Slack in production planning and control: a study in the construction industry

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Although buffers of inventories, time, and capacity are commonly recommended to mitigate variability in construction, they abstract away the role played by human agency. This study argues for slack as a socio-technical complement to buffers for dealing with variability. The investigation is based on two case studies conducted in construction projects that adopted the Last Planner® System. Data collection focused on understanding how slack practices and resources (SPR) were used in production planning and control, and was based on observations, analysis of documents, and interviews. Findings revealed 57 instantiations of slack practices and 8 types of slack resources. Several of these SPR diverge from what are traditionally called buffers, highlighting how the concept of SPR gives visibility to a wider range of variability coping mechanisms. Thus, it is important to make SPR explicit so that managers can reflect on why SPR are necessary, understand how they relate to each other, and assess their unintended consequences. Five propositions are presented, encompassing: how to identify SPR; the variety and general- or context-specific nature of SPR; and the value of maintaining SPR. These propositions contribute to risk management in production planning and control.

Keywords: slack; buffers; variability; production planning and control; Last Planner®.

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INTRODUCTION

In construction, like in other sectors, coping with variability is a key concern in production management. Variability is the quality of non-uniformity of a class of entities, which can be designed into a system (e.g., product variety) or be random (e.g. when a machine fails) (Hopp and Spearman, 2011). The use of buffers is commonly recommended as the main mechanism for coping with random variability that might hinder production goals (Büchmann-Slorup, 2014); this is the type of variability focused on in this paper. The allocation of the right size and mix of buffers in terms of inventory, time, and capacity, plays a key role in protecting a production system from variability (Spearman and Hopp, 2021). In industrial engineering, the design of buffers of intermediate products in assembly lines is a well-established research topic (Tan et al., 2018).

Despite the widespread use of the buffer concept, Formoso et al. (2021) argue that it casts a mechanistic view of production systems and does not properly account for the complexity of construction projects. In fact, the concept of buffer is strongly related to the queueing theory conceptualisation of production (Spearman and Hopp, 2021), which disregards the social aspects of socio-technical systems.

Slack is the socio-technical complement to buffers for dealing with variability. In this study, the definition of slack proposed by Bourgeois (1981) is adopted: “slack is a cushion of actual or potential resources which allows an organization to adapt successfully to internal pressures for adjustment or to external pressures for change in policy”. Although some authors refer to slack as the pool of resources that exceeds the minimum necessary (e.g., Nohria and Gulati, 1996), this view overly constrains the slack definition. In line with others (e.g., Saurin and Werle, 2017; George, 2005), we consider that resources that do not exceed the minimum necessary can also play the role of slack as they can be reallocated to support performance adjustment. The adopted definition of slack also implies that it plays a role in the risk management, which encompasses (Baker et al., 1999) identification, assessment (i.e., prioritization), response (i.e., elimination, reduction, transfer, or retention), and monitoring of the risk responses. Slack is useful for risk response. Indeed, firms that use plenty of slack resources have fewer trade-offs to make when responding to variability, in comparison to those that must pursue multiple objectives with rather limited slack resources (Xiao et al., 2018). Based on these definitions, this paper argues for the concept of slack as a complement to buffer, for the following reasons:

(i) The term slack is not immediately associated with any type of resource, while the term buffer usually refers to inventory, time, or capacity;

(ii) In construction, the term buffer is used interchangeably as a practice or resource (Howell et al., 1993; Frandson et al., 2015). By contrast, the literature on slack distinguishes slack resources from slack practices (Voss et al., 2008; Fireman et al., 2018). Slack resources are those that can be called on in times of need (Fryer, 2004) and they can be as diverse as time, money, material, people, space, and equipment, among others (Saurin and Werle, 2017). We do not consider capacity as a primary slack resource as capacity is an abstraction that does not exist by itself – i.e., it arises from other resources such as time and people or from a combination of different resources. In turn, slack practices convey how slack resources might be deployed (Voss et al., 2008; Fireman et al., 2018);

(iii) Slack encompasses both built-in practices (i.e., designed) and those arising from spur-of-the-moment means. The concept of buffer normally implies built-in

practices defined top-down by higher hierarchical levels. Thus, the amount, purpose, and conditions of use of a buffer are planned ahead of time (González et al., 2006; Lehtovaara et al., 2020). Büchmann-Slorup (2014) illustrates that perspective in the construction industry by proposing a method for the design of time buffers in location-based planning. However, in loosely coupled systems, such as many sub-systems in construction projects, there is a chance that unplanned resources, redundancies, and substitutions serve as slack (Sandberg et al., 2021). Righi and Saurin (2015) refer to these approaches as opportunistic slack, given that a resource can serve as slack despite the fact that serving as such was not its original purpose. Point (*iii*) also applies to another proxy of slack, namely the provision of manufacturing flexibility. This is clear in the literature on "flexibility designs" (e.g., Simchi-Levi et al., 2018) that refers to designs characterized by certain manufacturing and supply chain arrangements, in terms of resources such as layout, machinery, and labour (Pérez-Pérez et al., 2018);

(iv) The built-in nature of buffers implies that they are conceived to deal with variability described in advance and characterized statistically, such as randomness in activity durations and demand variability. Therefore, when variability is difficult to be anticipated and quantified as is the case for black-swan events (Taleb, 2007), the concept of buffer has limited value (Ballard et al., 2020); and

(v) While studies related to the use of buffers only assess a buffer's role in providing system protection and its possible role as waste, slack-related studies recognize the value of slack as a vector of innovation (Nohria and Gulati, 1996; Voss et al., 2008), resilience (Saurin and Werle, 2017), and sustainability (Xiao et al., 2018).

These differences convey that buffers are always slack but slack is not always a buffer. As such, there is a need for understanding the nature of slack practices and resources (SPR) in the construction industry. Consideration of the socio-technical complement to the buffer concept, allowed by the concept of SPR, might shed light on variability coping mechanisms that have not received due attention, either from construction management practitioners or from researchers. This broader set of mechanisms for mitigating variability encompassed by SPR are assumed to be used in construction projects regardless of not being explicitly named or acknowledged by managers either as buffers or SPR. This assumption is based on the complex nature of construction projects (Bertelsen and Koskela, 2005), which demands resilient performance. Like in any other complex socio-technical system, SPR can be regarded as an asset for projects to achieve their goals by adapting to uncertainty (Saurin and Rooke, 2020). Therefore, this research work intends to make a contribution to the visibility to SPR, which is a necessary step to account for SPR in construction management.

In order to limit the scope of this investigation, we chose to address slack that is managed in production planning and control (PPLAN). This choice of PPLAN is due to: *(i)* PPLAN plays a central role in the production management of construction projects, in which many day-to-day planning decisions offer opportunities for the design of SPR – e.g., delayed work packages may require the deployment of slack resources in terms of time and labour (Saurin and Rooke, 2020); and *(ii)* the limited consideration given to construction work variability in PPLAN methods (Dallasega et al., 2020) indicates that there are improvement opportunities related to the design of SPR. Against this background, the research question addressed in this study is: how are slack practices and resources used in production planning and control in construction?

The research investigation is based on exploratory case studies conducted in two construction projects. In both cases, PPLAN was structured according to the premises of the Last Planner® System of Production Control (Ballard and Tommelein, 2021;

Ballard, 2000). This choice was beneficial for this study as the Last Planner® System is: *(i)* widely adopted in many countries as a means to introuduce lean production concepts and principles in construction (Ballard and Tommelein, 2021) – this increases the practical relevance and external validity of this study; *(ii)* hierarchically organized at levels that correspond to different time spans, which is useful for the understanding of how SPR evolve in the course of a construction project; and *(iii)* recommended for the management of complex construction projects, in which variability is very high (Bertelsen and Koskela, 2005), and the use of SPR becomes more relevant.

