we have been developing and continue to incrementally improve an online glossary of Lean Construction terms (P2SL Glossary n.d.). Second, it stemmed from the authors' familiarity with the literature (especially in Lean Construction and Lean Production in general) and our joint effort to iron out workable definitions. Readers may not agree on the exact wording of the definitions provided in this paper, but they may find it worthwhile to map these terms to their own (in English or other languages) and find value in understanding the distinctions that are made.

This paper has a simple structure. The following section defines flow. The section thereafter presents a set of cogent and internally consistent definitions of different types of flow that can be discerned in construction production systems. We hope this will provoke discussion to further sharpen the here-provided list with definitions of various flows as well as to further augment the list.

DEFINITION OF FLOW

Kalsaas and Bølviken (2010 p. 54) cited the Oxford Advanced Learner's Dictionary definition of flow: "to flow" means to "*move freely and continuously* (verb)" and "flow" is "*the flowing movement / continuous stream of something* (noun)." This definition is adopted here and that "something" is the focus of this paper.

In construction, that "something" frequently appears in discrete parts (e.g., a trade crew, an assignment, a pallet of materials) and less frequently as a continuous medium (e.g., concrete flows when it is being pumped, paint flows when sprayed onto a surface, dirt flows when it is transported using a conveyor belt). The extent to which continuous flow is achieved in construction is a matter of degree.

DEFINITION OF TYPES OF FLOW

WORKFLOW

In the context of Lean Construction, early use of the term workflow appeared in the Last Planner® System (LPS): Ballard conceived the LPS as a means to counteract low workflow reliability (Ballard 1994, Ballard and Howell 1994).

In the LPS, workflow refers to a stream of chunks of work that have been planned and must be assigned to production units and executed in a timely fashion. Using Percent Plan Complete (PPC)—the most well-known metric in the LPS—Last Planners (front-line supervisors) can gauge workflow reliability by assessing whether WILL matches DID (see Ballard and Tommelein (2021) for an explanation of these LPS terms that are printed in caps). When the time comes to add an assignment to a weekly workplan, the Last Planner must assess the degree to which that assignment satisfies five quality criteria (being defined, sound, sequenced, sized, and allowing for learning)—a process that is called SHIELDING—and, if all are met, can make a reliable promise when committing to performing the work. The objective is to ascertain that the Last Planner's production unit will reap the benefit of planning and have sufficient, ongoing work of the right kind, achieved by having a reliable workflow coming towards them. This is to enable them to work close to or at their capacity, that is: have a high utilization. In turn, high utilization results in high productivity if the work is "done well," i.e., if it is both efficient and effective. The Last Planner achieves this by stabilizing the work environment by (1) reducing inflow variation (using SCREENING, making work ready, conducting first-run studies, SHIELDING, etc.) and (2) improving performance behind the shield, to include learning by doing and relentlessly improving how work is done (see Figure 1 in Ballard and Howell 1994).

While an assignment tends to be a relatively small chunk of work so that a production unit can start and complete it within the commitment period (e.g., spanning a day or a week), the LPS has been silent about the relationships between those chunks, that is: it has been agnostic about work structuring (Ballard 1999, Ballard et al. 2001, Tsao et al. 2004). It is only in the most recent benchmark (Ballard and Tommelein 2021) that a method is presented for work structuring, namely takt planning. While the higher-level schedules in the LPS (master- and phase schedule) typically show sequential dependencies, activities can be broken down and detailed in numerous ways and at many different levels until they become chunks. Chunks can have various dependencies or other relationships between them, even if none are shown.

Relationships between chunks at the assignment level may exist but not be shown explicitly. In fact, several of the following characterizations of flows, other than workflow, will reflect them.

WORKER FLOW

Worker flow (or people flow, more generally) captures the path a worker travels in the course of their workday. People come to work and go home each day, attend team meetings, go to the workface (the location where they install materials and products in their final position) or other location to perform work, take breaks, etc.

