USING PULL AND FLOW SYSTEMS TO IMPROVE PRODUCTION STABILITY IN REAL ESTATE DEVELOPMENT PROJECTS

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"Lean is a journey, not a destination".

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and overall ... To My Beloved Daughter, Madeline;

Who Grew Up Together With The Writing Of This Thesis.

ABBREVIATIONS

- BIM: Building Information Modelling
- CAD: Computer-Aided Design
- CPM: Critical Path Method
- DP: Detailed Planning
- ICT: Information and Communication Technologies
- IGLC: International Group of Lean Construction
- JIT: Just-in-Time
- KPI: Key Performance Indicator
- LCM: Lean Construction Management
- LPS: Last Planner™ System
- MIT: Massachusetts Institute of Technology
- PM: Project Management
- PPC: Percentage Plan Complete
- PP: Process Planning
- SOP: Standard Operating Procedure
- TFV: Transformation-Flow-Value
- TOC: Theory of Constraints
- TPS: Toyota Production System
- TSSC: Toyota Production System Support Centre Non-Valueal Reality
- VSM: Value Stream Mapping WIP: work-in-process

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Abstract

Objectives: The objective of this thesis is to understand the effects of the application of flow-based management systems on medium-size sites (€2-50 million work turnover) made by medium-sized companies (20-200 employees). The purpose of this research is to develop and evaluate a pull scheduling system based on the Last Planner™ System (LPS) to improve production flow stability of real estate developments made by SMEs. The research investigates the application of pull systems from manufacturing industries and those that have not been fully tested in the construction industry. **Method:** A three-block real estate development project in Brussels was used to ground the context where action research was chosen to initiate the research. Action research follows an ascending spiral that consists of 4 phases described in 1991 by Zuber-Skerrit: 1) planning, 2) acting, 3) observing and 4) reflecting. Once the first circle is initiated, the four activities lead to the next cycle. The reflections phase of circle (n) then leads to the planning phase of circle (n+1). These loops can be derived indefinitely or at least while the research has not met its objectives. Passing from action to critical reflection and back and vice versa in a cyclical process helps build a wider view and a greater understanding. In this context, three action circles were conducted. In this way, the methods, data and interpretation were continuously refined (Dick, 2002). The sequential development of the three blocks made by the same teams eased the process of capturing insights from a phase and building an optimal scheduling process. A lack of works planning, and progress understanding was found to be a major issue when the research started on the ongoing works of the first block. 5S and LPS were tested as a means of improving construction works planning at both the physical and managerial levels. The application of the first three Ss (sort, set, shine) yielded an impact on respect for the work site but were not sufficient to significantly affect the planning. The application of the first two steps of the LPS (master planning, phase planning and make ready) showed improvement but were also limited in their impact in the search for planning reliability. On-site measurements showed that despite a high percentage plan completion (PPC) score in the LPS, analysis of the progress of each apartment showed high volatility from one

week to the next. This volatility came from a lack of visibility in the scheduling system. Although the progress of each week was determined by what was and should have been done based on the LPS, more structure in the scheduling system and more reliability in the forecasts of the works were needed to increase the works stability. Given that takt time has been successfully used in the manufacturing industry to address variability in the demand, and that significant similarities exist between a construction site and a manufacturing line, it was decided to test this as a complement to the LPS in the research action taken on the second block of the building development. Encouraging results were measured, and on-site work in this block was improved. **Findings:** it was found that the discipline needed to respect the system, the rules and sequence of the work demanded high-level and constant surveillance from site management. In the long run, this could put the whole system at risk. In order to be as efficient, sustainable and duplicable as possible, the scheduling system should be visual, need no interpretation and lead works in a pull flow. Manufacturing has successfully used a simple but efficient system named k*anban* to achieve level production and ensure a fully pulled system in a variable demand environment while limiting the sources of errors. The third block proved that such a method can work in conjunction with takt time and LPS and improve the works stability by favouring a self-pull system. **Impact:** following the scheduling system developed by the action circles in Block 2, there has been a reduction of nearly 20% of the lead time measured and a significant increase in quality (the number of snagging works decreased by 95%). Therefore, the stress on the site management team decreased (captured by interviews). The early findings and encouraging results are signs of the importance of the research undertaken. **Limitations:** The research has been conducted on traditional sites regarding typology, size, techniques, management structure, and contractors, so the findings are addressed to a wide audience across the construction industry. The limitation of the research comes from the domain of the construction observed: real estate in Belgium. Although it is highly probable that the issues detected on site by the research and the mechanisms used to address those issues are duplicable in other domains of the construction industry, there is, at this point of the research, no clear evidence.

1 Introduction

1.1 Introduction

This section provides background to the research presented in this thesis. The first chapter presents the complexity of coping with contractual delays in the construction industry and the problem of works schedule predictability. Then, the rationale presents the reason for the research. The aim and objectives and limitations are then addressed. The research plan is presented before a description of the content of the thesis concludes the introduction.

This research aims to improve stability in the workflow on a construction site based on lean concepts. The research is grounded in previous contributions to stability in both the manufacturing industry (Fondhal 1961, Ohno 1988, Goldratt 1990, Goldratt 1997, Liker 2004, Smalley 2011) and in the construction industry (Ballard 1994, Ballard 1998, Ballard 2000, Koskela 2000, Koskela 2004, Koskela 2011 Tommelein 1999, Ballard 2000, Smalley 2011). The scope of this research is narrowed to the common residential developments made by small and medium-sized enterprises (SMEs).

The research also presents and confronts the more recent systematic literature review on the application of lean tools by SMEs (Tezel 2019) to fill the literature gap and offer the research as a contribution to the body of knowledge.

The rest of the section presents the personal motivation felt by the author who has spent a significant part of his professional life as witness to the inefficiencies in the construction industry while employed as an executive in large companies and an actor in this environment.

1.2 Background, context and problematic of the research

1.2.1 A complex environment

All construction projects should be delivered on time under the terms of the contractual agreement between the client and the contractors. However, construction is a complex, nonlinear and dynamic phenomenon, which makes it to some degree unpredictable (Bertelsen, 2002). The whole industry functions in a chaotic environment and this situation has lasted for so long that it has become a paradigm. Hence, this field of research is complex. The background of this research lies in more than a decade of the author's professional activity as a project manager and chief operating officer in the construction industry for contractors and project management companies. Of the 100+ construction projects across Europe, ranging from €8 million to €250 million works turnover, and of various project typologies (new constructions, renovations, real estate, offices, hospitals, for public and private clients) that the author or his team have directly monitored, not a single one was reported to have been delivered on time, i.e., on the contractual due date. This failure has led to the author's awareness that this situation should change and to the initialisation of PhD research to provide academic robustness to the path that should be developed and shared with the scientific community.

The above underperformance has already been duly observed and documented. After having closely observed and analysed the work of several contractors during the construction phase of the engineering procurement, and construction (EPC) of a number of industrial projects, Ballard (1993) reported on the poor quality of the end-product and that the significant difficulties encountered in the delivery process of offsite resources (design documents from the engineers, plant equipment and materials from manufacturing suppliers) caused widespread disruption and waste.

Ballard (1993) argued that the construction industry had not fully managed its transformation (the shift from craft to mass production) or, in other words, as it is called in other industries such as in the automotive sector: the shift from craft production to lean production. For Ballard (1993), it was imperative that the construction sector get inspiration from the manufacturing sector. After observing and analysing shop flow construction, he came to the decision that the lack of site project engineers and the lack of standards in the daily work methods were tangible signs and were fed from a historical and predominantly craft production model in the construction industry. The craft model is deeply anchored and emphasised in the dominant belief that each construction is a prototype, one that intrinsically requires and values crafting as the most adapted and most valuable type of production.

An analysis of the performance of 118 construction companies worldwide between 1995 and 2003 (Horta 2012) showed that the construction industry still suffered from low performance 10 years after Ballard's (1993) seminal observations. Mellado (2019) later demonstrated that while performance remains low following the traditional iron triangle of cost-time-quality, it is still the preferred method of analysing performance, despite it being proven to be ineffective. Ballard's 1993 approach to planning and measuring engagements scientifically under the LPS had still not become the prevalent approach in traditional construction companies.
Hence it is likely that what Ballard described in 1993, at the birth of lean construction, remains the case today on most construction sites.

The initial observations and measurements made by the author on the real estate development site used in this research (Chapter 6) show a similar situation: a focus on the cost-time-quality triangle, poor overall performance and low levels of planning reliability.

The research conducted here aims to bring project management of real estate development a more robust system of work coordination than the traditional critical path method (CPM) approach and the more recent LPS approach, with the eventual aim of achieving the on-time delivery of projects. Koskela (1994), Tommelein (1999) and Ballard (2015) showed that chaos and desynchronisation can be found in all phases of a construction site (engineering, design, procurement, construction) but, while desynchronisation gets amplified through various stages (the domino effect), the research investigates the ultimate process of coordinating work on site. Any construction project needs planning before, during and, sometimes, after construction. Planning is also a complex process that involves coordination between many stakeholders. The complexity of construction projects has constantly increased over time, with the entry of new materials, new trades, new owners and environmental requirements, new technologies, and the number of parties involved (consultants, quantity surveyors, contract administrators, planners, specialists, and so forth).

1.2.2 Motivation for the research: improving the current production stability of the works of SMEs on site

Following Chandler's historical-evolutionary line in the theory of the firm (Chandler, 1992), Kapas (2008) showed that production factories and project-based organisations are social technologies that have evolved as part of the co-evolution of physical and social technology. While the factory model was the original form of the capitalist firm, the project-based organisation model was conceived as a mutant until the late 1980s (Kapas 2008). Productivity had increased following successive refinements (compressions) of the production cycles in many industries that were able to rethink their operation processes (Kapas 2008). These sectors (information, manufacturing, warehousing, agriculture, etc.) leveraged the use of technology in incomparable ways in comparison to the construction industry.

Teicholz, (2013) showed that the value added per employee, which can be directly linked to productivity and performance, has exhibited different tendencies across sectors: the value-added per employee in the architecture, engineering and construction (AEC) industry decreased while it increased elsewhere (e.g., it multiplied by 10+ in the manufacturing sector). In his 2013 book *Labor-Productivity Declines in the Construction Industry: Causes and Remedies (Another Look)* (p. 12), Teicholz describes the evolution of value-added per employee in various sectors from 1950 to 2010, as shown in Figure 1.1. Teicholz (2013) illustrates a "real productivity" gap (or "value per employee" gap) between the construction industry and other industries. Upon closer inspection, it is noticeable that, over time, the value added per employee decreased in the construction industry.

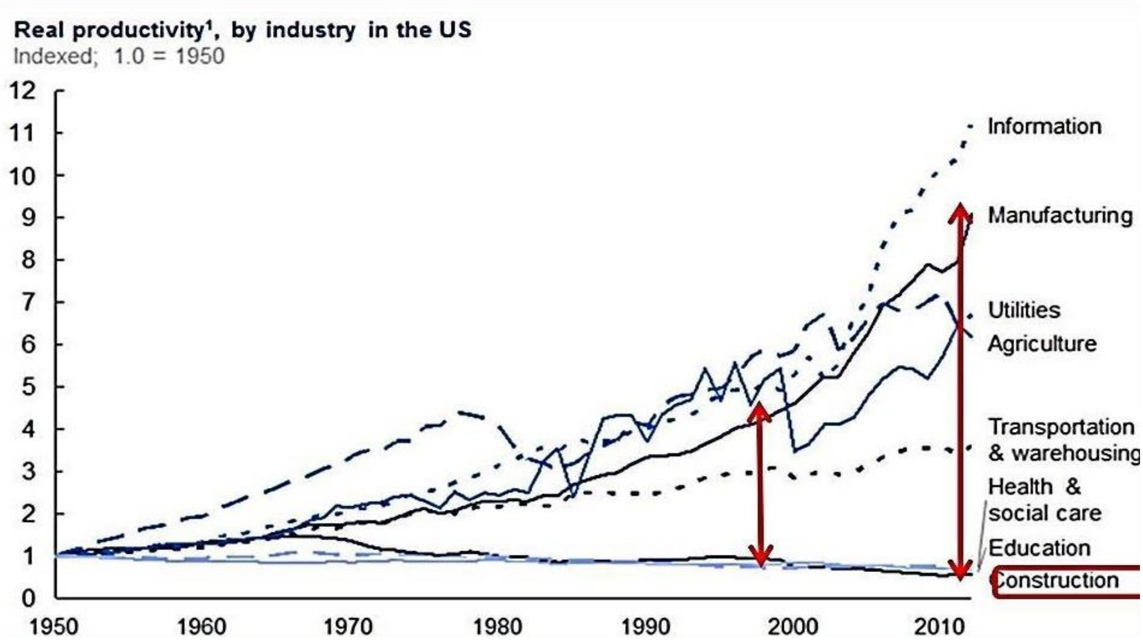


Figure 1.2.2-1 Real productivity by industry in the US (value added by employee) (Teicholz, 2013)

Nazarkoa and Chodakowskaa (2015) showed that measuring productivity in the construction industry was complex and that large differences in productivity levels could be found from using an indicator to another.

This research focused on planning performance rather than on site productivity: planning performance is the capability of an organisational system to keep to its planning.