BACKGROUND

Slack practices

The role of slack practices in supporting organizations to deal with variability has been discussed in several domains and associated with different managerial processes. Ebbs and Pasquire (2018) suggested the use of spare concrete suppliers in construction projects, especially during intense cold weather as that may hinder production at the concrete plant. “Set based design”, which is adopted in some industries, is another example of slack practice: it consists of the parallel development of alternative designs, and delaying the selection among the alternatives up to further product development stages (Sobek et al., 1999). Sagan (2004) discusses the use of technical redundancies to protect power plants from terrorist attacks. In the same vein, Azadegan et al. (2021) found that slack moderates the relationships between exposure to major supply chain disruptions and firm performance. Lawson (2001) makes the point that time slack is essential in organizational work as it allows people to pay attention, think, and benefit from knowledge – complex systems require more, not less, time for monitoring and processing information.

Despite context-specific applications, slack practices have some commonalities. Saurin and Werle (2017) identified several slack practices in a literature review that encompassed diverse sources including risk management (e.g., Clarke, 2005), operations management (e.g., Azadeh et al., 2016), project management (e.g., Sacks et al., 2016), and innovation management (e.g., Nonaka, 1990). These sources gave rise to the slack practices listed in Table 1. In addition, Saurin and Werle (2017) referred to two other practices originally mentioned by Schulman (1993), namely conceptual slack (i.e., complementary perspectives) and control slack (i.e., degrees of freedom in organizational activity). However, these two were not adopted in our case studies as they are hard to observe and too subjective for the categorization of our data.

The list in Table 1 is relatively concise and more generic than the traditional flexibility types such as those proposed by Pérez-Pérez et al. (2018): product flexibility; process flexibility; machine flexibility; routing flexibility; volume flexibility; expansion flexibility; and layout flexibility. These flexibility types reinforce our previous comment that the flexibility literature focuses on built-in approaches such as the design of production routes, products, and layout. By contrast, the practices in Table 1 are less context dependent and account for the possibility of self-organization by employees (e.g., margin of manoeuvre).

Table 1. Slack practices adopted in this study – based on Saurin and Werle (2017)

Practice	**Definition**	**Subcategory**	**Definition**
Redundancy	Resources in addition to the minimum necessary to perform a function (Nonaka, 1990), or more than one resource performing a required function (Azadeh et al., 2016).	Standby	The redundant resource is not immediately involved in the task at hand, and is typically not present in the operator's immediate environment (Clarke, 2005)
		Active	The redundant resource is involved in the task at hand (Clarke, 2005).
		Redundant procedures	Redundant checks are made to spot failures, usually involving different professionals and types of inspection (Ong and Coeira, 2010), and alternative procedures to execute an activity (Saurin and Werle, 2017)

Work-in-progress	Resources waiting to be processed in-between process steps and stages	Simultaneous work zones	Number of simultaneous work zones in a construction site. They offer alternative activities to keep the teams busy in case of temporary stoppages in one or more work zones (Bashford et al., 2003; Sacks et al., 2010).
		Stock of materials	Stocks of semi-processed products, raw materials, and finished products (Saurin and Werle, 2017). The latter two types are interpreted here from an expanded view of work-in-progress – i.e., raw materials are waiting to be processed, while finished products are waiting to be delivered to customers.
Margins of manoeuvre	Practices that create or maintain margins that allow the system to function despite unexpected demands (Saurin and Werle, 2017)	Defensive practices	Restricting other units' actions or borrowing other units' margin (Stephens et al., 2011).
		Autonomous practices	Local reorganization (Stephens et al., 2011) or adaptation of resources in time of need.
		Coordinated practices	Recognizing or creating a common-pool resource on which two or more units can draw (Stephens et al., 2011) such as multifunctional workers or general-purpose machines (Fireman et al., 2018)

The Last Planner® System of production control

The Last Planner® System provides a framework to manage workflows in construction across four hierarchical levels (Ballard and Tommelein, 2016; 2021): *(i)* master scheduling, which is the long-term plan that spans the project from start to end; *(ii)* phase scheduling, which spans a project phase from start to end; *(iii)* look-ahead planning, which is a medium-term rolling schedule for a period that usually varies between 4 to 12 weeks; and *(iv)* commitment planning, which is short-term to match the time period over which plan reliability will be measured, e.g., one week.

Led by the project manager, possibly with involvement of subcontractors, a master schedule (i.e., long-term plan) is developed, including milestones, duration, and sequencing of the major construction phases. Next, the production manager and key subcontractors develop a phase schedule by breaking down and elaborating on the master schedule's activities in order to sequence and set the duration of each trade's tasks. According to Ballard and Tommelein (2016, 2021), in phase scheduling, reverse planning is used, so that participants will understand handoffs between trades and engage in vigorous discussion on when and where to use time buffers in-between tasks or for the phase as a whole.

Led by a production manager and crew representatives, the work is further broken-down at the look-ahead planning level, and first-run studies may be undertaken to devise standards and improve performance (Ballard, 2000). Constraints are identified and removed in the make-ready process (Ballard and Tommelein, 2016). In fact, look-ahead planning makes use of slack practices. By selecting a planning horizon (e.g., 6 weeks) longer than the re-planning frequency (e.g., 2 weeks), redundant checks can be made to ensure that any constraints will be removed in a timely fashion. Further, decisions on crew sizing must consider the need to include buffers by underloading the workforce or including extra shifts, so that project's requirements are met (e.g., Hamzeh et al., 2012).

In short-term planning, Last Planners select tasks from a so-called workable backlog, comprising tasks that have been tested according to four quality criteria (i.e., definition, soundness, size, and sequence) (Ballard, 2000). This illustrates the use of another slack practice as the workable backlog consists of spare tasks. At this planning level, Last Planners have the autonomy to adjust plans on the spot, considering local circumstances that could not be anticipated (Ballard and Tommelein, 2021; Alberts and Hayes 2003).

The Last Planner® System has been associated with a number of benefits to construction projects, such as increased reliability in project delivery, shorter lead times, fewer disputes between contractor and owners, collaborative work, improved safety, and the creation of a culture of continuous improvement (Olivieri et al., 2019).

METHOD

Research strategy

Case studies are recommended for descriptive and exploratory research, offering insight into factors that influence the phenomena of interest (Yin, 2005). These characteristics fit the objective of this research, as there is an interest in understanding how SPR are used in real-world settings. Two case studies (A and B) were conducted in different construction projects in Brazil. In both, the empirical work consisted of understanding the PPLAN system, followed by categorizing SPR and their association with PPLAN levels. Propositions were developed based on the findings from the case studies. Those propositions are intended to be relevant to further theory development, theory testing, and for guiding action in production management.

External validity benefited from the strategic selection of the cases (Flyvbjerg, 2011). Three selection criteria applied: *(i)* there should be a PPLAN system based on the Last Planner® System, for the reasons mentioned in the Introduction section; *(ii)* the construction projects should have a substantial level of complexity, which could be estimated through proxies such as the large number and diversity of stakeholders, and uncertainties that reduced the reliability of the supply chain (Saurin and Rooke, 2020); and (*iii*) supply chain instability that made the need for SPR obvious – in case A a nationwide truckers' strike disrupted supply chains in general, and in case B production stoppages occurred due to the COVID-19 pandemic.

Internal validity was achieved by following good practices of case-based research (Yin, 2005; Eisenhardt, 1989), namely: *(i)* the use of multiple sources of data, thus allowing for triangulation; *(ii)* the development of a database that could be revisited anytime for re-interpretation of data; and *(iii)* the definition of a unit of analysis, which was the PPLAN system in both cases.

The main researcher played the role of a consultant in the two case projects, which made it easy to have access to data sources. Although the companies that led the PPLAN in each case had previous experience with the Last Planner® System, their directors felt that it was not used consistently across all projects and then the support from a consultant was sometimes necessary. The main researcher´s role as a consultant included facilitation of planning meetings at the medium and short-term levels, making sure that core practices of the Last Planner® System were used. Moreover, he was very careful to not actively encourage participants to think of SPR – these naturally emerged from the discussion and reflected issues that mattered for managing production. Further, the researcher was present at the construction site six hours a week and had no authority to make decisions on SPR. The reliability of our findings benefited from these careful procedures related to internal and external validity, in addition to the use of a verifiable data analysis approach (see next, in the Data Analysis section) (Yin, 2005).