Alves and Formoso (2000) refer to a related flow, the flow of production units (which could be an individual worker or several, e.g., a trade crew or design squad), comprising people (with individual expertise, know-how, motivation, etc.), tools, and equipment, which they studied together with material flow. They offered guidelines to make such flows more transparent and thereby amenable to more explicit and systematic management.

MATERIAL FLOW

Material flow refers to the physical movement of products, arriving from off-site (here leaving out the details of supply flows to the site) and being relocated on-site, some of which will be consumed or put in place (e.g., Tommelein 1998), and others will be wasted or removed from site after use. Figure 1 depicts flows of materials between off- and on-site locations, with the thickness of the arrows reflecting the author's assessment of the degree of desirability of the flow, assuming one tries to minimize overall flow. Dashed arrows and loops are the least preferred of all as they indicate a kind of rehandling. Each circle describes a function fulfilled in a certain location for a certain duration, where a location can fulfill several functions. These functions are explained in greater detail in Tommelein (1994).

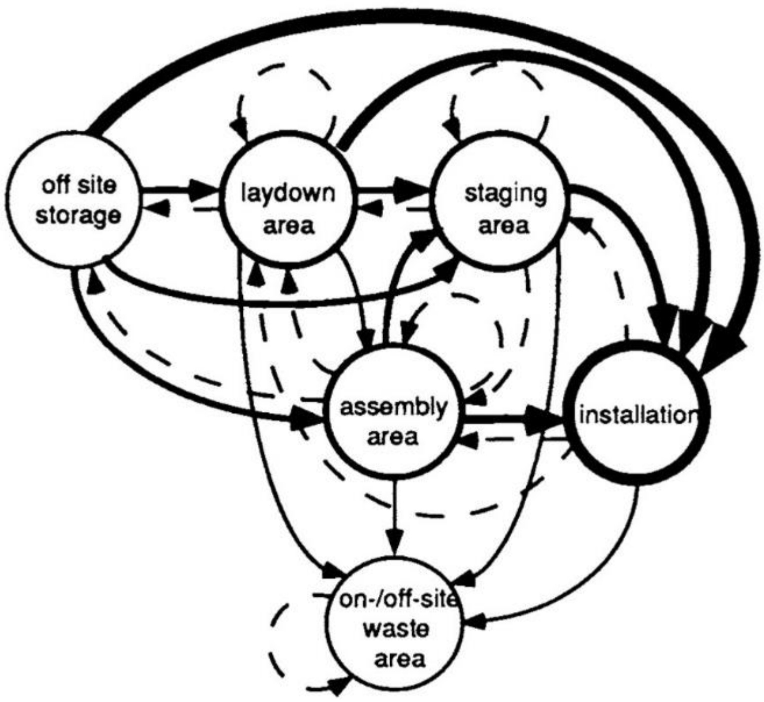

Figure 1. Preferred Materials Flow
(Figure 1 in Tommelein 1994 reprinted with permission from Elsevier)

EQUIPMENT FLOW AND TOOL FLOW

Equipment flow is related to worker flow and material flow. Equipment (e.g., bulldozers) and operators are separate resources, each with their own flows, but combined make up production units that will be engaged in unison for certain amounts of time to move or hold materials (e.g., when robotic equipment is involved, the production unit may be called a co-bot).

Tool flow is similar. Some tools (e.g., table saws) are stationary with workers coming and going to use them. Other tools (e.g., hammers) can be carried along by workers as they move about from one location to another.

TRADE FLOW AND TRADE LOCATION FLOW

The distinction we are making between trade flow (defined in this section) and process flow (defined later) is explained by drawing an analogy between manufacturing and construction. In assembly-line manufacturing, the product moves along a line from one workstation to the next according to the process flow, and production units (workers with their tools etc.) at each station—and thus more-or-less stationary—perform certain value-adding steps and thereby transform the product. In contrast, in fixed-position manufacturing as in construction, the production unit moves from one work area to another, more-or-less repeating the same kind of work.