In 1993, Ballard explained part of the poor performance in the construction industry was a result of how the planning system had been constructed to that point. Most planning systems were constructed offsite by a de-correlated-from-shop-floor engineer. Thus, there was no surprise that the output (master and/or detailed planning or programme) could not shield the production on site from upstream variation and uncertainty (delivery of the appropriate materials and tools, information being made available and adequate skilled workers being provided). These difficulties father discontinuities in the flow of work and reworks that often led to delays in the project and higher costs than expected or forecasted and, hence, a diminution of the productivity (Ballard, 1993). Howard et al. (1989) had already pointed out that high costs due to fragmented decision-making emerged from the increase in trade specialisation that eased flexibility in the construction industry.

More recently, Koushki (2005), Sacks (2007), Guo (2009) and Fayek (2013) have shown that over the past 40 years. However, several new and advanced technologies have been applied to construction projects, the efficiency of the industry has remained relatively low.
An increasingly technologically complex environment requires high skill levels from specialised contractors. Meanwhile, general contractors have shifted from overseeing production coordination to contract-brokering (Tommelein & Ballard, 1997a), which has exacerbated the fragmentation of the parties and the tensions in their relations.

The above explains why coordinating the different trades and specialists to deliver a project on time was difficult. To achieve impeccable coordination, people and systems need to work in a synergistic and self-reinforcing fashion (Collaborative Process Institute, 1997). The developments of the internet and information technology (IT) tools were envisaged as magic solutions to address coordination. To promote teamwork relationships and improve communication and coordination, partnering sessions or similar team-building programmes began to occur more commonly in the early 2000s; for example, ProjectNet, Team Builder, ProjectPoint, Constructw@re, and ProjectTalk. The tangible impact of these programmes, despite huge commercial promises, have yet to be demonstrated. O'Brien (2000a) proposed mapping the processes of all the participants in the process as a better way of determining and designing the tools that could be used in daily operations by the operators. Ballard (2000) stated that detailed information on all aspects of site requirements should be clearly identified to ensure coordination at the production level (logistics, assignments, specification of labour, equipment, materials, space use, and so forth).

The need for coordination is twofold: first, concerning physical production resources (e.g., labour, equipment, material, and space, where material should not only be read as raw material but also as work-in-process [WIP]), and second in terms of information. Architects and engineers now use powerful information treatment systems to create and add specifications and realise shop drawings in the form of 3D models that clearly show the final product. Construction managers and site foremen usually use the elements they have on hand (the ones they were given, not necessarily the ones they need) to erect the product in the right place, following the right sequence and at the right pace; however, there is a significant gap between the way a site is organised and the way the design and procurement phases are prepared, coordinated and monitored (Teicholz 2004, retrieved 2014).;For Aziz et al. (2013), the main reason for this appears to be that the new technologies cannot effectively reduce the cost of design and construction while improving the management of the construction process. For example, although computer-aided design (CAD) technology has improved the efficiency of drawing, it cannot reduce design errors and these, in turn, can cause the need for the reworking of construction, making it difficult to optimise the construction process to reduce cost.

To improve construction planning, one must have a clear understanding of the limits of the current practice at different levels. In a classic system, a project planner builds a project plan by determining an array of work sequences, task timelines and interdependencies that fit the client's requirements. This document is then sent to the contractors, who must respect it.

Although such plans are theoretically viable, in practice one's ability to keep to the budget and time constraint requested by the client remains questionable. When delays occur, their immediate explanation lies in the extra resources that increase the resources peaks on site and the unplanned reallocation of resources, causing an imbalance (Kenley et al., 2009). This imbalance produces further work desynchronisation and multiple scenarios (Seppänen 2009, Frandson 2019).

Under such circumstances, it is likely that multiple plans should be envisaged and developed to successfully deliver the construction on time and on budget.

The traditional approach to production planning is twofold. At the management level, monthly (or weekly) milestones, targets and performance aims are discussed and set as project baselines to meet the client's requirements. Master planning is usually drawn at this level. At the shop level, the works are planned daily by the site manager (or site foreman) who organises and coordinates the works on site by providing resources where assessed to be appropriate. The appropriateness of the site organisation can be questioned in this case as, although the weekly milestones are usually set by the project manager, the daily organisation remains mainly based on the site manager's personal experience. (Swain 2013). For a SMEs, the production planning has a third level. The planning should also satisfy the internal constraint of resource allocation (Saini 2018, Tezel 2020).

Whereas the work on site should follow a logical and robust sequence between trades to maximise efficiency, if no planner or trade coordinator is involved, work sequencing is mainly led the by professional experience of those observing the situation on site (Choo 2003, Ankomah 2017, Tezel 2020).

It is often argued in the common practice of project management in the construction industry that the flow principles and theories that have been developed over a long time by the manufacturing sector (which later led to lean management) cannot directly or indirectly be imported into the construction industry, the latter producing only prototypes, with no repetition in the processes. It is a belief that each building is different from the next, while in the manufacturing industry, production in series is widely used (Takim, Akintoye, & Kelly, 2003). In this research, it is claimed that the construction industry involves highly repetitive processes. The research conducted here is grounded in the previous work and experience of lean construction pioneers who have successfully developed methods directly inspired from flow systems developed by and for the manufacturing industry. The most notable is Ballard (2000), who developed a new approach to scheduling by tackling flow reliability through human commitment rather than by complex computed tools, or as it is called, the Last Planner™ System (LPS).

This research further investigates how flow systems can be imported into the construction industry, in practice, and contribute to closing the productivity gap with the manufacturing industry.

1.2.3 On the concept of flow stability

This paragraph introduces and discusses the concept of stability, a key concept in this study. The Cambridge Academic Dictionary defines stability as “a situation in which something such as an economy, company, or system can continue in a regular and successful way without unexpected changes”.

It can be recalled that in the early 1950s in Japan, Toyota faced, amongst other production difficulties, terrible die changeover processes, poor initial parts quality, unreliable production parts, and extensive WIP between processes as machine speeds were not synchronised to customer demand.

Taiichi Ohno, the great architect of what later became the Toyota Production System, and provided the foundation of the lean approach, experimented in the machine-intensive production shops at Toyota Motor Corporation between 1950 and 1955 to try to improve the production tools and approaches. Art Smalley from the Lean Enterprise Institute (2011) recalled that Toyota learned the hard way in that at the beginning of a transformation a great deal of basic stability is needed before succeeding with the more sophisticated elements of lean production. Ohno first addressed the fundamental issues of production before refining his approach and testing key concepts such as takt time, process flow, standardised work, the single minute exchange of die, and basic pull system mechanics.

Upstream stability

Smalley (2011) wrote that most initial efforts are spent improving production planning and control, especially regarding the management of upstream flows. Today at Toyota, TPS implementers of new overseas production plants follow a detailed framework to first establish basic stability before improving the process flow, developing pull systems, and achieving levelled production. This means that much effort should be realised in basic stability before trying to achieve the perfect stable flow. Toyota search for stability by establishing a consistent and predictable process before getting too far down the road with the latter elements of flow and takt time (Smalley, 2011). For Smalley (2011), achieving stability implies general predictability and the consistent availability of manpower, machines, materials, and methods – the so-called 4Ms.

Upstream stability is, hence, a prerequisite to production flow stability and can be checked by assessing the availability at sufficient levels of machine uptime to produce customer demand, materials on hand every day to meet production needs, trained employees being available to handle the current processes and work methods, and basic work instructions to follow quality standards.

Ballard (1994) stated that flow management is a much more difficult task on complex, fast track projects such as refineries, chemical plants, food processing plants, paper mills, etc. These projects have long, complicated supply chains, many players, typically are under pressure to hit market windows for production, and are subject to multiple, extensive process design changes motivated by the opportunity to make much more money than is lost through disruption of construction. In this environment, traditional approaches to construction management fail miserably. The conversion process model conceals everything that needs to be revealed, particularly the design of systems and processes to manage work and workflow. Ballard proposed the model below.

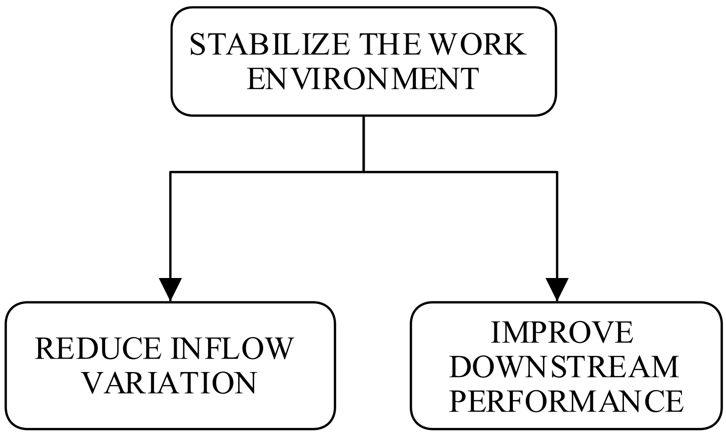


Figure 1.2.3-1

Production stability

Ballard (1998) believed that no theory of production control was needed in a construction world that was stable and predictable, and that construction was highly uncertain. For Ballard, stability and predictability are the consequences of production control, rather than arguments against the need for production control. Further, constructed objects are complex wholes such that the design and construction of their parts are necessarily interdependent upon each other.

In the construction industry, where making do is traditionally well established as a creativity inceptor (Koskela 2011), applying completeness checking tools such as the 4Ms is considered a means of improving predictability and the consistent availability of resources in the search for stability. Koskela characterised the complexity involved in managing upstream flows in this context as 1) the availability of inputs cannot always be assessed by a yes or no question (Koskela 2004), and 2) there seems to be a much larger variety of inputs than pointed out by Smalley. Koskela (2000) stated that construction consists of assembly tasks involving many input flows, and suggested a comprehensive classification of seven types of flow: design, components and materials, workers, equipment, space, connecting works, and external conditions.

In the search for an effective way of protecting production from upstream variability, the LPS was introduced in the construction industry (Ballard 2000) to increase the reliability of short-term planning. The main principle of the LPS is to create a shield on planned work from upstream variations and seek the conscious and reliable commitment of labour resources by the leaders of the work teams involved (Ballard and Howell 2000). A key basic in the LPS is that the necessary inputs, such as materials, information, and equipment, are available through a systematic review of the prerequisites of upcoming assignments in a make-ready proactive approach (Ballard 2000). The upstream flow of input should be as levelled and stable as possible while being capable of absorbing demand variations to allow a stable production flow under an efficient coordination approach.

1.3 Rationale

The search for operational performance in the construction industry and the recent introduction of complex IT tools on site (e.g. iPads and increased virtual reality), 7D modelling drawings, new materials (e.g. high-performance concrete) and techniques (e.g. 3D printing) require more and more parties be involved in the process of erecting a building, where flow management has become a key success factor for on-time and on-budget delivery (Suermann, 2009).

The argument developed in this thesis is that on-site performance can be increased by improving workflow stability. For less than a century (and increased in pace in recent decades), a variety of methods based on project control and the formalisation of planning have arisen: e.g., the Gantt bar chart that formalises various activities and the links between them in a readable time-framed chart, the Program Evaluation and Review Technique (PERT) that allows the decision-making process, and the predecessors and constraints of a given project to be followed and, more recently, the CPM that helps determine a shorter path of a project activity (a shorter sequence and time that leads to completion) (Olawale and Sun, 2010; Nicholas, 2001; Lester, 2000).

Since the mid-90s, a wide range of software and, now, clouded (on-line) tools have been developed to ease and even automatise the use of these project control methods, such as the MS Project, the Asta Power Project, and Primavera. It is interesting to note at this point that, despite the increasingly extensive use of these planning methods and formalisation software, most construction projects are still delivered late: up to 55 percent for traditional planning (Dawood 2010). Later research (Love et al., 2011; Crotty, 2012; de Melo et al., 2016) has confirmed this situation.

A deeper and more recent study conducted by Gledson (2018) analysed the planning and delivery of time performance in the UK, aggregating data from 2007 to 2017. It was found that planning and delivery efficiency were worse than previously considered:

> **"On average, only 38% of project activities started and finished on time",** Gledson (2018)

Gledson (2018) concluded that more predictability and productivity research should be conducted to increase this figure. Of course, more research on more samples from more countries should be undertaken to validate the above. This indication of poor performance is here to help the reader fully understand the context of the research and its desire to impact some aspects of the construction industry.

From the above, it appears that there is still room to improve performance in the construction industry. Measuring performance should, therefore, also be clearly addressed.

For Takim, Akintoye and Kelly (2003), measuring the performance of a construction project is manifold and requires daily efforts to collect and report information about the inputs, the efficiency, and the effectiveness of the activities on site. They further argue that a natural bias in performance measurement comes from the fact that the measurement is usually made by those who organise the work. Hence, measurements of the financial and non-financial performances of a project can be biased by internal considerations (this can be shown by comparing and contrasting their performance with others within or outside the company). Impeccable rigour in the measurement process and total impartiality in analysing the results are prerequisites in the exploitation of performance measurements. Many researchers and practitioners (Sinclair & Zairi, 1995; Mbugua et al., 1999; Love et al., 2000; Chan, 2001) have stated that measurements and dashboards are imposed in most organisations to follow, keep a log of, plan, schedule, anticipate and ultimately control the indicators. However, Takim, Akintoye, and Kelly (2003) have further argued that these classic indicators offer only a limited view of the actual situation as they narrow the investigative scope to immediate and restricted measures.