Case study A

Case study A focused on the assembly of a steel structure for the expansion of an airport terminal building with approximately 44,810 m², divided into two floors. Due to requirements of the client (i.e., airport operator), the release process for the start of a contractor’s services and the induction training of employees was strict and took at least 15 days, making it a relevant constraint to be considered in the PPLAN process.

The design, manufacturing, and installation of the steel structure was carried out by company Alpha, a leading steel fabricator in South America. The process type of company Alpha is classified as engineer-to-order prefabricated steel structures, in which orders need to be engineered, produced, and installed on-site according to customer requirements.

During the study period, which lasted for five-months, company Alpha had 70 projects underway and employed around 1,000 workers distributed across three manufacturing plants, each of them specialized in certain product families (e.g., gutters, roof tiles, collumns). Two or more plants may supply a single construction project, depending on the production mix demanded. At the peak, company Alpha had 52 people working in site assembly at this construction project.

The transportation of the components from the factory to the construction site was outsourced, as well as the assembly service itself. Employees from company Alpha's assembly department managed the assembly's subcontractors, in addition to carrying out quality and safety inspections.

Case study B

Case study B focused on the execution of a 50,661 m² two-floor store with a cast-in-place concrete structure and steel roof structure. This store was part of a commercial building of 97,790 m², which also included a health hub, a hotel, a shopping mall, and a conference centre. The construction process was managed by company Beta, which was also in charge of managing design and materials supply. That company outsourced Alpha for the design, manufacturing, and installation of the steel structures for the roof. The construction stage of this project had an estimated duration of four years. The construction of the store lasted nine months.

Company Beta had approximately 100 employees and its core business is the coordination and execution of residential, commercial, and industrial building projects. Company Beta's organizational structure encompassed three main departments: production, staffed by production managers, foremen, quality technicians, and safety technicians; planning, staffed by a planning coordinator and planning analyst; and contract and design, staffed by a contract manager, one supply chain analyst, one financial analyst, and one design coordinator.

Data collection

Sources of evidence were the same in both case studies, including documents, participant and non-participant observations, and interviews (Table 2). As indicated in Table 2, data collection in case B was less time-consuming than for case A for two reasons: *(i)* data collection for case B occurred after the completion of data collection in case A, and therefore the researcher could make use of his experience in order to be more efficient in the gathering of relevant evidence; and (*ii*) to some extent, case B was a repetition of the patterns of SPR identified in case A, thus converging to data saturation and making it unnecessary to continue data collection.

Table 2. Sources of evidence in the case studies.

Sources of evidence	**Duration**		**Research stages**	
	Case A	**Case B**	**(i)**	**(ii)**
Documents	X	X	X	X
Participant observation	44h	30h		X
Non-participant observation	256h	128h	X	X
Interviews	5h	2.5h		X

Notes: *(i)* understanding of the PPLAN system; *(ii)* identification and categorization of SPR

Documents analysed included: phase schedules, long-, medium-, and short-term plans; site layout and logistics plans; and reports of indicators such as time deviation and project progress. In these documents, pieces of evidence of built-in SPR and their implications on project performance were sought.

Non-participant observations were carried out by the first author every second week in case A and once a month in case B. In this type of observation, the researcher watches the subjects of their study but without taking an active part in the situation under scrutiny (Scott and Marshall, 2009). Those observations focused on understanding the practicalities of the construction activities (e.g., procedures for the assemblage of the steel structure) and the instantiations of SPR in the production areas (e.g., when one contractor borrowed a crane from another contractor). As for **participant observations**, the first author attended 10 medium-term and 10 short-term planning meetings in case A, while in case B he attended 6 short-term planning meetings, in addition to a collaborative phase scheduling workshop. This type of observation occurred in the context of the role of the first author as a consultant – therefore, he participated in the discussions but he had no decision-making authority. Key elements of participant observation were accounted for such as going to the place where the action was taking place, building rapport with the participants, and spending enough time interacting to get the needed data (Jorgensen, 1989). Participant observations paid heed to decision-making that gave rise to the use of SPR, whether they would eventually play out as actions in the construction activities or in other processes such as design and procurement. For both participant and non-participant observations, the researcher recorded notes on a field diary, usually completed on the same day of data collection.

Semi-structured interviews based on the Critical Decisions Method (CDM) were conducted in both cases. The interviews were audio recorded and fully transcribed. These interviews followed the four CDM phases (Crandall et al, 2006), namely: *(i)* incident identification, in which the interviewee is asked to recall a challenging event in which they used their cognitive skills to cope with the situation; *(ii)* development of a timeline, in which the main milestones (e.g., decision-making points; deployment of responses to variability) of the reported event are identified and their approximate time of occurrence is recorded; *(iii)* deepening, when some of the milestones are explored in depth (e.g., why did you make that decision? How effective was the response to variability?); and (*iv*) "what if" queries, when the interviewee is invited to reflect on what could have occurred under other circumstances (e.g., in an earlier career stage; working with other teammates). In case A, the project manager and the production manager were interviewed. In case B, the planning coordinator was interviewed. The incidents discussed in the interviews were, for case A, the recovery from a significant deviation from the expected timeline due to the nationwide truckers´ strike, and, for case B, the measures to mitigate the scheduling impacts of shutdowns stemming from the pandemic. The understanding of these critical events was relevant as SPR tend to be more visible and necessary under conditions of high variability. Therefore, the CDM interviews were complementary to the other sources of data, which focused on variabilities that were found in everyday work. Despite of this, the large number of hours devoted to participant and non-participant observations (458 hours, in total) also contributed to the understanding of the two critical events as they unfolded over several weeks. Thus, when jointly considering interviews and observations, and in light of the objective of this study, data saturation (Fusch and Ness, 2015) was achieved for understanding those two events.

Data analysis

A thematic analysis was carried out based on data from all sources. In line with Pope et al. (2000), the following steps were adopted for the thematic analysis: familiarization; identifying themes; coding; charting; and mapping and interpretation.

Familiarization involved reading the raw data several times in order to gain understanding of the recurring themes. Next, the main theme defined upfront (i.e., SPR in construction) was broken-down into four sub-themes imposed on the data by the researchers as a heuristic device. These sub-themes are: instantiations of slack practices at each PPLAN level; slack resources employed at each PPLAN level; variabilities addressed by each SPR; and unintended consequences of the SPR. The rationale for the sub-themes is presented in Table 3.

Table 3. Framework of data analysis

Sub-themes of data analysis	**Relevance for the research question**	**Information sought in the sources of data**
Instantiations of slack practices	Understand which and how slack practices are employed in construction projects	Applications of slack practices in a specific context
Slack resource	Understand which and how slack resources are employed in construction projects	Examples of slack resources (e.g., time, material, money, equipment, procedures, people)
Actual or potential variabilities addressed by the slack practice and resource	Understand the objective of using SPR – i.e., to cope with specific actual or potential variabilities	Potential variability anticipated in the design and planning stage (e.g., possible breakdown of equipment) and actual variability that played out in reality and were not anticipated in design and planning (e.g., delays due to the truckers´ strike).
Unintended consequences	Understand the unintended implications of SPR on project performance	Examples of unintended consequences, desired and undesired

In the coding stage, excerpts of text were tagged according to the subthemes. When different excerpts were associated with the same sub-theme, they were tagged with the same code, representing the same piece of evidence. The moment in which the SPR was conceived was the main criterion for coding the association between SPR and PPLAN levels. For instance, if the slack practice was conceived before the start of the construction stage, it was associated with the long-term level. Similarly, slack practices developed on the spot by front-line workers and their immediate supervisors were associated with the short-term level. The association between SPR and planning levels does not necessarily mean that they were devised during formal planning meetings. The first author carried out a preliminary coding based on these criteria and the second author conducted a careful review – both authors read the full transcripts of interviews and observation notes.