It may be possible to structure the production system so that production units (of the same or different trades) can follow one another from one location to the next. This is not necessarily the case, but along this line Birrell (1980 p. 399) describes location flow as follows: "the construction work is made up of many flow lines, each of which contains a mobile work squad [crew or production unit] which moves through a set of work locations (which are the same set of work locations for all work squads)."

Birrell's location flow refers to trade specialists moving from one location to another and performing work in each location; we define this as the trade location flow. In construction, the trade or their company must provide the requisite resources to meet the requirements of the project schedule. Often-times it is desirable to keep resource continuity. In the case of crew continuity, this means the same number of people and the same people. In practice the crew composition can change over time with people joining and leaving for various reasons (e.g., an apprentice joining the crew, a crew leader being called to help on another job, or work varying from one location to another). Therefore, trade location flow is synonymous with trade flow; it could be, but it is not necessarily synonymous with worker- or production unit flow. Figure 2 illustrates the direction of a trade flowing from Floor 1 Zone 1, to Floor 1 Zone 2, all the way to Floor 2 Zone 3, i.e., changing work locations over time, according to a takt plan.

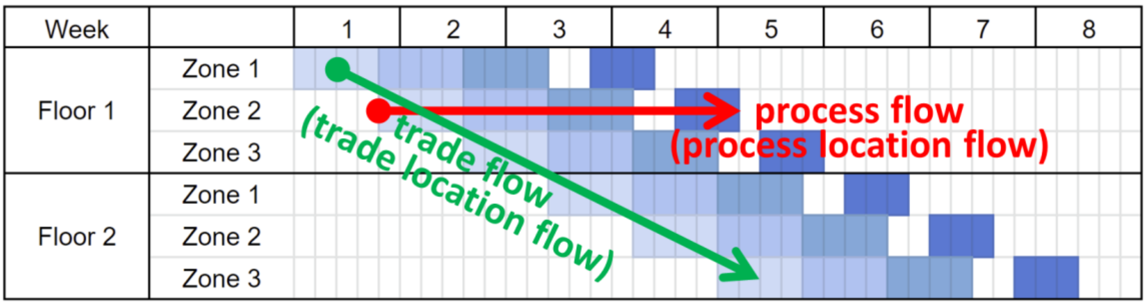

Figure 2: Trade flow and process flow

ASSEMBLY FLOW, ASSEMBLY SEQUENCE

Assembly flow is related to materials flow, but it focuses on materials with different characteristics coming together by performing a sequence of steps for the purpose of making a "final" product (i.e., the assembly). The term may suggest that discrete parts will be put together to make the whole but, in its general sense, assembly may also involve non-discrete materials of which a quantity more-or-less certain is needed (e.g., placing concrete, applying glue) to make the whole.

Assembly flow is mentioned in the Lean Construction literature (e.g., Koskela 1999 p. 246) but it is rare in construction project management to begin with simple parts and spell out all the steps from start-to-end that are needed to put them together. At the highest level of planning the master schedule depicts assembly flow in some very abstract way, but even when details are elaborated on in production-level plans, at the time of execution many aspects of the assembly flow still are not depicted. Might this be because people doing the work presumably will know what to do, and do they? Would more comprehensive assembly instructions be of value, e.g., for training, to measure process capability, and to establish standard work?

In any case, creating assembly instructions is a subject of formal study (e.g., Agrawala et al. 2003). It is also an art. Consider for example IKEA's practices (e.g., Pavlus 2015) and what can be learned from them for use in construction (e.g., Li et al. 2008). Danzico (2017) states "While many of us have at least one frustrating IKEA assembly story, what the process does accomplish merits astonishment. Each tool and part is enumerated. Each step is isolated and requires a kind of mindfulness to do one thing at a time. Right and wrong are charmingly illustrated with line-drawn figures. And all of this—whether for a 4- or a 400-part piece—is done without a single letter of type. In this way, good and affordable design is easily accessible to speakers of any language, any level, any skill. The instructions serve all equally."