Despite being a fundamental indicator (as a source of other indicators' performance), workflow reliability is rarely measured on a construction site. The main measures used to monitor performance are the physical progress and financial expenses at a certain date, while concentrating on poor time predictability and performance, aggregated at the industry level (Pasquire 2012, Thomas, 2003, Gledson, 2017; Gledson and Greenwood, 2017, 2016)

This thesis reflects the doctoral work undertaken on a 3-block real estate development over a period of three years. While many published studies describe the application and development of lean tools on large sites (with over €200 million work turnover) made by large and lean mature companies (see 3.1 of the Introduction), the approach developed on a 145 medium-sized apartment project made by common SMEs proposes investigating the shared features. The author has aimed to increase the stability of the production flow on site by testing existing tools and methodologies in this context of common sites.

The application of lean construction to common sites made by SMEs is very rarely analysed by the research community. Tezel et al. (2019) showed in a systematic literature review that, SMEs often constitute the largest group in construction supply chains. Loforte Ribeiro and Timóteo Fernandes (2010) have suggested that over 99% of all construction companies in Europe are SMEs, and most employ fewer than 10 people. In 2015, 92% of all 669, 227 construction enterprises in the USA were classified as small enterprises.

Lean construction (and building information modelling), despite being two prominent concepts challenging traditional practices in construction management, are timidly adopted by SMEs. An analysis of 114 papers shows that, despite the importance of SMEs, the current lean construction literature falls short in terms of both publications and their content. This gap is detailed in Section (2.4) (*In search of production stability in the manufacturing industry: the growth of flow theories and pull*) of this thesis.

The application of the main tools (5S and Last Planner™) of lean construction developed in Chapter 6, *Case Study of block 1: inception of lean*", proved insufficient to achieve a stable workflow. Other tools from the manufacturing world were tested, such as takt time in the form of takt planning (see (7.3) *Takt planning: Development of research Stage 2.3) and* kanban in the form of a visual kanban, see (8.1) "Human factor bias: introduction of discipline and kanban".

By measuring the weekly progress in each apartment, comparing the data with the theoretical forecast and analysing the results in terms of means and standard deviation, it was possible to evaluate the impact of the application of the flow-based production systems on the stability of the works.

While an action research approach was first chosen and implemented to structure the research on site (see (3.2) *The choice of research method*), a design science approach was later preferred to better fit the actual situation on site and the context of the research (see (3.3) *Recent research into the search for consensus*). Throughout the construction of the three blocks, and the gradual application of flow theory tools, it has been found that the stability of the flow could be largely improved, providing a more robust forecast to the site and decreasing the lead time.

1.4 Research aim, objectives, questions and limitations

The aim of this research is to provide a better understanding of the effects of the application of flow-based management systems on medium-size sites (€2−50 million work turnover) made by medium-sized companies (20–200 employees).

The researcher developed and evaluated a pull scheduling system based on LPS to decrease work volatility at the site level. The expected consequence was a reduction in both delays and costs, made possible by optimised and robust site scheduling. The following objectives have been identified, to address this aim and the research questions:

1.4.1 Objectives of the research

- To understand the problem
- To understand current theory about planning and scheduling
- To identify advances in planning and scheduling arising from manufacturing and lean thinking
- To analyse current scheduling practice and determine its limits (in terms of applicability and performance)
- To develop, test and measure the impacts of a pull system based on LPS using a longitudinal case study. The research limits the scope to residential units made under a traditional form of an EPC contract. Further application of takt planning in other construction types and sectors can be envisaged (hospital, schools, warehouses, housing, etc.). The same approach can be tested even in civil projects (bridges, roads, tunnels, etc.), and
- To propose guidance for lean construction practitioners based on this research.

1.4.2 Limitations of the proposed approach and conclusions

1.4.2.1 Impact of takt and kanban approaches

The impact of takt planning was mainly measured by flow stability as developed in (7.3), *Takt planning: Development of research Stage 2.3*, and its consequence on lead time and snag works reduction. The impact of the application of kanban is developed in Chapter 8, *Case Study on block 3: further development of a pull flow system*. Following the application of these two approaches, stress reduction and financial improvement were the expected consequences of the system; however, these have not been analysed in-depth in this thesis.

1.4.2.2 Gains in delays / H&S: cause-consequence and/or correlational effect ?

While the reduction of delays and both quality and safety improvement were measured in the context of this research, future research is needed to investigate the qualitative cause-consequence and correlational effects. Analysing naturally occurring circumstances and the application of the stability index in other contexts. such as large apartment blocks and/or larger contractors that are not addressed in this research, will help continue the growth in understanding of the concept of workflow stability.

1.4.2.3 Savings on construction costs

The financial gains were shared by the project developer in 2018 at a lean construction conference in Nottingham (NTU Lean Construction study-show case, 2018 February 21st). From the developer's assessment, the gain represented 13% on average in the square metre cost from block 1 to block 3 and is to be largely credited to the approach developed in this research. However, given that the researcher was not provided with the full costs report (that is fully understandable given confidentiality agreements), it is not possible to assess nor to affirm the direct effect of the approach on this gain; thus, the thesis does not investigate the latter.

1.4.2.4 Duplicability in other sectors of the construction industry

Finally, the duplicability of the findings of each phase were tested over successive phases and the conclusions on its conditions were subsequently investigated. Duplication in other sectors is discussed but not tested in this research. The research limits the scope to residential units made under a traditional form of an EPC contract.

Further application of the planning approach in other construction types and sectors can be envisaged (hospital, schools, warehouses, housing, etc.). The same approach can be tested even in civil projects (bridges, roads, tunnels, etc.).

1.5 Research plan

The approach used was to synthesise the available literature, field trials and extensive case studies. Following insights provided from the literature review, field trials and case studies, a guideline and roadmap were developed for lean implementation at the project level.

1.6 Content of the thesis

- **Chapter 1** The *Introduction* provides the context of the thesis, presents the aim and the plan and content of the research.
- **Chapter 2** The *Literature Review* is then developed with a focus on understanding the latest flow-based theories in the manufacturing industry (the origin) and in the construction industry (the context).
- **Chapter 3** *Research methodology* develops the research method, provides justification for the use of action research and design science and explains how the data were collected.
- **Chapter 4** *Research processes* describes the processes from diagnosing the actual state (identification of the problem) to initiating the next improvement cycle.
- **Chapter 5** *Complements* closes the presentation by developing further the context by providing more insights into the background of the project, then the problem encountered by the practitioner and, finally, presents the 3-block apartment developments on which the research is grounded.
- **Chapter 6** *Case Study of block 1: inception of lean,* **Chapter 7** *Case Study on block 2: Development of the solution* and **Chapter 8** *Case Study on block 3: further development of a pull flow system* detail the research from the diagnostics on site to the evaluation of the research solution in block 1, block 2 and block 3.
- **Chapter 9** *Collecting and analysing data on workflow stability* details how the data were collected and analysed.
- **Chapter 10** presents the *Tangible impacts of the research*.
- **Chapter 11** *Appendix* closes the thesis.
- **Chapter 12** *References* concludes the thesis.

2 Literature Review

This chapter helps the reader understand the developments of flow management systems, the gap between construction and manufacturing industries, and how new management approaches to workflow can be further developed in the construction industry based on existing systems in manufacturing.

This chapter is organised as follow:

- Section (2.1) Glossary *of definitions* introduces the main terms used in the thesis, and Section (2.2), Approach to the literature review, presents the approach used by the researcher in selecting the articles used as references.
- Section (2.3), *The Pull system and production flow stability* presents the core concepts of the research,
- Section (2.4), *In search of production stability in the manufacturing industry: the growth of flow theories and pull* , links the theories and systems to stability, which is the core quest of the research.
- Section (2.5), *In search of production stability in the construction industry: importing flow theories and pull systems from the manufacturing industry and developing dedicated approaches*, links the above with the construction industry, which is the environment of the current research.
- Section (2.6), *Linking manufacturing and construction flows* , confirms the applicability approach in the construction industry.

Chapters 3, *Research methodology*, 4 *Research processes* and 5 *Complements*, then present and develop the path followed by the researcher in the research undertaken into the three real estate development blocks.

2.1 Glossary of definitions

- *Cycle time*: cycle time is the amount of time a team spends working on producing an item, up until the product is ready for shipment. It is the time it takes to complete one task.
- *Kanban*: this is a Japanese manufacturing system in which the supply of components is regulated through the use of an instruction card sent along the production line.
- *Lead time*: the time between the initiation and completion of a process.
- *Performance*: the action or process of performing a task or function.
- *Productivity*: the effectiveness of productive effort, especially in industry, as measured in terms of the rate of output per unit of input.
- *Stability*: the state of being stable, with low or no variation in time.
- *Takt time*: the rate used to complete a product in order to meet customer demand. This comes from the German word *takt* meaning beat or pulse in music.
- *Variability*: the tendency to shift or change, the state of being variable.
- *WIP*: work in progress, the quantity of work being transformed in the process.

2.2 Approach to the literature review

The main objective of this section is to present how production stability, which is the core concept in this research, has been developed to date, how much it has been addressed in the flow management literature and how to it can be linked with the other main flow management theories.

Based on the problem of the client, developed in (5.2) *Problem of the practitioner (a real estate* developer), the researcher investigated academic articles related to flow theories in general (mostly in the manufacturing industry) and then in the construction industry. Understanding the origin and development of these concepts has helped the researcher understand the links between them and the difficulties encountered when applied on a small site made by an SME. Academic articles and references published in journals and conferences such as the IGLC (International Group for Lean

Construction), ARCOM (Association of Researchers in Construction Management), LCI (Lean Construction Institute), and ASCE (America Society of Civil Engineers) were first selected as the basis for understanding the concepts and approaches developed to date in relation to the problem identified.

Then, the researcher narrowed the literature review and selected papers from the Scopus database down by using the following filters:

- ten top-rated journals selected based on cite score form Scopus,
- articles having the key words *lean construction* or *lean tool*,
- engineering and material science article selected,
- published journal articles.

The researcher finally updated the literature review with 2019-2020 papers after the PhD viva (2019) to have the most up to date references in the final version of the thesis. *Lean construction and BIM in small and medium-sized enterprises (SMEs) in construction: a systematic literature review* by Tezel et al. (2019) complemented the literature review in light of the focus of the research (i.e., lean construction with SMEs).

The literature review is articulated in seven sections. It first presents the concepts of pull and stability in general then chronologically develops the rise of these concepts in the context of the manufacturing industry before linking them to the construction industry and narrowing their application to the SME world.

Section (2.1) *Glossary of definitions*, presents the most important concepts and words used in this thesis, Section (2.2), *Pull system and production flow stability,* introduces the literature review and suggests a better understanding of the path to follow, Section (2.3), *Pull system and production flow stability* introduces the growth of pull and stability. This is followed by Section (2.4), *In search of production stability in the manufacturing industry: the growth of flow theories and pull* , and (2.5), *In search of production stability in the construction industry: importing flow theories and pull systems from the manufacturing industry and developing dedicated approaches*, which provide an understanding of how the different theories of flow have emerged historically and addresses the search for stability from different approaches. At this point, the reader should have a good understanding of both the complexity and the long-term development of flow theories in the manufacturing industry. Section (2.6), *Linking manufacturing and construction flows*, links the former to the construction industry, the context of this research, before Section (2.7), *Lean Construction research on SMEs*, narrows the scope of the literature review to the construction SME, the scope of this research.

As shown in the literature review, two main responses have been developed in the manufacturing industry to address the emergence of variability in mass demand, which started in the 1920s. While America developed systems based on opulence (throughput, inventory size, oversized tools, high volumes, and high demand), Japan developed their path in a lean environment as the volumes of their demand (mainly domestic) permitted no waste. From the 1920s through to the 1990s, both approaches and systems were successfully developed in parallel. Line of balance, material requirement planning, total quality management, 6 Sigma, and ISO are the names of the relevant approaches developed in America over this time. Autonomation, just-in-time (JIT), poke-yoke, kanban, production level, and 5S have, meanwhile, been developed in Japan. This proliferation of management methods shows that the manufacturing industry has expended great effort in developing its operating and managerial tools to address unstable demand.

As argued and later developed, strong similarities can be found between the construction industry and the manufacturing industry. The construction industry must also cope with variable demand (each building is different), and it is also based on a sequenced operating system. Therefore, in both industries, managing the operating flow is an important consideration in the search for optimal productivity.

However, while many approaches have been developed in the manufacturing industry on both sides of the Pacific, the construction industry lacks such development. Gantt charts and the CPM date from the 1910s and 1930s, and these strategies are still widely used in the construction industry. The recent uptake of the critical chain method and the development of LPS in the 1990s have offered new perspectives. Nevertheless, a long path remains in the construction industry to catch up with the manufacturing industry.