The thematic analysis continued with the charting stage, which synthesized findings from the previous stages. For each case study, tables were developed (see Results), each corresponding to the PPLAN levels, presenting evidence from the previous steps as rows and sub-themes as columns. Last, the mapping and interpretation stage focused on the joint analysis of the tables. Data interpretation benefited from one-hour presentations and discussion of the results with the project manager of case A and the planning coordinator of case B.

Following these stages, propositions were developed in line with the inductive approach. This approach is bottom-up, involving the search for patterns in data and the creative development of explanations – theories – for those patterns (Woo et al., 2017). The propositions address the nature of SPR in construction and their implications. The inductive, non-mechanistic development of propositions is widely used in case-based research (e.g., Zegarra and Alarcon, 2019).

RESULTS

PPLAN in case study A

In case study A, company Alpha led the PPLAN, being the sole party responsible for developing the long-term plan and counting on the involvement of subcontractors at the medium and short-term planning levels. Alpha was also in charge of managing the overall process of delivery of the steel structure, including design, fabrication, logistics, and assembly. Thus, Alpha was well positioned to assess how SPR deployed in one stage of the value stream (e.g., design) could affect other stages (e.g., manufacturing).

The PPLAN system had three levels: long-term, medium-term, and short-term. The medium-term planning level had a horizon of four weeks and a control cycle of two weeks – i.e., a new four-week medium-term plan was produced every other week. Medium-term planning meetings involved the project manager, the production manager, the safety technician, representatives from each subcontractor, and a planning consultant. Constraints for the scheduled activities were identified and an action plan was drawn up for their removal. Project progress was assessed, and an indicator was used for comparing planned versus actual progress.

Short-term planning was carried out in weekly meetings involving the production manager, the planning consultant, the safety technician, representatives from the subcontractors, and front-line supervisors of the main jobs. These meetings also involved the analysis of the extent to which the previous plan had been followed. Reasons for the non-completion of work packages were analysed and an action plan was devised for addressing recurring causes.

An important element of the PPLAN process of company Alpha was the division of the building structure in complete stages, or production batches (i.e., including collumns, beams, roof tiles), which guided the work of upstream processes such as design, manufacturing, logistics and assembly. At the same time, the performance of these departments was assessed monthly in terms of the weight of delivered components, in tons. As a result, stages that implied heavier weight were prioritized in upstream processes, although not necessarily contributing to complete stages and not being aligned to the planned sequencing of site assembly.

PPLAN in case study B

In case study B, company Beta led the PPLAN, which had the same three levels as case study A had. Alpha representatives participated only in the medium-term and short-term planning meetings, and thus had relatively less autonomy and influence on the implementation of SPR, in comparison to case study A. As previously mentoned, PPLAN was strongly affected by the pandemic. Two months after starting the construction stage, in March 2020, all activities came to a sudden halt due to pandemic restrictions,. Activities restarted in mid-April with a shortened work week. In mid-June there was another full stoppage that lasted two months. In the return to the activities, in August 2020, the construction site was allowed to operate under the regular pre-pandemic working hours. Due to those events, the long-term planning went through three revisions, which had to be negotiated with the client organization. Despite the resumption of activities in

August, the impacts on the supply chain were still being felt as there was a shortage of some materials.

After restarting the activities in August, the phase scheduling level was added to PPLAN. A workshop was set up to devise the phase schedule for the following seven months. This workshop involved staff from companies Beta (production and planning managers, planning coordinator, supply chain analyst) and Alpha (project manager, production engineers, and planning analyst).

The medium-term planning had an eight-week horizon and a four-week control cycle – i.e., every four weeks a new medium-term plan was developed looking eight weeks ahead. Planning meetings were attended by production engineers, the company’s planning coordinator, the safety technician, and a supply chain analyst. Similar to case A, medium-term meetings included constraint analysis and the calculation of an indicator of project progress.

At the short-term level, weekly meetings for the development of plans were held, led by the production manager, and counting on the participation of subcontractors. At this meeting, the extent of compliance with the deadlines set on the previous round of planning was assessed, reasons for not completing work packages were discussed, and a remedial action plan was set up.

Slack practices and resources in cases studies A and B

Tables 4, 5, 6, and 7 respectively show the instantiations of SPR related to long-term, phase scheduling, medium-term, and short-term planning, considering both cases A and B. Results of case study B are highlighted by a shadowed background. As for the long-term, the instantiations are mostly aimed at shielding production from time and cost deviations (e.g., 5, 6 and 7, in Table 4). In some situations, the same instantiation mitigated two variabilities – e.g., financial contingencies allowed for additional equipment and labour to mitigate both the low productivity of the steel structure assembly as well as delays in the delivery of components to the construction sites.

By contrast, some variabilities demanded more than one type of instantiation. This occurred, for example, with the variability in the delivery of components, mitigated by instantiations 4, 5, and 7. These situations reflect variability that emerges from several interacting factors.

Table 4. Slack practices and resources in long-term planning

Instantiations of slack practices	Slack practice	Variability tackled by slack practice	Slack resources	Unintended consequences
(1) The coordinator of the design team acted as a backup of members of the design team	Redundancy – Active	Lack of knowledge of the design team members on technical and non-technical issues	People	None
(2) The project manager acted as a backup of the production manager in the activities related to design approval by municipal authorities	Redundancy – Standby	The activities for design approval implied peaks of workload for managers	People	None
(3) Inventory of raw materials stored in the manufacturing plant of steel structures	Work-in-progress	Delays in the delivery of raw materials to the manufacturing plant due to logistics problems caused by the truckers' strike	Materials	Cash flow mismatch due to early expenditure to acquire inventories of raw material
(4) Expediting the production and delivery of steel structure components	Work-in-progress	Unavailability of the manufacturing plant due to the need to share capacity with other projects	Materials	Extra storage area in the Construction site
(5) The budget for the assembly of steel structures had a 15% margin for contingencies	Margins of Manoeuvre – Defensive	Several possible variabilities – e.g., low productivity of the assembly operations, need to hire additional assembly equipment to catch up with delays stemming from delays in the manufacturing plant	Financial	None
(6) Estimates of production rates in the long-term planning were below the historical average	Margins of Manoeuvre – Defensive	Low performance of the manufacturing and assembly operations	Time	None
(7) Design, manufacturing, and construction started by the work zones with the lowest number of requirements that demanded client approval. This allowed for a quicker approval by the client (before starting any works), buying time to the most complicated zones	Margins of Manoeuvre – Autonomous	Delays in the design approval by the client	Time	None
(8) Estimation of low production rates and a corresponding four-week buffer to account for possible shutdowns and restrictions stemming from the COVID-19 pandemic	Margins of Manoeuvre – Defensive	COVID restrictions and its implications for productivity	Time	None
(9) Extra crane operator in case the main operator was absent for any reason.	Redundancy – Standby	Absenteeism	People	None

At the phase scheduling level, slack practices were classified as margin of manoeuvre, redundancy, and work-in-progress (Table 5). As for the redundancy category, two out of the three examples were related to procedures, such as double-checking whether the schedule of the supplier of steel structures and the schedule of the construction project were synchronized.