To illustrate, Figure 3 depicts that more-or-less 14 steps are needed to assemble a BILLY bookcase (IKEA 2021). "More-or-less" is used here because defining these steps, what is included in a step vs. what separates one from the other, is an act of work structuring. The rationale for the characterization and depiction of each step has to do with presentation (e.g., graphical conventions, clarity, and comprehensibility in making the drawing) and the means and methods for doing the work (parts needed, changeovers, use of tools, number of times some work is repeated, etc.).

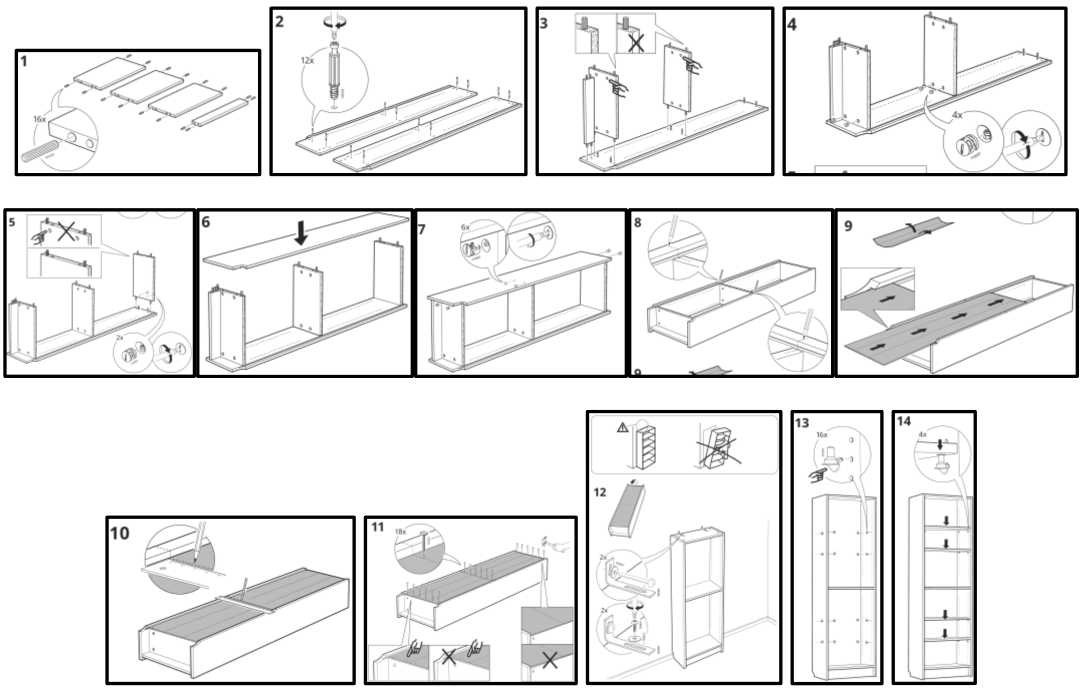

Figure 3: Assembly sequence for BILLY bookcase (IKEA 2021)

Of note is that steps are numbered, thereby implying a linear sequence although some could be re-sequenced without ado (e.g., steps 1 and 2). Furthermore, the numbering of discrete steps appears to imply a finish-to-start relationship although no such relationship arrows are shown or exist necessarily (e.g., a combination is possible by doing some work of step 2 followed by some work of step 3, then reverting to doing more work of step 2 followed by more work of step 3).

Also of note is that assembly instructions are non-specific about the actual, physical place or context where work may take place although these are of course relevant (e.g., if you assemble the bookcase while it is lying on the ground, will you be able to tilt it upright without hitting the ceiling?). The assembly sequence can be broken up to perform certain steps in one place and other steps elsewhere (e.g., steps 1 to 11 could be done in a place distant from the final installation location of the bookcase, but step 12 to secure the bookcase to the wall to prevent it from falling over, a safety concern, must be done in situ).