For Ballard (2005), flow reliability is the appropriate concept, and reliable workflow impacts the productivity of downstream players. Ballard reminds us that understanding and managing the construction process as a flow has been a key issue for the IGLC since its very first meeting in 1993. For Koskela (2005) and Kagligou (2005, 2006) the influences on IGLC thinking have included Shingo (1989) and the TPS (Shiomi & Wada, 1995; Ohno, 1988) along with its Western interpretation as lean production (Womack et al., 1990; Womack & Jones, 1996). Koskela (2011) later cite even earlier sources of inspiration such as Aristotle (app. 330 B.C.).

The following sections investigate the research literature and methodologies undertaken in search for production stability.

2.3 Pull system and production flow stability

As developed in the literature review, the concept of flow is the holistic umbrella of the quest for improvement in both the manufacturing or construction industries. The first section of this chapter introduces the development of push and pull systems from a historical perspective, then the two approaches are linked to the concept of stability. The quest for stability in the production flow is then developed in the subsequent sections. While section 2.4, *In search of production stability in the manufacturing industry: the growth of flow theories and pull* , addresses the rise of stability in the manufacturing industry, section 2.5 *In search of production stability in the construction industry: importing flow theories and pull systems from the manufacturing industry and developing dedicated approaches,* links the latter to the construction world and develops it.

2.3.1 Historical perspective

Although pull and push approaches have been used extensively in the recent literature, the appearance of these terms used in the context of production flow is relatively recent. Schonberger (1982) first described the pull and push approach in *Nine Hidden Lessons about Simplicity*, based on an analysis of Japanese manufacturing techniques.

On the one hand, a push system is a manufacturing system in which production is based on a projected production plan and where information flows from the management to the market, the same direction in which the materials flow. On the other hand, a pull system is a manufacturing system in which production is based on actual daily demand (sales), and where information flows from the market to the management in a direction opposite to that of the traditional (push) systems.

Karmarkar (1986c) characterised the difference between push and pull in terms of the order release process. Pull systems, in his view, trigger an order release when the inventory is physically removed from the finished parts or finished goods stock. Push systems authorise production in advance of demand. Silver and Peterson (1985) characterised push and pull somewhat differently. They distinguished push from pull on the basis of the information used in the decision-making process. Push systems, as they define them, use global information, while pull systems use local information. Takahashi, Muramatsu, and Ishii (1987) distinguish push from pull, in a multistage production facility, in terms of centralisation. Pull systems decentralise decision-making so that the production order level at each cell is determined by consumption at the immediate successor cell. Push systems, on the other hand, centralise decision-making so that ordering is determined by net requirements, cumulative lead times, and feedback information. Pyke, D.F and Cohen, M.A (1989) developed a comprehensive framework from the above authors on push and pull in manufacturing and distribution systems and suggested that traditional resources planning and kanban (which are typically considered to be pure push and pure pull, respectively) are hybrids of push and pull.

Sarkar, B.R and Futzsimmons J.A (1989) worked on the performance of push and pull systems in a simulation and a comparative study. Pyke D.F and Cohen M.A (1990) worked on the implementation of push and pull in manufacturing and distribution. Zhao, X and Lee T.S (1993) worked on freezing the master production schedule for a material requirement planning system operating under demand uncertainty. Harison (1999) suggested that deciding about a pull or push strategy depended on the certainty of demand for the product. Kim, Chhajed and Palekar (2002) did a comparative study of the performance of the push and pull systems in the presence of emergency orders. Mashuchun, Davis and Patterson (2004) studied the performance difference of push and pull control strategies for supply network management in a make–to-stock-environment. Huang et al. (2014) reported that in many cases, switching from a push to a pull system reduces the inventory by half, leads to fewer shortages, and increases sales (Aben 2006; Camp 2006; Krishan and Kothekar 2007; Ploss 2008; Grant 2008). Sarbjit (2017) proposed a study that would help to determine push or pull strategy and also how a combination of both can be appropriate.

2.3.2 Pull system and stability

For Womack & Jones (1996), the seminal approach that later became the TPS is the origin of lean production. The term *lean* referring to a production system was first used in an MIT Sloan Management Review article by John Krafcik (Fall 1988) titled *Triumph of the Lean Production System* which is based on five important principles: value, value stream, flow, pull and perfection. The term *lean* in this context was later popularised by James P. Womack, Daniel T. Jones et Daniel Roos in *The Machine that Changed the World* (1990). Liker (2004) also emphasised the importance of former principles:

> *"To be a lean manufacturer requires a way of thinking that focuses on making the product flow through value-adding processes without interruption (one-piece- flow), a pull system that cascades back from the customer demand by replenishing only what the next operation takes away at short intervals and a culture in which everyone is striving continuously to improve".*

The principle of value is the starting point for the application of lean thinking: determining the main characteristics of a product and what a customer is willing to pay for it. This is also a first step in the identification of waste in the process. The second principle is that of the value stream: understanding the physical flows of materials, people and information. Value Stream Mapping, which was adapted by Rother & Shook (1999), is an important tool to visualise material and information flow (Liker 2004). The principle of flow refers to achieving the optimal order of process activities, by reducing variability and irregularity (such as bottlenecks) so that materials and information may move in a predictable way along the supply chain. Pull (together with flow) are regarded as the core characteristics of lean thinking and the cornerstones for the elimination of waste. Toyota defines waste as any activity that does not add value for the customer (Liker 2004). The idea of pull is to produce only as much as the following work activity needs while keeping the inventory at a minimum. The principle of perfection is closely related to the idea of continuous improvement - constantly striving for perfection in processes (Brady 2014).

These principles, which are applied using the tools of the TPS, are illustrated in Figure 2.2.1 below:

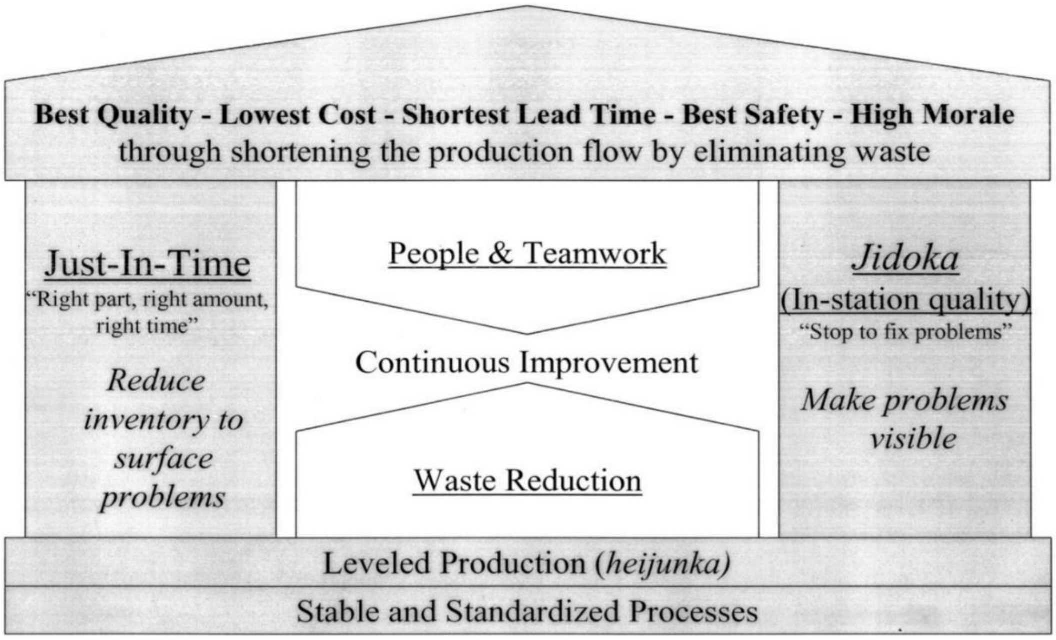


Figure 2.3.2-1: The TPS house (Liker, 2004, p. 33)

Howell and Ballard (1994) developed the concept of pull in the context of a lean approach applied to the construction industry and linked it to stability by addressing the reduction of inflow variation to produce a stable production flow. They pointed out that, from the field point of view, lean construction followed the strategy of improving stability in planning from the bottom up. Howell showed that the first phase involves shielding work execution and then moving up to adjusting the mechanism and, finally, to rethinking the initial planning.

For Licker (2004), the concept of stability is grounded in *Heijunka*, the second foundation of the TPS House. Licker (2004) reminds us that for Toyota, a stable production flow will emerge from stable and standardised processes:

> *"The foundation of the house needs to provide the overall stability on which just-in-time systems can be built and the system constantly adjusted by stopping to fix problems. Heijunka means levelling. The goal is to create a levelled stream of orders and a level workload. When the workload is levelled, there are opportunities to standardise processes. And levelling the workload is also necessary to know how much inventory to hold in the supermarkets.*
>
> *If there can be a run on the store for a particular product, the system will not be able to keep up. Stable, standardised processes are necessary, or just-in-time production will mean no production. Without inventory to compensate for instability, the system will constantly shut down. And this will be even worse if someone is pulling the cord and stopping the line every time there is a problem." (Licker 2004).*

Sections 2.4 to 2.7 link the fundamental lean approach to its application in the context of this research (construction sites made by SMEs) through the search for stability.

2.4 In search of production stability in the manufacturing industry: the growth of flow theories and pull systems

This chapter presents how production flow became a major focus in the search for system productivity in the context of manufacturing industry growth through the 1910s

to the 1980s and, finally, the formalisation of production stability in the late 1990s. This chapter provides a historical perspective of the growth of stability in the manufacturing sector. Section (2.5),
In search of production stability in the construction industry: importing flow theories and pull systems from the manufacturing industry and developing dedicated approaches, then provides the perspective of the construction industry that followed a similar path years later.

Production flow theories are an established research area under the heading of production efficiency: In *Walking through Lean History*, Womack reminds us that it is very often forgotten that the Venetians developed the capability to build hundreds of ships each year, meeting the Mediterranean campaign's demand for battleships through a standardised design and continuous production flow.

Frederic Chapin Flane (1934) described this 600-year-old flow-based production, and how, in 1574, the Arsenal's expertise in building ships quickly was so dominant, and their operations management afforded so much of what we would today call competitive advantage, that King Henry III of France invited himself so that he could watch the construction of a complete galley in continuous flow. In 1925, a paper from Wollard titled *Some Notes on the British Methods of Continuous Production*, introduced flow variation into industrial production.

The process control chart (PCC) was developed by Walter Shewhart in 1924; it represented, at this time, a large step forward in industrial quality toward the modern approaches that were later expanded to encompass wider applications in science and statistical applications.

The PCC approach was later formalised and presented in his 1939 book *Statistical Methods from the Viewpoint of Quality Control*. It was the first time in literature that a continuous quality improvement was described as a cycle: Plan-Do-Study-Act. Deming later developed this to the better-known version, Plan-Do-Check-Act (Deming, 1939).

In 1954, in *Principles of Mass and Flow Production*, Frank G. Woollard (1954) investigated flow in upstream processes, stating:

> *”the virtue of flow production lies in the fact that it brings all inconsistencies into the light of day and so provides the opportunity to correct them”.*

His intuition was that :

> *”the high visibility conferred on the company‘s activities by flow production will lead to unceasing and continuous improvement” (Woollard 1954, p. 87).*

In a multi-operational environment, i.e., the vast majority of production sites, production-scheduling aims at reunifying the different stakes by creating a profitable balance between conflicting objectives (Hopp & Spearman, 2008). There are two ways of achieving this profitability by applying the approach of production control by meeting demand: push-based and pull-based. The controlling system can be similar, but the production flow is considered *vice versa* in the two approaches.

According to Hopp and Spearman (2008), the distinguishing feature between push and pull systems is how the movement of work is triggered.

> *"In a push system, work orders are scheduled based on actual or forecasted demand from a central system. In a pull system, work is authorised based on the current system status.”*

They further refine this definition (2008) based on the fundamental difference between the two approaches’ intrinsic effect.

> *”A pull system establishes an a priori limit on WIP, while a push system does not.”*

In brief, in a pull system, customer demand will enable production; the product or service (downstream process) is pulled (initiated) by the customer. Smalley (2004), in his book *Creating Level Pull,* further classifies the different pull systems into three categories: 1) *replenishment pull*, which feeds the production line as the production is being produced, 2) *sequential pull*, which allows for several types of production, and 3) *mixed-pull*, which is a hybrid type of production from the first two.

Smalley (2004) insisted that the size of the production lots, or batches, should be kept as small as possible (dictated by customer demand), whereby one-piece flow is the ultimate small batch. Pulling production can also mean stopping production if the demand decreases below certain levels (and demand is absorbed by the inventory) or stopping the production to avoid overproduction and signal replenishment by means of a kanban system that will trigger production only when the formal order is given from the demand.

The above production approaches made significant steps in the search for productivity stability. Earlier, the bulk of production flow and inventory were controlled using reorder-point/reorder-quantity (ROP/ROQ) methods. The ROP/ROQ systems were based on process sequences that needed a large inventory of standard pieces, specialised machinery and Go / NoGo gauges (Hopp & Spearman, 2002). ROP/ROQ were typical push systems; the inventory and flow were forced into the system to ensure enough production and to meet customer demand. The demand, until the 1930s, was dictated by the offer, and the offer was limited to a few models available for each product.