Table 5. Slack practices and resources in phase scheduling

Instantiations of slack practices	Slack practice	Variability tackled by slack practice	Slack resources	Unintended consequences
(1) Dedicated crane for unloading materials from delivery trucks of steel structures reduced the need for using the main crane	Redundancy – Standby	Unavailability of the main cranes that is shared with other traders	Equipment	None
(2) The planning coordinator double-checked and closely monitored the progress of design´s approvals by the client	Redundancy – Redundant Procedures	Client´s delays in the approval of the design of the anchor bolts	Procedure – inspections	None
(3) The production manager double-checked and closely monitored adherence to the delivery schedule of steel structures	Redundancy – Redundant Procedures	Delivery of incomplete batches of steel structures to the worksite	Procedure – inspections	None
(4) One-week buffer of components for steel structures in the construction site	Work-in-progress	Delays in the supply of steel structures	Materials	None
(5) Expediting the delivery of anchor bolts, using the standard model available at the factory	Work-in-progress	Lack of adherence in the supply of anchor bolts	Materials	Higher costs of materials
(6) Work on Saturdays or night shifts in case of delays	Margins of Manoeuvre – Defensive	Low productivity	Time	Extra costs
(7) Design changes in the height of the beams in order to reduce the time for shoring	Margins of Manoeuvre – Autonomous	Lack of synchronization between the progress of the concrete and steel structures	Design – technical solution	Rework and higher costs of design
(8) Reallocation of workers to the work zones lagging behind the schedule	Margins of Manoeuvre – Coordinated	Low productivity	People	None

Table 6 presents the SPR in the medium-term level, which offered examples of coping with the truck drivers´ strike. This is exemplified by the following report from the project manager: "*one of our actions was to change the thickness of the columns, which were originally specified as 16mm. We did not have 16 mm raw material at the factory, so we changed it to 19 mm, which was available at the factory. The material originally specified in design had no reliable expected arrival date due to the strike. While from a technical viewpoint our decision was in favour of structural safety* (due to the thicker material), *we were wasting materials. However, that expenditure would be irrelevant in face of the possible penalty in case of missing the project completion deadline".*

The importance of the medium-term level for the promotion of slack can be illustrated by the following remark by the project manager of case study A: *"in the medium-term planning we have a reasonable slack of time before production…thus we can think about contingencies that need to be addressed"*. Furthermore, case A revealed the role of medium-term planning as the last effective opportunity to make product design changes in engineer-to-order projects – i.e., if such changes were made during short-term planning, there could be rework across the processes of manufacturing, delivery, and assembly.

SPR at the medium-term level also implied unintended consequences. For example, this occurred in instantiation 7, related to the delivery of incomplete batches to the construction site. While it prevented the stoppage of some construction activities, it created the need for extra controls in order to ensure that the remaining missing parts arrived on time, in addition to unplanned financial expenditures due to increasing the number of deliveries for some batches. In contrast, instantiation 8 had a positive unintended consequence. The double-checking conducted by company Beta, in which a contractor´s employee visited the factory of company Alpha to make sure that just the right materials would be shipped, contributed to reducing the needed storage area on site. The upside of slack was also visible in instantiation 9. It was related to changes in product design and can be characterized as an incremental innovation aimed to simplify structural design, which was extended to other projects of company Alpha.

Table 6. Slack practices and resources in medium-term planning.

Instantiations of slack practices	Slack practice	Variability tackled by slack practice	Slack resources	Unintended consequences
(1) Outsourced design team had the contractor's internal design team as a backup	Redundancy – Standby	Low productivity of the outsourced design team	People	Delays in the design of other projects under the responsibility of the contractor´s design team
(2) Assembly workers based in other worksites attended induction training in advance, being ready for admission if necessary	Redundancy – Standby	Delays that would imply extra workers to catch up with the schedule	People	Delays in the schedules of other projects
(3) Spare stud bolts equipment with approved purchase order	Redundancy – Standby	Breakdown of equipment	Equipment	None
(4) Spare nail gun for steel deck with approved purchase order	Redundancy – Standby	Breakdown of equipment	Equipment	None
(5) Spare cranes with approved purchase order. Installers from the crane´s company attended induction training in advance	Redundancy – Standby	Delays that would imply extra equipment to catch up with the schedule	Equipment	None
(6) Project manager acted as a backup to the production manager for problem-solving activities	Redundancy – Standby	Peaks of simultaneous work zones, which demanded more time from managers	People	None
(7) Expediting the production of steel structure components in the manufacturing plant, even if batches were incomplete	Work-in-progress	Idleness of the assembly workers in the construction site	Materials	Unfinished construction stages and need for extra controls in the meantime up to completion
(8) Empty areas left in the construction site to store materials if necessary	Margins of Manoeuvre – Defensive	Lack of space to store materials in the construction site, which could occur in case of overproduction by the manufacturing plant	Space	Difficulty to find space to store other materials in the construction site
(9) Changes in the design of the steel structures to simplify components and make it easier to manufacture them	Margins of Manoeuvre – Autonomous	Capacity bottlenecks in the manufacturing plant	Design – technical solution	Higher costs with materials
(10) Changes in the design of the connections between beams at the edge of the building and the safety nets for fall arrest – these changes would speed up the assembly of the steel structures	Margins of Manoeuvre – Autonomous	Low productivity of the assembly team	Design – technical solution	Higher costs with materials
(11) Changes in the design of the main beams, in order to reduce the number of connecting parts. These changes allowed for and were associated with the pre-assembly of some elements.	Margins of Manoeuvre – Autonomous	Low productivity of the assembly team	Design – technical solution	Higher logistics costs: the pre-assembled elements implied in pieces of irregular shape, which did not make the best use of the trucks´ capacity.
(12) Changes in design of the deck solution to reduce the need for secondary beams	Margins of Manoeuvre – Autonomous	Low productivity of the assembly team	Design – technical solution	None
(13) Design of the steel structures was submitted to client´s approval in small batch sizes. It allowed for the earlier start of production in comparison to the option of submitting a large batch to the client.	Margins of Manoeuvre – Autonomous	Client's design approval is slow	Procedures – working in small batches	None
(14) Use of multifunctional teams in the assembly of the steel structures	Margins of Manoeuvre – Coordinated	Peaks of workload during the assembly of the structure	People	None
(15) Replacement of materials as to use those available in the plant	Margins of Manoeuvre – Coordinated	Lack of the originally specified raw materials	Materials	Higher costs with materials
(16) Extra shifts at the manufacturing plants were reserved for coping with requests from the studied project	Margins of Manoeuvre – Coordinated	Manufacturing delays	Time	Higher manufacturing costs and delays in the supply of steel structures to other projects

(17) Contractual arrangement with subcontractors in order to ensure replacement of workers in case of leave by COVID	Redundancy – Standby	Absenteeism stemming from COVID	People	None
(18) Double-checking the steel structures received in the construction site, in order to make sure that the order was properly fulfilled	Redundancy – Procedures	Lack of adherence in the supply of steel material	Procedures – inspections	It reduced the storage area for steel structures, since the double-check prevented the storage of materials that were not in the right sequencing of assembly
(19) Designers continued their work at home during the initial stages of the pandemic. This allowed for expediting design activities, putting these ahead of the construction schedule in comparison to normal times.	Work-in-progress	Project delay for execution of work zones	Design	None
(20) Inventory of steel structures stored in the construction site was increased from 1 to 3 weeks	Work-in-progress	Lack of materials	Materials	Extra storage area, and additional managerial effort to control the inventories
(21) Storage of steel structures in temporary areas where construction activities were taking place	Margins of Manoeuvre – Autonomous	Lack of space	Space	Safety hazards and more complicated workflows
(22) Concentration of concrete pouring activities on the same day of the week in order to get priority from suppliers. The contract with the supplier of concrete established a minimum daily volume of deliveries.	Margins of Manoeuvre – Coordinated	Suppliers of concrete prioritized large orders, and thus they could be unavailable	Materials	Queue of trucks waiting to unload, parked in public areas

Table 7 presents the SPR at the short-term level. The short-term level revealed the role of opportunistic SPR, mostly in terms of adaptive performance by the assembly crews and production management teams to cope with deviations from the schedule. The instantiations classified as margins of manoeuvre were conceived outside of the regular planning meetings - e.g., the reallocation of workers from one work zone to another during the workday in order to meet daily production goals; borrowing equipment from other contractors working concurrently. An example of margin of manoeuvre was reported by the production engineer in the context of the strike of truck's drivers: *"transportation factory-construction site relies on large trucks, which bring mostly large and heavy pieces but also many smaller and lighter ones. The anchor bolts should be on the construction site at least three weeks before the starting date…and that was exactly when the strike happened. Then, we used passenger cars to deliver the anchor bolts… cars could escape the blockages set by the truckers in the roads".*