Because of the desired simplicity and worldwide use of IKEA instructions, not everything is or can be shown. For example, when securing a bookshelf to a wall made of studs and drywall, in seismic zones it is important to use screws long enough so they will be secured well into the studs, not in drywall alone; the sequence does not indicate the amount of time needed to perform each step; and a worker must have some skills (e.g., be competent in using a hammer or screwdriver). Furthermore, not everyone wishes to follow the assembly instructions. Creative minds may hack them to customize their assembly or invent new products (e.g., Rosner and Bean 2009).

OPERATION FLOW

When reading Lean Construction papers, a significant amount of confusion appears to stem from the distinction between operation flow and process flow. Many authors refer to Shingo’s (1986) schema of production shown along two axes. One is along the flow of materials being worked on, the so-called process from raw materials to finished goods, and the other along the flow of steps a production unit (e.g., worker(s) with tools and equipment) performs on those materials. Of note is that this schema does not tie any steps to specific locations.

In this paper, we adhere to Shingo’s definitions of operation flow and process flow. Operation flow refers to a sequence of steps to complete a certain scope of work, all done by “agents of production: the people in charge of making products, as well as the machines, tools, and other equipment that assist them” (Shingo 1986 p. 3). An agent could be a worker, production unit, or crew of a certain trade. At this level of definition of what an operation is, steps tend to not be location specific. Operation steps typically are a subset of steps in an assembly sequence. That is, operations are sequences of work chunks that must be performed more-or-less one after another, e.g., to make an assembly or a part thereof, to complete a part of an installation or all of it, or to deliver a certain service (e.g., steps 1 to 11 to assemble a BILLY bookcase make up the trade’s “assemble bookcase” operation).

Operations comprise multiple chunks of work, to become an assignment to be performed by workers of a certain trade and typically of one company. Operations may span across multiple commitment plan periods. When a Last Planner commits to taking on an assignment, with assignments getting to them ideally in a reliable one-piece workflow (otherwise more work structuring might have been in order), they commit to completing the operation. The operation flow relates to people-and-machines utilization and productivity (point speed) (e.g., Rooke et al. 2007).

PROCESS FLOW AND PROCESS LOCATION FLOW

Process flow, with materials worked on (or services provided) stepwise by different trades, determines how long it will take to get the "object of production: the product" (Shingo 1986 p. 3) to the customer. This time is called the process cycle time and relates to the system's speed (aka. throughput rate). A product may have to flow through several processes before it is ready for the customer, that is, multiple process flows make up the product flow (defined next). Figure 2 illustrates a process flow by showing the different trades' work in different colors, with each instance of the process being performed in a certain location (e.g., on Floor 1 in Zone 2). Accordingly, we define process location flow to be synonymous with process flow. The more general term location flow is sometimes given this meaning (see the Discussion section) but differentiation between trade location flow, process location flow, and location flow in general is in order. Locations may or may not be occupied over the course of the duration of a project by trades performing steps belonging to one or multiple processes or operations.

A process flow comprises steps for each of the trades involved. These steps are part of the trade's operations. So, process flows and operations flows are interwoven with one another. In figure 2, for example, the step in the darkest color may be the step for the final installation of a bookcase (i.e., steps 12, 13, and 14 of the assembly sequence for the BILLY bookcase make up the trade's "install bookcase" operation).

VALUE FLOW, PRODUCT FLOW, SERVICE FLOW

Product or service flow like assembly flow is related to materials flow, but it specifically captures not only steps but also the time and resources needed to create something that is of value to the customer. Often left out are the specifics of space requirements and the location where steps take place. The product can be one of many things, physical or abstract. Product flow may be illustrated by means of a value stream map, showing cycle time as well as value-added time and non-value-added time (e.g., Cano and Rubiano 2020). So, as defined here, product flow aligns with value flow (e.g., Luoma and Junnila 2011).