The best example is the Ford T Model, which was available in only one shade of black. Painting all their models in black not only enabled Ford to realise large economies of scale but also significantly reduced drying time. Manufacturing industry interests dictated the offer and, hence, tried to control the demand. Following the 1930s, demand became more exigent and required product diversity as a driver for mass consumption. This diversity forced the manufacturing industry to adapt the offer to more and more varied demand.

The development of computers and software (initially, the ability to compile a large amount of information) eased the processes of managing variability in the demand by tracking the inventory. The mass production system in the 1930s was based on a large throughput of parts, large inventory sizes and optimised, but oversized, tools. The time lag between steps increased and it required, but also promoted, the use of sophisticated information systems. A concrete answer was proposed in the 1960s by Orlicky and Wight Plossl, who developed a new system which they termed *material requirements planning* (MRP). MRP was mainly a sophisticated information management tool, one of the earliest production-scheduling approaches operating through the use of computers. Although it started slowly, MRP was extensively developed in 1972. Productivity in the US had to be rethought to feed an increasing demand and pull the whole economy. An MRP Crusade was then launched by the American Production and Inventory Control Society (APICS) to promote the use of MRP and provide the industry with a better tool and approach to material planning, and to push finished goods into the market (Hopp & Spearman 2008). MRP is considered a push system given that there is limited consideration of the customer demand in its approach, which is mainly based on the compilation of schedules of the production that should be launched based on a documented experience of its level and statistical inputs (Hopp & Spearman, 2008).

The development of total quality management and later of 6 Sigma, based on standards and statistical analysis, in the 1970s, led to the development of MRP II, which incorporated capacity planning, capacity requirements, master planning and input-output control. It required, of course, even more complex and powerful software.
We can say that, from the 1930s to the late 1990s, the American production system relied mainly on the development and use of more and more complex software.

MRP soon dominated the production systems in the US, while in Japan, several companies (e.g., Toyota) further developed the older ROP/ROQ approaches to a higher level. The situation of production in Japan in the 1940s was quite different from the one the US was experiencing in that, in Japan, the production volume was far lower than in the US, where long production runs enabled the efficiency approach to develop.

Taiichi Ohno was given the mission to develop a system that would enable Toyota to compete with American automakers based on significantly lower volumes., and in response, he designed, tested, developed and formalised what has come to be known as the Toyota Production System (TPS). Ohno thought the TPS could “make goods, as much as possible, in a continuous flow” (Ohno, 1988).

Ohno based the TPS on two pillars: autonomation and JIT production. Autonomation, or “automation with a human touch”, developed how to build a best practice approach. Later, a number of additions have helped the system to perform optimally. Another component of autonomation is the limitation of errors by the use of *fool-proofing* or *poke-yoke*. In the search for self-responsibility on the floor by the operators, TPS promotes the use of small devices in the production line so that the operator can make quick qualitative checks (colours, dimensions, weight, etc.). A self-controlling approach to quality as production progresses along the production line allows problems to be detected as far upstream as possible (as far upstream as the first poke-yoke). In case of a problem found, the whole production line is stopped until the problem is corrected. Using this system meant rework lines were no longer needed, problems that pulled efficiency down were identified and treated and corrective actions were proposed very quickly. Hence, Ohno, (1988) set the essence of lean as the reduction of waste.

Another *gemba-oriented* approach to reach impeccable quality developed by Toyota under the TPS is 5S, or the means to create, maintain and improve a safe, sound and favourable workplace for the operators. The five Ss stand for seiri, seiton, seiso, seiketsu, and shitsuke. These can be translated as remove, sort, clean, improve, and maintain, a set of organisational and housekeeping techniques to achieve autonomation and visual control.

The following sections offer an overview of the main flow systems and theories that have arisen from the 1910s, when Henri Ford’s flow production system was based on a unique model, to the current state of manufacturing, in which demand varies rapidly, both in quantity and in the means of production and delivery.

2.4.1 The 1910s: On the emergence of the Gantt and Program Evaluation and Review Technique (PERT) charts

While the rise in production levels introduced new planning needs, controlling, and recording a work schedule and its progress, two American mechanical engineers (Henry Gantt and Frederick Taylor) developed a new method later to be called the Gantt chart. A Gant chart displays horizontal bars that represent activities of work, the length of the bar indicating the length of the activity, determined by the scale of the horizontal axis. For Gant and Taylor, a bar was a task, and each bar could be linked to another/others to indicate a sequence.

Gant charts are still used extensively today and they are the base of scheduling in the construction industry. A Gantt chart focuses on the sequence of the works, and, hence, does not represent interrelationships or constraints among the activities within a work sequence. The PERT diagram was later developed to provide a road map indicating the major activities and their interrelationships, but this does not integrate the cost and quality inputs.

2.4.2 The 1940s: On the emergence of takt time

Variability in the demand introduced a need to adapt the pace of production while keeping limited inventories and waiting times. In a takt time system, customers' demand pulls the components and defines the pace at which the production must be set to meet the demand. Of course, it is not realistic to believe that the demand will settle at a stable level and allow the process to produce parts or components at an equal stable pace.

Takt time is the opposite to the pace of demand: if there is an increase in demand, the takt time must drop to avoid a shortage in supply and if there is a decrease in the demand, the takt time should increase to avoid overproduction and the subsequent overstocked inventory. This means the output interval between the two outputs should vary to follow the demand (increased or decreased). Rahani et al. (2012) insisted on the importance of adapting the takt time to the demand to avoid the extra costs and inefficiencies that are fathered by a takt time lower than the demand (i.e., producing ahead of demand). Rahani recalls that this would lead to the storage and retrieval of finished goods, the purchasing of raw materials in advance (needed for storage and to decrease the cash flow), an increase in manpower and wages, the production line being underutilised given other goods (that may be in demand) are not being produced, and costs incurred for storing and managing the unsold output.

In 2002, Hopp and Spearman proposed a definition of a pull system:

> *"A pull production system is one that explicitly limits the amount of WIP that can be in the system. By default, this implies that a push production system is one that has no explicit limit on the amount of WIP that can be in the system".*

To level production and give this a strategic aspect of productivity improvement in a pull environment, Ohno proposed to use takt time or takt-paced production. Boeing capitalised on this notion and defined takt-paced production as follows (published by Hopp and Spearman 2008):

> *"Takt-paced production describes the rate of assembly in a factory. Lean does not mean doing things faster; it means doing things at the right pace. Essentially, the customer's rate of demand establishes the pace or Takt time. So, rather than simply maximising the rate of work, lean sets the pace in the factory, ensuring that the customer's needs are met on time."*

One could instinctively consider that the application of takt time demands that demand must be extremely regular to meet the production pace, and then reach efficiency. In manufacturing plants, setting a takt time (or a pace) instead of following demand and inserting variability helps smooth the production, and work on efficiency and meet demand. This is particularly made possible when a manufacturing plant knows its client and has kept a log of the demand levels that can be taken as a source for constraining the system with an initial takt time and adjusting this to the actual demand. Of course, the whole takt machine works smoothly until the first grain of sand stops the system.

Buffering the production line from demand variability helps keep production overcapacity to absorb a determined level of uncertainty and guarantee that the system continues to run at a stable pace. This buffer or contingency, either of production or of demand, is made possible with either an order backlog or production inventory. An order backlog will be generated when the demand exceeds the production capacity set by the takt time. A production inventory will be generated when the demand is lower than expected; in this case, the production pace is too high, and the production should be stored to meet future pick-ups in demand.

The whole takted production system is based on the assumption that the suppliers of the line can meet the production demand at the determined pace. This is to say that particular attention should be paid to the long lead items, those items that can take more than the throughput time in the line. These items should then be accessed from internal fabrication centres or outside suppliers, i.e., made to stock.

In real life, demand can vary greatly (e.g., because of seasonality or random surges) and in *valley curve* activity, the order backlog (demand) may temporarily run dry before the demand once again reaches levels that are too high to meet. In these under- and overcapacity periods, takt time should be adapted by anticipation, inventories of production stored and/or some jobs released. A takt time-based system can be adapted to a make-to-forecast mode that will customise the capacity production and buffer levels in anticipation of the demand volatility.

A common confusion concerning takt time is that the literature has commonly defined pull to be make-to-order, which only applies at the strategic or managerial level. At the production level, takt time should be understood as *make to stock*, or even *make to forecast*, to say that the inventory of production or inventory of orders is intrinsically generated and or needed by the application of takt-based methods to guarantee the smoothness of the production line and, hence, efficiency in productivity.

2.4.3 The 1940s: Limitation of the WIP *One-piece flow*

One-piece flow is a process management system that seeks optimisation through controlling the movement of the parts between operations, one part at a time, within a production line. The production system, which is based on one-piece flow integrates sequencing, setup time and make-to-order approaches. Stockton et al. (2005) introduced manpower flexibility in the line and proposed walk cycles for an existing one-piece flow production line. In the example developed, the operators in the production line were limited to a repetitive sequence of loading and unloading machine tools. The machines were laid in a U-line to ease manpower line flexibility and flow within the process line.

Important factors were considered when designing the U shape of the line in the search for one-piece flow, such as the selection of the work model, the assignment of the operation in the process line and the sequence of production. When the time comes to change task in a linear U-line, it is impossible to maintain any production at any stage of the line; the whole line must be stopped.

Hence, in a one-piece flow production line, a buffer is required to absorb the production disruption and to overcome the freezing of the line. This can be calculated using demand history or experience or statistical data. As in a sound pull system, in a one-piece pull production system, the producer only starts producing when a kanban (signalling tool) stops piling in the line. The main difficulty lies in the uncertainty of the demand. Li et al. (2009) suggested that the design of a one-piece flow production line in an uncertain environment requires multi-objective evaluation that generates the need for an optimisation model. Then, the multi-objective task can be optimised to reduce the cycle time (CT), optimise the changeover, limit the cell load variation, and keep the number of cells manageable. Despite these attempts to understand and propose research into one-piece flow systems, Miltenburg (2011) has pointed out that the literature is still very limited in this research field and deserves greater consideration.

2.4.4 The 1950s: Production-levelling *line of bala*nce

Monden et al. (1983) suggested that U-line balancing problems are augmented by task-time variability and human factors or various disruptions. Task-time variability and the disregard for work rates are mainly due to the instability of human factors. Becker et al. (2006) and Chiang et al. (2006) noted that an activity is in essence a source of variability, intrinsically containing variables: any activity will be carried out differently from one worker to another and is highly dependent on the environment in which the production line has been designed. Thus, it is of great importance the costs of biases generated by the human factor and machine specifications are limited. The difference in the time the operator walks from one workstation to another and the machine's own CT, which can also vary due to internal or external factors, leads to a non-balanced line or, in short, an imbalance. This tendency is emphasised in the case of change over time to meet demand fluctuation, where imbalanced lines are created in a mixed-model line. As in a one-piece flow approach, the resources necessary to produce the outputs are adapted to meet demand while overcoming the line's intrinsic imbalance.

Monden et al. (1983) proposed a model based on man-machine flexibility that enables the free flow of materials, information, and human resources within the process unit. Miltenburg et al. (2001) suggested that customisation of the machinery to meet the optimised cycle time can ease a balanced process flow. In an optimised mixed-model flow, demand should command, and the design of improved workstations is no exception. Attention to the steps and manoeuvres to be operated within changeovers can help balance the flow in the production line by promoting quick configuration changes, making possible the production of smaller lots (or batch) that is the key to achieving an optimised balance.

2.4.5 The 1950s: Production-levelling

Volatility in the business environment increased after the 1930s and led to fluctuation in customer demand and to variability in production. While American industry was trying to address this volatility by the line of balance, as described above, Japan tackled this issue from another angle. To avoid underutilised or overburdened capacities created by fluctuating customer demand (e.g., manpower, machines, idle times, breakdowns, defects, and so forth), a production-levelling system was created at Toyota, called *heijunka*. «Heijunka is a Japanese word referring to processes that help level or smooth out production. In a heijunka system, every product type is manufactured within a periodic interval, and the system itself controls the variability of the job arrival sequence to permit higher capacity utilisation. In doing so, heijunka avoids peaks and valleys in the production schedule (Bohnen et al., 2011; Huttmeir et al., 2009). This management of low volumes and high-mix production was further developed as group technology by Licker (2004), and later by Bohnen et al. (2011), as a clustering technique for part-family formation and family-oriented levelling patterns.

Shortly after having validated the utility of heijunka as a means of production-levelling, Taiichi Onho introduced a new management strategy that aimed to create a competitive advantage: just-in-time production (JIT). At this time, at the end of WW2, Japanese industry was almost completely defeated. US industry proved its ability to reach very high production levels; the productivity of an American car worker was nine times that of a Japanese car worker at that time. Onho had been assigned the task of developing a system that would enable Japanese workers to reach such levels, even though similarities in both the markets and production strategies were limited.