Table 7. Slack practices and resources at short-term planning

Instantiations of slack practices	Slack practice	Variability tackled by slack practice	Slack resources	Unintended consequences
(1) Dedicated crane for unloading materials from delivery trucks of steel structures used to support the assembly team when necessary	Redundancy – Standby	Peaks of demand for cranes	Equipment	Unloading the delivery trucks out of the regular working hours
(2) Front-line supervisors carried out production activities when workers needed help	Redundancy – Active	Complicated and unanticipated procedures for lifting some types of structures	People	None
(3) The designer of the rigging plan was requested to stay full time on the construction site to assist in the creation of alternative rigging plans	Redundancy – Active	Delays in developing alternative rigging plans	People	None
(4) Development of alternative rigging plan scenarios	Redundancy – Redundant Procedures	Lack of predictability of the sequencing of lifting the structures	Procedures – production activities	None
(5) There was more than one competent worker for the operation of the crane cited in practice (1)	Redundancy – Active	Absenteeism	People	None
(6) Welder can work as assembler if necessary	Redundancy – Active	Peaks of workload during the assembly of the structure	People	None
(7) Double-checking the level of inventories, both by the production manager and by the storekeeper	Redundancy – Redundant Procedures	Failures in the inspection of materials at the warehouse	Procedures – inspection	None
(8) Backlog of work packages to be carried out if the execution of the regularly planned work packages is delayed or suspended	Work-in-progress	Delays in construction activities	Procedures – production plans	None
(9) Use of a passenger car to transport anchor bolts to the construction site during the truckers' strike	Margins of Manoeuvre – Autonomous	Lack of materials	Equipment	Higher logistics costs
(10) Work on Saturdays and at night shifts to compensate for delays	Margins of Manoeuvre – Autonomous	Low productivity	Time	Higher assembly costs
(11) Reallocation of workers among crews and in additional shifts in order to meet daily production goals	Margins of Manoeuvre – Autonomous	Low productivity	People	Delays in the activities from which workers were removed
(12) Equipment borrowed from other companies in the worksite	Margins of Manoeuvre – Autonomous	Unexpected peaks for workload	Equipment	Movement of equipment from one work zone to another, implying safety risks
(13) Reallocation of workers across crews and work zones in order to meet weekly production goals	Margins of Manoeuvre – Autonomous	Low productivity	People	Delays in the activities from which workers were removed
(14) Use of public areas nearby the construction site for parking concrete mixer trucks	Margins of Manoeuvre – Autonomous	Lack of space in the worksite to serve a large number of trucks during concreting	Space	Higher safety risks and annoyance to the neighbourhood
(15) Use of alternative areas to store materials in the construction site	Margins of Manoeuvre – Autonomous	Lack of space	Space	Complicated workflow and safety hazards
(16) Backlog of work packages to be carried out if the execution of the regularly planned work packages is delayed or suspended	Work-in-progress	Delays in construction activities	Procedures – production plans	None

(17) Work on Saturdays and night shifts to compensate for delays	Margins of Manoeuvre – Defensive	Low productivity	Time	Higher costs of assembly
(18) Use of overtime for the crane to move materials from one storage area to another	Margins of Manoeuvre – Defensive	Lack of space	Time	Higher costs of assembly

Some instantiations at the short-term level were necessary only due to the unintended consequences of other practices at higher levels, which suggests that some SPR have a recursive nature. For example, the decision to maintain large inventories of steel on-site, which was made at the medium-term level in case study B, demanded the use of the crane frequently on an overtime basis (which was a decision made on the spot, daily) in order to move materials to alternative storage areas. Similarly, in the same case study, the medium-term planning decision of concentrating concreting activities on the same day demanded actions on the spot, such as the need for finding appropriate places for parking trucks.

Aggregated results of cases studies A and B

Figure 1 presents the overall distribution of the 57 instantiations of slack practices (35 in case A and 22 in case B) across PPLAN levels. Although the long-term level accounted for only 16% of the total, it created the conditions for the use of practices at the phase scheduling (13%), medium (39%) and short-term levels (32%). For instance, the allocation of extra workers and equipment to cope with delays, an instantiation that played out in the medium- and short-term levels in case study A, was possible only due to financial contingencies created in the early versions of long-term plans developed during the bidding stage.

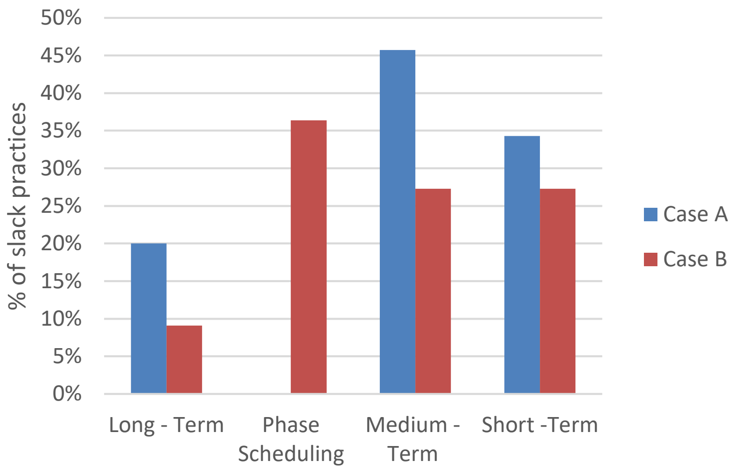

Figure 1- Distribution of slack practices across PPLAN levels

Figure 1 – Alt text: distribution of slack practices across PPLAN levels in cases A and B.

As for the overall analysis of the eight types of slack resources, their distribution in both cases (Figure 2) shows that financial resources were deployed only in the long-term level (case A), while materials were used in all levels except for the short-term. Possible interpretations for these findings might be: the higher uncertainty in long-term planning, which calls for versatile slack resources such as money; and in engineer-to-order projects, materials tend to have long lead times, making the short-term too late for the acquisition of additional materials. Time appeared as a resource at all levels, reinforcing its importance widely acknowledged by the literature on buffers. Despite this, the variety of slack resources and their fragmentation across PPLAN levels is clear in Figure 2 – e.g., in the medium-term level, in case A, seven out of the eight types of resources were used.

Note the similarity between the identified types of slack resources and the preconditions for a construction task set out by Koskela (1999). Five out of the seven Koskela´s preconditions (i.e., design, materials, workers, equipment, and space) are explicitly accounted for while the other two (i.e., connecting works and external conditions) are implicit in the slack resources referred to as time, financial, and procedures. This similarity adds to the validity of the identified slack resources, when considering that a certain type of slack resource is logically associated with the corresponding type of precondition – e.g., when design serves as a slack resource it is fulfilling the role of design as a precondition for a construction task.

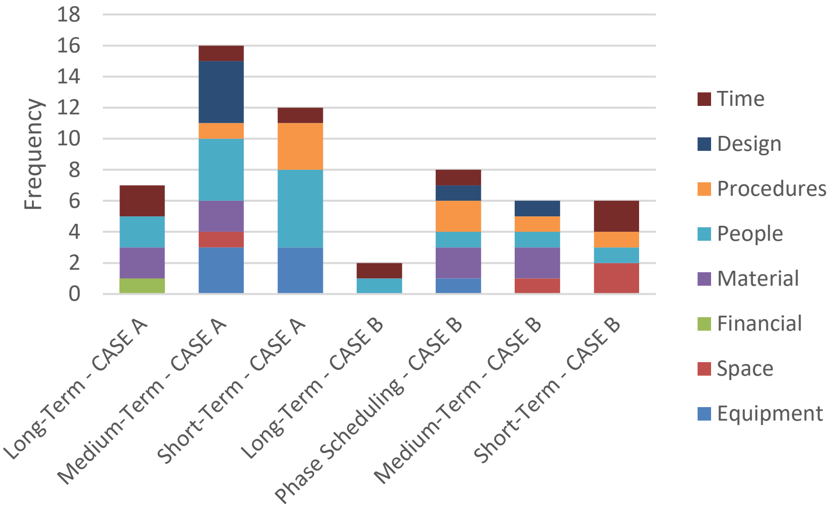

Figure 2- Frequency of slack resources across PPLAN levels

Figure 2 – Alt text: Frequency of slack resources across PPLAN levels in cases A and B.