OTHER FLOWS

It is possible to identify other flows, e.g., communication and information flows (e.g., Fisher and Yin 1992, Titus and Bröchner 2005), knowledge and understanding (which Pasquire (2012) and Pasquire and Court (2013) identified as the eighth flow, augmenting Koskela's (1999) aforementioned seven flows that are the preconditions for work), monetary flows, flows related to managing multiple projects (what Sacks (2016) calls portfolio flow). The list provided in this paper is not exhaustive. Further work is in order to augment the set of terms provided here with refinements and additional definitions of flows.

DISCUSSION

The definitions of terms provided in this paper are internally consistent; they build on one another. Some readers may use a different spelling or definition for a term, e.g., work flow, work-flow, and workflow are all in use. There is no general agreement on spelling of this noun.

The terms location flow and trade flow vary in meaning when reading the literature. Among others, Binninger et al. (2019) appear to equate location flow with process flow (process location flow) as defined in this paper. Lehtovaara et al. (2021 Figure 1) appear to equate operations flow with trade flow as defined in this paper. Sacks (2016 Figure 6) appears to equate location flow with process flow as defined in this paper, and trade flow with operations flow as defined in this paper. The ambiguity may stem from Shingo's schematic of the structure of production (Figure 1-2 in Shingo 1986 p. 6), showing the relationship between process flow vs. operation flow. We stress that Shingo's figure is indeed a schematic (i.e., a map of something, not the real thing) depicting the various steps relative to each other on different axes, and the depiction should not be interpreted as indicating the actual location where these steps take place.

The term workflow used by different authors also refers to different flows. For example, Kenley (2004 p. 1) uses 'work-flow' and 'work flow' to refer to "the flow of resources through locations" so that "work completed in multiple locations will be treated as part of a continuous process" Kenley (2004 p. 5). His resource flow corresponds to trade flow (trade location flow) as defined in this paper.

It is hard to reach an agreement on terms when definitions are spelled out in a single language. It is even harder when terms get translated to different languages (e.g., try translating "lean").

FUTURE RESEARCH

Bertelsen et al. (2006) suggested that theoretical concepts pertaining to flows in construction should be developed. In addition to defining additional types of flow and studying interdependencies between flows (a topic broached by Howell et al. 1993 and Tommelein and Ballard 1997 among others), more research should be done to define metrics that gauge their quality (Kalsaas and Bolviken 2010 p. 52, Bølviken and Kalsaas 2011, Kalsaas 2012). This paper did not say much about metrics, but of course different flows will have different metrics, e.g., the PPC metric applies to workflow, and several flow metrics may be defined specifically related takt plans (Binninger et al. 2019).

Assessing the quality of combinations of flows is not an easy task. Sacks et al. (2017) attempted to define a composite metric for flow in production of repetitive construction projects but admit that "The meaning of a composite index value to a user is dependent on that individual's understanding of the notion of flow and it may obscure the relative importance of its components." One would expect any optimization of multiple flows simultaneously to require tradeoffs. "Various perspectives of flow must be considered and harmonized" (Binninger et al. 2019 p. 1279).

CONCLUSIONS

Many flows can be identified in construction. A first step towards managing them is to recognize they exist and to define them by name and by their characteristics. The purpose of this paper was to shed light on a certain number of flows namely workflow, worker flow, material flow, equipment flow, tool flow, trade flow and trade location flow, assembly flow (assembly sequence), operation flow, process flow and process location flow, and value flow (product- or service flow). We know all too well that this list of flows is not exhaustive, and that follow-on research is needed in this regard.

This paper contributes to the IGLC scholarly community's and the Lean Construction practitioners' body of knowledge by offering a cogent set of definitions for different types of flows encountered in construction production systems. The contribution of this paper is not so much addressing a gap in knowledge, but rather clarifying terms that are ambiguous in use by different authors.

Flows will invariably encounter turbulence if not subjected to work structuring. The distinctions made between flows and their metrics will help people make performance tradeoffs when designing production systems.

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