Thus, Onho would, at most, be able to get inspiration from the US, but copying and pasting their systems would not be an option. The domestic differences were vast. While the American car manufacturers had to face very high demand and were consequently able to make lots or a batch of a model or a component before switching over to a new model or component, the Japanese conditions were quite the opposite. At this time, the Japanese market was highly fragmented and comprised many small markets that had to be addressed in a tailored mode and in small quantities. In the US, the market was so dynamic that the prices of finished goods rose high. That is to say that even with a sub-optimised production tool, the US manufacturers were still able to generate profits. Conversely, the low demand in Japan led to price resistance that forced Taiichi Onho to think beyond the existing productivity approaches. He rapidly identified waste as the main issue to be addressed in the pursuit of reaching US productivity levels. He started to think of productivity as being pulled down by waste in the process and sought, through JIT, to eliminate it; items would be moved through the production tool only as and when needed and indicated by the system.

De Treville (1987) claimed that learning was an important aspect of any continuous improvement process but that it could not reach a satisfactory level only through the application and analysis of JIT. A great source of information is the observation of disruptions in the production line, most importantly in situations or production sites where difficulties in production or waste could not be found using an analytical approach. De Treville (1987) later proposed embedding flow control with flexibility in the resources in the form of a balanced line and/or increased learning made possible through disruptions that cannot be immediately observed and need more sophisticated tools. Learning is key to the improvement process, particularly in the JIT approach. Long-term productivity gains are attained by investing in learning and switching from short-term productivity for information collection.
Idle workers should be considered as resources (not problems); an opportunity to improve line balance by training workers in the search for buffer removal.

However, De Treville (1987) has pointed out that the exploitation of disruptions in a learning process requires critical attention being paid to the design of the improvement actions that are undertaken and to the buffers that are inserted, the risk being the introduction of productivity losses and organisational stress:

> *”A separate decision as to the ‘best’ type of JIT must be made for every intermediate buffer. Designing a JIT system hence requires a large understanding of the context and of the specific design choices.” (De Treville 1987)*

A new approach in the search for efficiency arose at the end of the 1980s and, gradually, JIT production was replaced by planning based on the resources of the enterprise. Resource-based planning filled an increasingly larger part in the production world, eclipsing the JIT movement in the US. However, in 1990, an important book was published in the form of a case study conducted by Womack, Jones and Roos (1990) called *The Machine That Changed the World*.

The authors presented a comparison between manufacturing techniques in the automobile industry in the US, Europe, and Japan. They analysed the roots of the approaches and captured the efficiency levels. Having conducted a number of investigations, they found, with their significant differences, that that the Japanese methods, and particularly those of Toyota, were vastly superior. They also seized the opportunity to phase-out JIT production, which had already been almost forgotten, and proposed the generic term *lean manufacturing*.

De Treville (2006) later emphasised respect for people, the establishment of good job characteristics and motivation as the main subsystem of TMS, in line with the fundamental principles of lean flow management.

2.4.6 The 1960s: On the emergence of kanban and the inception of pull systems

Some literature tends to significantly change the way management sees production and its surroundings (e.g., Orlicky's new way of life) and TPS. The ideas and systems described in such literature had a significant impact on society and are milestones for new systems thinking. In 1977, Sugimori et al.'s *Toyota Production System and Kanban System: Materialisation of JIT and Respect-For-Human System* was the first published academic paper on kanban and it confirmed that papers can have a dramatic impact on production and control systems. Sugimori (1977), and later Kimura and Terada (1981), developed the mechanics of kanban and how to implement it. Schonberger (1982), Hall (1983) and Monden (1983) published studies on TPS, JIT and kanban but their impact on the industry was only notable in the 1990s.

In the late 1990s, Ohno expressed a switch in how the market created a new way to view demand. The old way, in that manufacturers considered their workplaces as the production sites of units, based on desktop planning alone, that would then be distributed and sold by commercial teams, was to evolve dramatically. This former vision based on push (distribute products onto the market to create the demand) switched to a more customer-demand-centred approach. The customer was now to set the pace of production and the quantity of the products to be bought and, hence, to be produced. An order from a client was, one could say, considered to be the first kanban of the line that would, going upstream, lead to supplying the manufacturing plant and meeting the demand.

With the adoption of kanban, and its investigation by those researchers, the term *pull* arose for the first time. The link between the new kanban and the older base stock system was first acknowledged by Karmarkar (1986, 1991), bridging Simpson's work (1958), who described the base stock system as follows:

> *"When an order is placed, it is filled from inventory if the inventory is not zero. If the inventory is zero, the order is placed in a backorder file, to be filled when an item arrives. In any event, a manufacturing order is immediately placed with the preceding manufacturing operation to produce an item to replace the item that has been consumed. The manufacturing operator, in turn, immediately places an order for the required raw materials against the preceding inventory, and as soon as this order is filled [i.e., he has the needed inventory], he proceeds to 'operate' on it to produce the required item. In this way, an order against the last inventory for a finished item is immediately transmitted all the way back along the line to all the manufacturing operations, each of which is galvanised into production."*

Speaman (1992) noted that, despite the many similarities that can be found, the two systems (kanban and base stock) are not identical:

> *"Kanban would not place an order for more parts if a demand (in the form of a move card) had arrived when there was no stock in the outbound stock point. Instead, there would be one or more production cards already in process and whenever one of these was completed, the waiting move card would be immediately attached to the recently completed container of parts and the production card would be sent back into production. In this way, a kanban system bounds the amount of WIP there can be in the system while the base stock system does not."*

Zazanis joined Spearman (1992) and demonstrated that the conditions of operations, environment and external factors are important factors and that the improvement of performance in pull systems is highly dependent on three primary logistical drivers:

1. *Less congestion:* A comparison of an open queueing network with an equivalent closed network shows that the average WIP is lower in the closed network than in the open network, given the same throughput. The effect is relatively minor and is due to the fact that queue lengths have no correlation in an open system but are negatively correlated in a closed queueing network, an observation made earlier by Whitt.

2. *More control:* This fundamental benefit results from several features:

   a. *Work-in-process is easier to control than throughput*. A direct measure of the WIP is made possible when measuring throughput requires more effort, time and calculations; that penalise the reaction time.

   b. *Throughput is typically controlled with respect to capacity*. Opposite to WIP, which can be observed directly, capacity requires a number of other data and measurements, such as process time, setup time, random outages, worker efficiency, rework (…), that will determine the actual capacity of the production of the unit.

   c. *Throughput is controlled by specifying an input rate*. As the capacity of the line is a fixed physical bottleneck, the input rate is the main variable in the production equation (considering the human resources of the line are also fixed). If the input rate exceeds the capacity of the line, throughput will be equal to the bottleneck, and WIP will build up at all stages. If the input rate is less than the capacity of the line, then the throughput will be equivalent to the sum of the inputs. Sharply assessing the capacity and adapting input rate guarantees that the optimal capacity can be reached while limiting the WIP. Consequently, it is of huge importance to finely control the WIP levels as direct indicators of the whole system efficiency to seek robustness. Conversely, the systems that only control throughput generate errors and can be much less efficient in the search for productivity.

3. *Work-in-process cap: The benefits of a pull environment owe more to the fact that WIP is bounded than to the practice of pulling everywhere*. Limiting the WIP by inserting bounds, or a throughput of a closed-queueing network without blockage, will be largely beneficial to the results of a kanban system.

In the same vein, Spearman and Zazanis (1992) proposed CONWIP, a hybrid push-pull system. CONWIP has the same genetic approach as kanban but can be applied to a wider range of operations. Later publications by Veatch and Wein (1994) also demonstrated that the kanban system largely benefits WIP management. However, at this point, the understanding of pull varies between authors and advocates. For Hopp and Spearman (2002), one reason for this is that pull systems are mostly discussed in general terms and at a very high level, leaving the operation managers with their own understanding and interpretation which is too often solely linked to just-in-time.

As seen in the introduction of this chapter, Ohno has described extensively the conditions required to make pull work, amongst which are creating a standard of work method (autonomation) and levelled production. However, he failed at providing a working description of what *pull* is. Confusion in the gemba between kanban, JIT and pull are common, and the result of this is low performance of the improvement systems tested. Conversely, a push system, which is most commonly intuitive, has almost become synonymous with MRP.

Cheng (1993) proposed a definition of pull, stating that parts could only be moved from one work station to the next one in the queue when it was ready to welcome the input and continue the process. This idea was later developed by Hopps and Spearman (2003):

> *"Pull systems by far outreach the responsiveness of a push system. The responsiveness of the system to changes and problems which arise in upstream processes allow the downstream processes to be shut down. This prevents the accumulation of inventory on the plant floor."*

A key catalyst for this change was Womack and Jones' *Lean Thinking* (1996), which was a follow-on to their highly successful *The Machine That Changed the World*. Still, no clear definition of pull was provided. The book starts as follows, as recalled by Hopps and Spearman (2003):

> *"Pull, in the simplest terms, means that no one upstream should produce a good or service until the customer downstream asks for it, but actually following this rule in practice is a bit more complicated."*

As seen in the above paragraph, managing inventory levels has become an important strategy in the search for resources and quality optimisation. The kanban, a subsystem of lean manufacturing, was created in Japan by Taiichi Ohno to control the production and supply of components and limit inventory needs. Sipper et al. (1997) added that kanban can be seen as a twofold signalling system: *production Kanban* and *transportation* k*anban*, which is called a dual-card kanban signalling system.

Given that production faces demand uncertainty, it is necessary to introduce buffers to stabilise the production flow, adapt the kanban systems and exhaust/produce inventory so that it reaches acceptable levels. For Sipper et al. (1997), the application of kanban systems, through the mixed-model of production coupled with optimal inventory-level management, allows more reactivity to face demand variations (a decreased lead time) and an optimisation of the utilisation of resources (machinery, workers, materials, etc.). Junior et al. (2010) later claimed that, coming back to the fundamental approach of learning, the implementer can raise knowledge and continue improving the observed system by analysing the variations of the kanban. By keeping a log and exploiting the data collected, the kanban becomes a robust, objective but highly visible and trackable witness of the intrinsic effectiveness of the production line.

Ohno on the one hand and Womack and Jones on the other hand later complemented their views on the notion of pull and kanban. While the former addressed the strategic level about the basic connection between production and demand, the latter developed the tactical aspects of lean implementation. Womack and Jones considered that the experience of a client started at the order stage and that the plant had to adapt to the demand and not the contrary.

Hopp and Spearman (2008) distinguish between push and pull production control systems as follows:

> *“In a push system, such as MRP, work releases are scheduled, and in a pull system, releases are authorised. The difference is that in the former case, a schedule must be prepared in advance, while an authorisation is decided by the status of the plant.”*

However, the popular understanding at the managerial level is that a pull system consists of make-to-order while a push strategy is based on make-to-stock. From this, one could say that a make-to-order MRP system would be an ideal pull system, which is fully contradictory to the historical intent of the pull approach as Ohno, Hopp, Speaman (…) defined it. Again, a common bias in the understanding of the new approach comes from the fact that there is not enough understanding linkage between the top managerial level and the operational management level.

2.4.7 The 1980s: The introduction of the theory of constraints and the critical chain

The limits of the CPM have been progressively demonstrated over the years. The CPM does not fully consider non-critical activities and the risks attached (logistics, labour or information), nor does it consider that a critical path may change over the project life. Eliyahu Goldratt designed the theory of constraints, considering that any interdependent system can never be better than its weakest point. Improving a project and its schedule thus became dependent on the identification of constraints and their mitigation.

In a book named *Critical Chain*, Goldratt (1997) introduced the eponymous concept. The critical chain approach proposed going beyond CPM calculations. CPM used the resources required to deliver the project and was mainly based on rigid project scheduling and a strict sequence in a project's activities. Critical chain proposed that more flexibility in the resources allocated to the project was key in keeping a project on schedule. Goldratt seized on flexibility as an opportunity to integrate uncertainty. Uncertainty could then not be considered a problem, but rather as a buffer, something that could be followed and managed to increase predictability and from which problem resolution could be learned to lower the uncertainty.

2.4.8 1999: Formalising the search for stability: Decoding the DNA of Toyota

Toyota has long been seen not only as a car manufacturer but also as an innovative company that has applied a scientific approach in search of impeccable quality and higher productivity. For Spear, Toyota is a community of scientists conducting scientific experiments that lead to the manufacture of cars in the most efficient way. The problem, states Spear, is that the TPS is not, and will most certainly never be, a written dogma. The TPS is based on the sharing of experience and passing the culture of excellence from managers to managers vertically and in both directions. The approach is designed to favour the workers who understand the rules by applying them in the gemba, with the training being a positive side-effect of solving problems before seeking, identifying and solving other problems. Doing and favouring this helps Toyota to continuously increase knowledge at the individual level, and the sum of all the individual knowledge is what could be considered the actual TPS.

Generalisation of the knowledge across the company helps Toyota to better design their activities and always produce better products (of higher quality and more efficiently). Of course, and the key to the TPS lies here, Toyota expects significant effort from the managers so that they are willing and able to constantly question their operations and, hence, help facilitate the learning-by-doing culture.

The experience conducted in the research came to the same conclusion, showing that the willingness to learn is a leading prerequisite for the adoption of lean working practices on a construction site.