Overall results also pointed out the relevance of the unintended consequences of SPR – 46% of the total instantiations in case A and 56% in case B. These consequences were commonly related to costs of materials, transportation, and labour. Less straightforward consequences occurred in the sharing of some slack resources between different projects. In these cases, slack resources that were beneficial from the perspective of one project (e.g., use of company Alpha design team as a redundancy to the outsourced design team) could be detrimental to other projects that demanded the same resources.

DISCUSSION AND PROPOSITIONS

The case studies illustrates how the concept of SPR gives visibility to a wide range of variability coping mechanisms in PPLAN, empirically demonstrating that they encompass buffers but are not limited to these. Time, which is often associated with the term buffer, accounted for only 12% of the resources in case study A and 18% in case study B. In addition, the case studies indicated that SPR can contribute to incremental innovation (e.g., instantiation 9 at the medium-term level) and are not necessarily designed during formal PPLAN meetings. Due to the dynamics of construction projects, some variabilities can only be detected on the spot, demanding the quick deployment of SPR – e.g., one subcontractor borrowing equipment from another in order to cope with a rise in demand. As a result, there were several examples of resources serving as slack even though that was not their original purpose – e.g., passenger cars for the transportation of materials. Hamzeh et al. (2019) frame these opportunistic manifestations of SPR as improvisations and identify three factors that influence on their effectiveness: the improviser´s personal profile, characteristics of the organization, and specific factors related to the task at hand.

Further, the case studies illuminate the role played by processes other than PPLAN in the provision of SPR, such as: *(i)* procurement, as several SPR were defined through contractual arrangements between contractors and their suppliers; *(ii)* design, as some SPR stemmed from changes in the design of the building structure; and *(iii)* training, as exemplified by the SPR that implied the expediting of induction training. However, these processes were related to PPLAN regarding the definition of work packages and actions for the removal of constraints – e.g., the signing of a contract that specified SPR could be a constraint at the medium-term level. This conclusion on the PPLAN centrality is consistent with previous studies that have explored the integration between PPLAN and other processes, such as design (Wesz et al., 2018) and safety management (Saurin et al., 2004). Against this background, the first proposition is stated as follows:

Proposition 1: in addition to PPLAN, there are other formal (e.g., procurement, design, and training) and informal processes (e.g., improvisation at the front-line) that are useful for the design and deployment of SPR.

An additional insight into the nature of SPR was gained from the data analysis according to the PPLAN levels. This analysis revealed the evolutionary nature of some SPR during the project life cycle. The most salient example refers to financial slack established at the long-term level, which was transformed into other types of resources along the project timeline. The versatility of financial slack has been acknowledged by Wiengarten et al. (2017).

Interactions between SPR intra and inter levels were also evidenced from the case studies. For instance, the availability of weekends to catch up with the schedule made room for all other SPR to be deployed during that time window – e.g., the availability of reserve equipment is pointless during weekends if the construction site is closed. Thus, the notion of meta-SPR is proposed as those general-purpose (e.g., money and time) and antecedents of operational and context-specific applications. Instantiations that proved to be effective at different levels also demonstrated versatility. In the case studies, this occurred, for instance, by the reallocation of workers, replacement of materials, and double-checking of materials – all of them were used, although deployed differently, at the medium and short-term levels in both case studies. This discussion lays the ground for the second proposition:

Proposition 2: SPR differ according to their general-purpose or variability-specific nature, which has an impact on their ability to cope with unexpected events.

Despite the value of general-purpose SPR, adaptive capacity is finite and black-swan events might challenge the most carefully designed systems. In particular, the external environment is a permanent source of variability (Cilliers, 1998) as illustrated by the strike of truck drivers and the pandemic. The unexpected character of variability is mostly a matter of degree rather than a binary possibility. What counts as unexpected also depends on requisite imagination, which means that the extent of the unknowns might be reduced as a result of risk assessment efforts (Love and Matthews, 2020). However, the significant body of knowledge on risk management in construction (e.g., Tepeli et al., 2019; Hamzaoui et al., 2014) has not been fully accounted for by PPLAN methods. Ballard et al. (2020) proposed a framework for risk management for planning and control, but this is limited to the long term-level planning level. Torp et al. (2018) propose a conceptual model where uncertainty management[1] is integrated in the plan and meeting structure of the Last Planner® System – however, this model has not yet been tested in practice. Wehbe and Hamzeh (2013) present a theoretical proposal for using the failure mode and effect analysis technique for risk management at the medium-term level.

The case studies suggest that in the integration of risk management into PPLAN, one should consider risks at the micro (e.g., risks at the construction activities at the front-line such as an unavailable crane), meso (e.g., risks at the construction project level such as a client that delays the design approval), and macro levels (e.g. risks at the national level such as the pandemic and the truckers´ strike). In addition, risk management is important for the sizing of slack resources as it helps to prioritize the risks. The value of risk management is acknowledged by proposition 3.

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[1] Torp et al. (2018) use the term uncertainty management to cover both the reduction of threats and exploitation of opportunities. This is the same way the term risk management is used in the present paper. Also, SPR are useful to cope with both threats and opportunities (Saurin and Werle, 2017).

Proposition 3: the design of SPR and the reliability of production plans in construction might benefit from the formal management of the risks that may affect production.

A thorough risk management process must consider the possibility of unintended consequences of changes (Perrow, 1984). These consequences were detected in both case studies and across all PPLAN levels. Managers who devised those SPR tacitly assumed that their overall net impact would be positive. Putting it another way, the managers thought that the benefits of using SPR outweighed the losses resulting from not using them.

Despite that, the existence of tangible unintended consequences indicates that their costs may have to be added to the cost of deploying SPR. The cost of unintended consequences might be framed as waste as it corresponds to a second layer of extra resources with the drawback of not adding protection against variability. This framing is consistent with the definition of waste as the use of more resources than needed, or an unwanted output from production (Bolviken et al., 2014). Proposition 4 stems from these insights on unintended consequences.

Proposition 4: the integration of risk management into PPLAN in construction should account for the unintended consequences of the introduction of SPR, aiming at the reduction of wastes arising from them.

As such, proposition 4 emphasizes the downside of the relationship between SPR and waste. There is an upside, as SPR are a means for avoiding making-do, defined by Koskela (2004) as a type of waste that occurs when a task starts without meeting all its preconditions or the task is continued even though at least one precondition is unavailable. Fireman and Saurin (2020) argue that, by providing alternative means for meeting preconditions of work packages, SPR prevent that a failure for making-ready immediately implies making-do. In this respect, a full production stoppage in the absence of fulfilled preconditions is also an SPR as its ultimate purpose is to buy extra time. A number of SPR in cases A and B were clearly triggered by the failure in meeting preconditions for the start of work packages – e.g., the use of passenger cars to transport components.

By highlighting that SPR might imply unintended consequences, proposition 4 also raises the question of whether there is an amount of slack resources that is the most beneficial. This point is acknowledged by some authors who propose an inverted U-curve to display the non-linear relationship between the amount of slack and its benefits (Azadegan et al., 2013). Figure 3 presents an adapted curve that includes the role of waste. In this Figure, the amount of slack resources varies from none to too much, and their benefits from none to most.