The overall TPS approach has been summarised within in four rules, proposed by Spear:

Rule	Hypothesis	Signs of a problem	Responses
1	"The person or machine can do the activity as specified. If the activity is done as specified, the good or service will be defect-free."	"If the activity is not done as specified, the outcome is defective."	"Determine the true skill level of the person or the true capability of the machine and train or modify as appropriate. Modify the design activity."
2	"Customers' requests will be for goods and services in a specific mix and volume. The supplier can respond to customers' requests."	"Responses do not keep pace with requests. The supplier is idle, waiting for requests."	"Determine the true mix and volume of demand and the true capability of the supplier; retrain, modify activities, or reassign customer-supplier pairs as appropriate."
3	"Every supplier that is connected to the flow path is required. Any supplier not connected to the flow path is not needed."	"A person or machine is not actually needed. A supplier provides a good or service."	"Determine why the supplier was unnecessary and redesign the flow path. Learn why the non-specified supplier was actually required, and redesign the flow path."
4	"A specific change in an activity, connection, or flow path will improve cost, quality, lead time, batch size, or safety by a specific amount."	"The actual result is different from the expected result."	"Learn how the activity was actually performed or the connection or flow path was actually operated. Determine the true effects of the change. Redesign the change."

Table 2.4.8-1 The Toyota production system (TPS), adapted from Spear (1999)

Spear argues meta routines can be built by the regular application of the basic rules of system design and generate:

> *"highly situated learning that is both broadly distributed" and where "learning occurs through frequent practice that allows for repeated*

> *failure". Spear also states that "The point of process improvement is to improve the participants' process improvement capabilities by coaching them as they try to improve the process."*

Learning and disseminating the learning culture and the outputs of the learning is key at Toyota.

On the link between organisation and production, Spear added that:

> *"The factory was not only a place to produce physical products; it was also a place to learn how to produce those products and [...] keep learning how to produce those products."*

Reducing variability should, nevertheless, remain at the centre of the goal as a key to building on a more stable environment, the only way to guarantee the composure of the system in the long run. Any issue that would pollute the system stability must be identified as early in the process as possible to reduce such issues recurring in the line. Learning about process inefficiencies provides learning opportunities for the organisation that should then be exploited to improve process designs and build the main asset of the company: human resources (knowledge) (Spear 2009). Workers' motivation is especially dependent on their variety of skills and level of responsibility; thus, dedicated human resources practices are necessary.

2.5 In search of production stability in the construction industry: importing flow theories and pull systems from the manufacturing industry and developing dedicated approaches

While Section (2.4), *In search of production stability in the manufacturing industry: the growth of flow theories and pull* provided a perspective on the rise of the concept of production stability, Section (2.5), *In search of production stability in the construction industry: importing flow theories and pull systems from the manufacturing industry and developing dedicated approaches* presents the same historical development in the context of the construction industry. *Section (2.6),Linking manufacturing and construction flows* then links the two developments.

2.5.1 The 1930s: Critical path method (CPM)

While production systems were being developed, tested and improved in the manufacturing industry, being tackled from different angles in the US and in Japan, the construction industry mainly relied on the Gantt chart and CPM until the 1990s, and the vast majority of the construction players still mainly rely on these tools. While the Gantt was first used in the 1931 Hoover Dam construction project (a hydroelectric station at the border of Arizona-Nevada, US), the CPM was first been presented in 1961 in a paper for the US Navy by Fondahl. The CPM, also called critical path analysis, is presented as a mathematical algorithm for scheduling a set of project activities.

The CPM is, nowadays, an important tool for project managers that is taught extensively in engineering schools and is used worldwide. The *critical path* can be defined as the sequence of consecutive activities that constitute the longest duration in a given project. In other words, the critical path shows the longest duration that is needed if no optimisation of the tasks that constitute it is found, while, at the same time, it shows the minimum time to complete the project. If any activity is delayed in the critical path, the duration of the project will be delayed similarly (all activities are linked without any kind of identified buffer). Depending on the complexity of the schedule and of the complexity of the project - a schedule can be linked to others - a given project can have several critical paths. The critical path is commonly represented as a succession of red lines that indicate the spin of the Gantt chart.

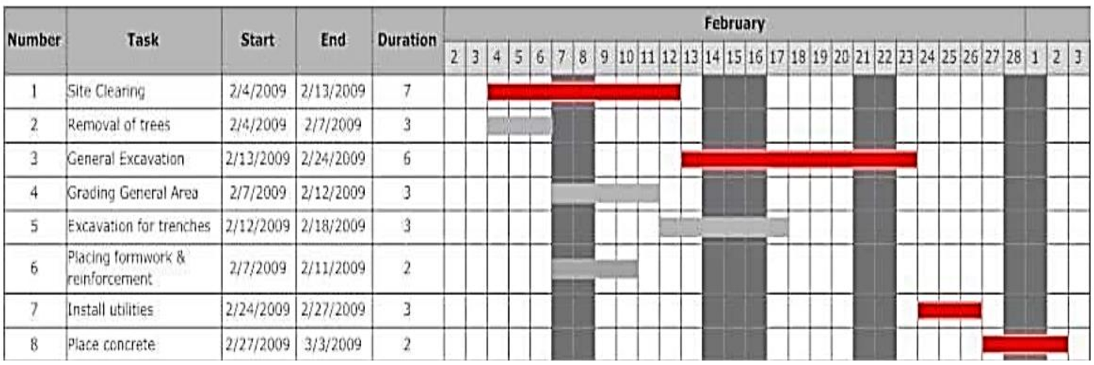


Figure 2.5.1-1 Example of a Gantt chart

The limits of the applicability of CPM in the construction industry are marked by construction projects differing from manufacturing plants mainly in terms of their highly variable production rates. The impact of this variability is demonstrated by the simulation *Parade of Trades*, from Tommelein et al. (1999), and is presented in Thomas et al. (2002) and Sack and Goldin (2007). For Sack and Brodetskaia (2007), a major issue in accurately and reliably managing flow progress in the construction industry is the application of the CPM and the software.

The CPM mainly focusses on determining the critical path from an array of tasks linked by interdependencies, which is valid in a linear process such as in the manufacturing industry, but the processes in the construction industry are very different. In the transformation concept that manages construction management approaches, Koskela and Vrijhoef (2000) recall that total transformation can be achieved only by realising all parts of it, introducing decomposition into parts and, further, into tasks. These tasks are then assigned to workstations, and resources are added to the system to make progress.

2.5.2 1994: The Last Planner™ System (LPS)

The LPS aims to address flow stability and reliability. It is a well-developed lean production tool for project planning and management (Ballard, 2000). Implementation of the LPS demonstrates the continuous improvement of project flow and increased levels of percentage of promise completed (PPC). However, even where the LPS has been applied well, PPC levels of 100% have not been achieved (Bortolazza et al., 2005).

Many techniques have been developed to run the five levels of strategy contained in the LPS: (a) milestone planning, (b) phase scheduling (the macro-collaborative scheduling of the next phase), (c) making all tasks ready to start in six weeks, (d) production planning (works synchronisation), and (e) feedback and checks on the completion of commitments. A sixth conversation has been added to capture the essence of the TPS: learning. Despite its unquestionable advantage over the CPM, the

LPS still needs to be improved. The LPS is not itself capable of reacting to the unpredicted conditions that emerge in the course of a workday and has no mechanism to prioritise the work packages already filtered through a make-ready process. Each manager should adapt the use of LPS to his or her own environment and constraints. Another limit of the LPS is that it is not sufficient by itself to ensure both work stability and continuity, as shown in the site research conducted.

2.5.3 The 2000s: Continuous flow

A number of papers address the concept of continuous flow as part of a larger scheme, and the concept of continuous flow is worth exploring also as a complement. Kreamer's (2004) categorises flow as:

> *" adding and non-value-adding activities, even flow, variability, seven preconditions and value flow. "*

Below are discussed some of the main citations from IGLC articles that support this hypothesis. The search for continuous flow can be addressed from various angles. Continuity be the converse of discontinuity. Therefore, to avoid any discontinuity in the flow of production, the gap between two tasks can be filled by delaying the start of the first to link its end to the start of the following. Yang has argued that there is nothing new in this given that the project managers who work in a seasonal environment have already estimated the necessary postponement when experience informs them of the probability of work discontinuity (Yang 2002).

Another angle can be to divide the work or create output aggregations that will ease the continuity by limiting the variability of the output, thus enabling more control in the continuity of the process. Hopp and Spearman introduced the concept of the bath flow systems in their paper *Factory Physics* in which they develop their science of manufacturing. Building on this idea, they propose looking at the production, more like a line flow or a continuous flow process. Ballard (2005) points out that, although the concept is valid and merits development, there is a failure to take into full consideration the job on the shop floor. Bulhoes, Picchi, and Granja (2005) proposed an approach of continuous improvement as part of a broader overall improvement effort. This research was later developed to highlight the role of production stabilisation to create an adequate environment for the implementation of continuous flow (Bulhoes, Picchi, & Folch, 2006).

Other authors have addressed the importance of flow continuity, without necessarily offering a means of achieving it:

> *"In the construction sector, still heavily dependent on human resources to impose the rhythm of production, Jidoka means greater autonomy for the operatives to enforce a continuous work flow" (Kemmer et al. 2006).*
>
> *"During the PSD meetings, much attention was given to the production-assembly synchronisation in order to promote a continuous workflow" (Schramm 2006).*

There are indications that the principle of continuous flow adopted in the production and assembly of prefabricated structures can be extended to the design of the process, despite its complexity owing to the large number of different professionals involved, including external designers, and frequent changes demanded by the client (Bulhoes & Picchi, 2008).

In a construction industry that is lacking in the adoption of lean concepts, importing the concept of continuous flow is an ambitious challenge given that in the other industries where continuous flow has become central in a lean approach, this effort was supported by many various lean-related tools and methods already in use.

2.5.4 The 2000s: Batch flow

Batch flow has been extensively addressed and researched since 2002, and the concept of batch flow is complementary to the five proposed by Kraemer (2004) and to continuous flow. Lean production emphasises the creation of smooth and small batch flow with little inventory of WIP, short cycle-times and the development of being able to react to new constraints and evolutions in the output to constantly fit the market demands (Partouche, 2008). The particularity of the construction industry is that the site is, in essence, temporary. This implies that the environment of the production line, the site itself, changes from project to project. Moreover, the production line (the site) also evolves from its inception through to its completion, and the production flows are in constant evolution.

Hence, a site be a temporary production system that is operated by temporary workers, one that fathers great variability in its production capacity and efficiency. To overcome this difficulty, Arbulu (2006) proposed dividing the work into batches of equal size and focusing on the flow of these batches.

If the construction streamline cannot be addressed as a whole, some unit production should be found, aggregated and their flow managed. The use of a pull signal that could release the same amount of work flows through the production system would then reach flow stability, even in a highly unstable environment. This mechanism implies that the levels of WIP are the same for each signal. However, that is rather unlikely when dealing with different trades with significantly different production rates and logistical constraints.

Arbulu continues and advocates that the gap between the application of batch flow systems in the manufacturing industry and the construction industry should be closed by *"increasing workflow predictability beyond one day and by reducing delivery times"* (Arbulu, 2006). Now, even if a stable system can be found and implemented on site, it is likely that the final end-product will evolve across the production of the product itself. Clients and owners like to introduce changes to the final object to be constructed and delivered (design changes, technical changes, extra specifications, detailing, new financial or time constraints, etc.) that may directly or indirectly affect the stability of the process and/or ruin the flow of work on site. In this vein, Partouche, Sacks and Bertelsen (2008) remind us that the importance of creating a smooth product flow and reducing variation (in the end-product design) are well-understood in mass production systems where lean approaches have been developed, but they are new in the construction industry.

Arbulu and Tommelein, (2002) emphasise the importance of batching in the construction industry as a means of reducing the effect of the intrinsic variable environment just described as a big contributor to lead time. They advocate that, virtually today but physically tomorrow, the batch size should be one. Focusing on a batch size of one is equivalent to addressing a one-piece flow, something that is highly manageable and which eases the creation of a system of continuous flow with the least delay.

Alves and Tommelein, (2003) further develop and argue that the smaller the batch the higher the possibility of detecting problems or defects in the production line (site) that, if treated in a lean “bad news early is good information” culture offers opportunities for creating a smoother flow of work through the various workstations in a production system. The small-batches assembly strategy, standardising and controlling the assembly cycle, and process stabilisation have led to a 105% increase in productivity in relation to the budget structure (Bulhoes 2006).

2.5.5 2000s Information (or data) flow

Information (or data) and its treatment has become a key success factor in the search for a stable flow, given that a larger and larger volume of data is used across the industry. This increase started at the end of the 1990s and accelerated with the development of fast-track information-sharing (intranet) and the internet. It has now become highly important in ensuring reliable and accurate data transfer among participants to avoid a slow-down in the efficiency or blocking of the production flow that could be caused by delays and interruptions in the information flow. Polat and Ballard (2003) showed that dramatic effects can be generated by waste in the total chain of the works that may be caused by interruptions and delays in information flow, inefficient or neglected ordering systems, inaccurate data transfers and long delays for required information (Alves et al. 2007).

Howell and Macomber, (2006) present the data flow as a loop that starts with a request, is transformed into a promise, and leads to a workflow in the form of information and materials being released from one participant to the next. The different steps through which data should go through should then be conceptualised. The design process must be as precise and accurate as possible to ease the flow of information, coordinate interdependent flows and integrate the design with the supply and site construction constraints to guarantee value creation (Loria-Arcila & Vanegas, 2005).