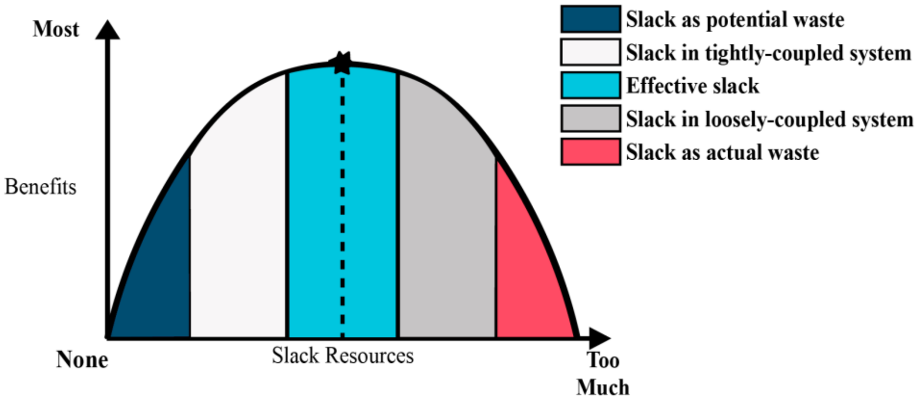

Figure 3. Schematic of an inverted U-curve representing the non-linear relationship between the amount of slack resources and their benefits.

Figure 3 – Alt text: schematic of an inverted U-curve representing the non-linear relationship between the amount of slack resources and their benefits.

The far-right zone of Figure 3 corresponds to actual waste as there are too many slack resources in the sense that they do not provide significant benefits – i.e., more resources than needed are used, thus implying an actual manifestation of waste (Bolviken et al., 2014). The far-left zone corresponds to potential waste as there are too few slack resources. In this situation, waste is potential as it will only play out if variability strikes and there is an unwanted output (i.e., waste, according to Bolviken et al., 2014) as a consequence of insufficient slack. Both ends highlight the dual nature of SPR, which in lean production tend to be seen as waste, while from the complex systems perspective tend to be seen as necessary protection against variability (Saurin, 2017). The central zone under the curve represents the ideal balance between the amount of slack resources and their benefits. The two intermediate zones, on the left and on the right to the central zone, consist of slack resources placed on predominately tightly and loosely-coupled systems, respectively. In tightly-coupled[2] systems, SPR are usually built-in, explicitly designed with efficiency concerns in mind. In turn, loosely-coupled[3] systems have naturally embedded significant slack resources and these can be often taken for granted, encouraging waste (Perrow, 1984). Figure 3 gives rise to the fifth and last research proposition:

Proposition 5: at a certain moment in time, and given the local consensus on risk tolerance, there is an amount of slack resources that effectively balances the trade-off between benefits and drawbacks of slack.

The wording of proposition 5 conveys that the variables involved in Figure 3 are not easily amenable to quantification. Thus, Figure 3 should be primarily used for reflection on the amount of slack resources. Given the varied nature of SPR, finding a common metric to yield an overall quantity of slack resources is elusive. Saurin and

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[2] An example of tight-coupling in construction is the sequencing of the building structure – i.e., there are few if any possible alternative sequencing options.

[3] Loose-coupling is common in construction sites, such as alternative suppliers of everyday materials (e.g., bricks) and alternative routes for the transportation of materials from one workstation to another.

Werle (2017) offer a possible alternative by using a questionnaire survey in which workers point out their perceptions on the effectiveness and coverage of different SPR. In fact, proposition 5 suggests that what counts as too little/too much slack is context-dependent and thus it changes over time. For instance, double-checking the level of inventories (see example 7 in Table 7) was necessary because of failures in the warehouse management; in face of process improvement, keeping double-checking would be seen as waste.

It is also worth noting that the context involves both technical and non-technical factors, which play a role in risk tolerance (Slovic, 2001). In the construction industry, competitive bidding exemplifies a non-technical factor that discourages contractors to use a broader range of SPR, even though these are usually accounted for, to some extent, by the inclusion of financial slack in the bidding price (Elfving et al., 2005). However, this type of slack is largely a black box in the absence of a formal assessment of the SPR potentially necessary. This study sheds light on how to open that black box by providing a vocabulary for thinking about SPR and indicating a number of manifestations that may inform more realistic cost estimates.

CONCLUSIONS

This study addressed the question “how are slack practices and resources used in production planning and control in construction?” Two exploratory case studies offered insight into how a variety of SPR is deployed in PPLAN. The adopted analytical structure allowed for the joint investigation of variability coping mechanisms that shared the same theoretical and practical foundation, while having little in common at a cursory view. This structure was composed of five themes: instantiation of the slack practice, type of slack practice (e.g., redundancy, work-in-progress), variability tackled by the slack practice, slack resources, and unintended consequences. Several of the 57 instantiations of slack practices and 8 resources identified (e.g., one contractor borrowing equipment from another) diverged from the traditional view of buffers as time, inventory, or capacity.

The results demonstrated that SPR are ubiquitous across all PPLAN levels and that they play out in other managerial processes. This pervasiveness suggests that it is important to make SPR explicit to managers so that these can reflect on why SPR are necessary, how they relate to each other, and their unintended consequences. Our findings also demonstrated that SPR can be either designed or arise from self-organization of employees on the spot. The latter case is assumed to be a natural response to the inevitable variability that exists in construction projects. In turn, the design of SPR might benefit from its incorporation into structured management processes such as PPLAN. In fact, our results might be useful for the improvement of risk management in the PPLAN of construction projects. Three of our propositions (i.e., 3, 4, and 5) are explicitly connected to risk management. As such, this study indicates that PPLAN and risk management should be integrated processes, and that this integration might benefit from using the concept of SPR. For example, long-term planning could account for the design of versatile SPR (e.g., financial reserves) that can be deployed during the project life-cycle and support the management of both expected and unexpected risks. In turn, opportunistic instantiations of SPR can be concealed from the view of managers when the desired outcomes are obtained – i.e., managers may wrongly assume that these outcomes were due to effective planning on their part. Giving visibility and understanding these instantiations might contribute to more effective risk management and planning.

The implications of understanding SPR in PPLAN were encapsulated in five propositions for further theory development, theory testing, and for guiding action in production management.These propositions are concerned with: how to identify SPR (propositions 1 and 3); the variety of SPR and their general or context specific nature (proposition 2); and the value of maintaining slack resources, which depends on their unintended consequences (proposition 4) and continuous reassessment in light of a changing context (proposition 5).

Some limitations of this study must be acknowledged. First, the findings and the propositions might have been influenced by the context of the case studies, which pertained to two construction sites in Brazil and were subjected to major disruptions from the external environment. Second, the PPLAN of the case studies was based on a specific approach, namely the Last Planner® System. Although this may have influenced our empirical findings, the subsequent propositions were presented at a high level of abstraction, being of interest to other production planning and control models. Third, the focus on PPLAN may have concealed the full variety of SPR in the construction projects. Fourth, this study did not quantify the influence of SPR on project performance. Fifth, the dependence relationships between SPR were not modelled, although there was evidence that some SPR are antecedents of others.

Several opportunities for future studies derive from this research such as: *(i)* additional in-depth descriptive studies of SPR, considering other typologies of construction projects and PPLAN methods other than the Last Planner® System; *(ii)* a deeper assessment of how management processes other than PPLAN contribute to the management of SPR; *(iii)* the modelling of the interactions between SPR, also considering their relationships across the PPLAN levels; *(iv)* the development and empirical testing of frameworks for the integration of risk management to the Last Planner® System; *(v)* the investigation of the intrinsic strengths and weaknesses of each type of SPR; *(vi)* the testing of the research propositions both in case studies and large samples of companies; and *(vii)* the investigation of the impacts on project performance when the expanded buffer concept, represented by the notion of SPR, is explicitly and systematically used in PPLAN.

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