Value is created by the flow, both for internal and external customers. The transformation of inputs into outputs to clients (internal or external) is delivered by the suppliers, and materials and information flow from one to another within the process, through value-adding and non-value-adding activities). Meiling and Johnsson, (2008) advocate that data treatment has become an important aspect of the possibility of this transformation and that information flow should be addressed as any other flow.

With the establishment of building information modelling (BIM) and other fast information transfer possibilities, information is shared at a higher and higher pace. The adoption of efficient methods for organising and improving access to the information has become critical for the creation and maintenance of a reliable workflow. For this, many IT tools have been proposed to automatically classify the received documents and promote information flow management. Once in place, these IT tools can be further developed and adapted to optimise the in-house information flow management of a company, support a more global pull system and be fully integrated into the performance system (Caldas & Soibelman 2002).

2.5.6 The concept of flow in the construction industry

The concept of flow has been investigated from many angles since Koskela’s (1999) seminal work on the subject. Several studies have focused about flow, tackling the concept from different angles. The different approaches to the subject include the following:

- *creating flow in construction* (Santos 1999; Santos et al., 2002; Alves & Tommelein, 2003; Shen & Chua, 2008)
- *tools to support flow* (Bulhoes, Picchi, & Granja, 2005; Alves, Tommelein, & Ballard, 2006; Gafy & Abdelhamid, 2008; Tuholski & Tommelein, 2008; Senthilkumar & Venkatachalam, 2009; Kerosuo, Koskela, Miettinen, Maki, & Codinhoto 2012)
- *mechanisms to pull production* (Caldas & Soibelman, 2002; Sacks, Goldin, & Derin, 2005; Arbullu, 2006; Rooke, Seymor, Koskela, Bertelsen, Owen, & Cleary, 2008; Brodetskaia et al., 2010; Tiwari & Sarathy, 2012)
- *visual devices to increase transparency* (Formoso & Santos, 2002; Santos Moser 2003; Tan, Horman, Messner, & Riley, 2003; Nakagawa, 2005; Schramm & Formoso, 2007; Lima, Formoso, & Echeveste, 2008; Chavada et al., 2010; Koskela & Patricia et al., 2011; Brady, Tzortopoulos, & Rooke, 2012)
- *reduction of the CT* (Ballard, 2001; Elfving et al., 2002; Walsh, Sawhney, & Bashford, 2003; Chin Yoon Jung et al., 2004; Sacks, Goldin, & Derin, 2005; Jang & Ballard, 2007; Partouche, Sacks, & Bertelsen, 2008; Chin, 2010)
- *batch size reduction* (Alves & Tommelein, 2003; Maturana, Alarcon, & Deprez 2003; Thomassen & Nielsen, 2004; Al-Sasi & Brown, 2006; Esquenazi & Sacks, 2006; Ward & McElwee, 2007; Carneiro, Filho, Alves, Nascimento, Carneiro, & Neto, 2009).

Picchi and Granja (2012) argue that despite the many studies undertaken on flow, the application of continuous flow in construction is still understood only in a fragmentary way. Bertelsen and Sacks (2007) argue that the general understanding of the construction process within the industry and on the part of public administrators is too simple as it sees the process from a transformation perspective only, entirely ignoring the important flow perspective.

They advocate that the construction process should be seen as a basically ordered system where order should be improved as much as possible and where unforeseen events, unfortunately, happen from time to time, as opposed to understanding construction as a complex and dynamic system where the complexity and its effects should be managed directly. They conclude by stating that, therefore, a new mental model is needed.

Hopp and Spearman (1996) suggested that the application of queueing theories can ease the flow processes in a search for stability: stability as the converse of variability.

While Brodetskaia (2007) argue that a theoretical understanding of flow operations by the shop managers is needed, which would help them make better utilisation of their resources from day to day and then lighten the choice of the system to be used, Alsehaimi and Koskela (2008) further elaborate that project management theory focusses on the transformation concept without considering either the value or flow concepts.

Sacks (2009) agrees, challenging the meaning of process and reminding the reader that Koskela (2004) showed how established researchers, publishers and/or authors, such as Womack and Jones (2003), could be in a state of confusion over two key concepts: 1) flow and 2) value generation. This misconception can lead to missing the difference and the opportunities that each of the two concepts bring in the understanding of performance generation.

At its origin, the concept of lean production has been based on the concept of flow to better understand performance as a whole. The concept of value, which has been spread by the quality movement with only a limited understanding of its meaning (too often reduced to money generation), has latterly been unified with the concept of flow under the lean production umbrella. However, there is still a huge effort to be made, both in the academic world to bring clear definitions and in the practical world, to understand the concepts of both value and flow.

Kalaas and Bolviken (2010) argue in their paper *The flow of work in construction: A conceptual discussion* that the lean literature is still unclear and imprecise concerning the concept of flow. Shingo (1988, p. 232, 305, 308) uses flow in the sense of a chain of events, and he sees the distinction between process and operation as one of his main contributions to production theory and as being fundamental for the understanding of production. He explains process and operation through a two-dimensional figure, with the processes flowing vertically (parallel to the *y* axis) and the operations flowing horizontally (parallel to the *x*-axis). Processes are the chains of events during which raw materials are converted into products (p. 305). Processes are object flows, flows of goods (p. 78). Operations are the chains of events during which workers and machines work on items (p. 305). Operations refer to *a human temporal and spatial flow that consistently centres around the worker* (p. 5) and are subject flows, i.e., flows of people (p. 78).

Both processes and operations consist of four phenomena which differ in terms of content: processing, inspection, transport, and delay (pp. 79–80). When working to improve production, processes should have priority over operations (pp. 310–311). Shingo's main point is understood as being that maximising output from operations implies sub-optimisation, and operations should be coordinated to maximise overall throughput or throughput time for the flow of objects. This focus is central in lean thinking and represents a philosophy that differs from, for example, the Western thinking underpinning methods addressing the economic order quantity at the operations level (Wilson, 1934).

When Shingo's terms are applied to construction, the process can be conceived of as the progress of the project, while the work undertaken by the different trades constitutes the operations. A construction project is seen as a process of aggregated sub-processes, but not primarily comprising sequential but also reciprocal interdependencies.

Operations in constructions can be split into work packages with their own internal flow (processing, inspection, transport or movement, and delay). When work packages are aggregated, with all the sub-flows involved, each package or task becomes a process in Shingo's concept, influencing the progress of the whole project.

Kalaas and Bolviken developed a preliminary concept of flow that contains the following properties:

- Flow is seen as a chain of events.
- It seeks to build and expand on Shingo's flow concept with the dimensions of process and operation, which include processing, inspection, delay, transport or movement and supportive work.
- The question is not whether production flows, but rather how it flows.
- Added value or added use-value is part of the concept.
- Results should be reworked in flow with a negative value.
- Construction work is discrete production, and interruptions represent an attribute to be considered rather than an assumption that there is an uninterrupted continuous flow.
- A distinction must be made between conditions for flow and the flow as such.
- Both sequential and reciprocal dependencies in building production must be taken into account.

2.6 Linking manufacturing and construction flows

This section presents the links that can be found between the two contexts presented in (2.4), *In search of production stability in the manufacturing industry: the growth of flow theories and pull* , and in (2.5), *In search of production stability in the construction industry: importing flow theories and pull systems from the manufacturing industry and developing dedicated approaches*.

Section (2.7), *Lean Construction research on SMEs*, narrows the literature review to address the concept of the SME and closes the literature review.

2.6.1 Two vs three types of flows

Car production and the construction process have been investigated by Koskela (1999). For Koskela, car production has two material flows: the most visible flow consists of the flow in the progress of vehicles through the assembly line and the less visible flow concerns the materials brought to the assembly line to build the car :

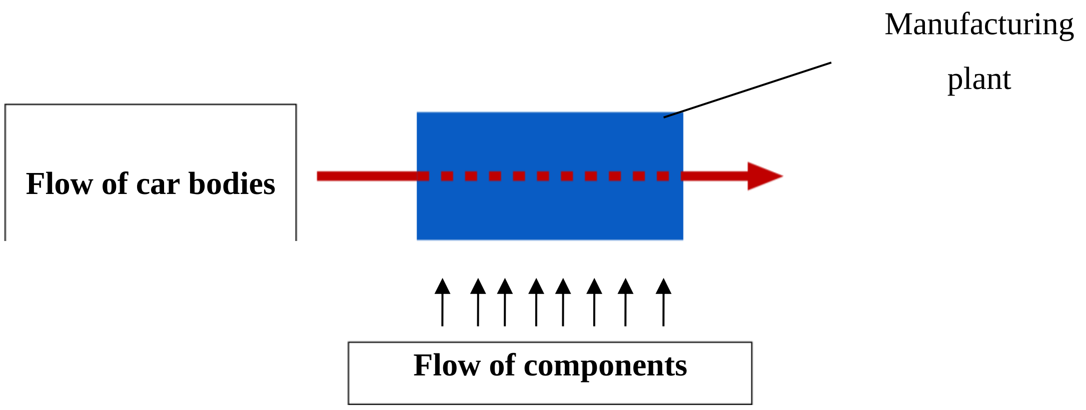


Figure 2.6.1-1 Illustration of cars' manufacturing production flow

“The material flow of components to the site is comparable to that of car production. The building frame proceeds through the different assembly phases (referring to the processing of all locations by a workstation) like a car proceeds through different workstations. However, due to the size of a construction product, there is an additional workflow where all installation locations proceed through the workstations, called the ’location flow’” (Koskela, 1999).

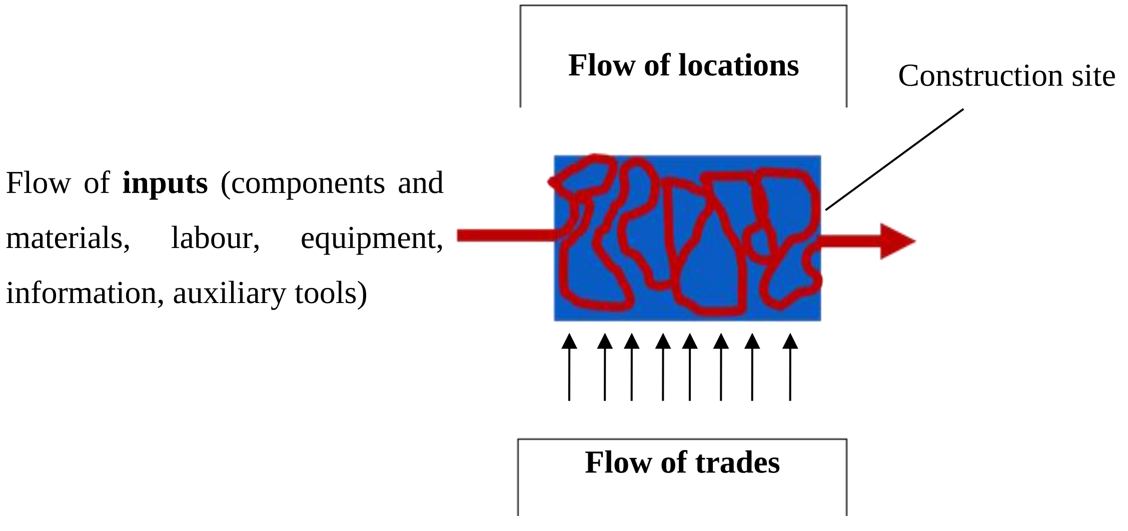


Figure 2.6.1-2 Illustration of construction site production flow

While a construction building is static, a car body is (inherently) dynamic, and while trades are dynamic on a construction site, the workstations in a manufacturing plant are static. We can, therefore, define a construction site as an *assembly line in multiple locations*. Any given activities can be performed only when all the required input flows with minimally required volumes appear simultaneously in each location (Brodetskaia, 2007).

Just like in a manufacturing plant, the productivity of the whole construction process is impacted by the performance of as little as one trade. If the productivity of a single trade slows down, the weakest productivity trade becomes the weakest link that determines the productivity of the whole project chain (it creates a bottleneck). The acceleration of production of only a single trade leads to an accumulation of work locations in front of the successive trades.

In search of a high-paced continuous workflow, construction managers are often tempted to push new locations into production to create a pull flow (i.e., large surfaces of trade production) without necessarily understanding that it mainly increases WIP and production CT.

2.6.2 Improving flow

Given the high volatility of the emergent market in Japan, Ohno's first intention in developing what would later become lean strategies was to improve the efficiency of developing and delivering new models of cars at Toyota. While Henry Ford focused on the process and mainly the process, later called the flow-based strategy, Ohno decided to get a broader view of the value chain that would eventually lead to customer satisfaction; the value-based strategy was born (Howell, 1999).

Ohno aimed to be able to adjust each car according to the customer's needs. Bejder (2005) narrows this down and states that "Value can only be defined for the critical customer and is only meaningful when expressed in connection with a specific product".

The seminal concern in the lean approach was the analysis and understanding of flow. This led to an emphasis on value and, soon after, to the concept of waste, which should be eliminated. Shingo (1988) identifies two types of flow:

> *"Process refers to the flow of products from one worker to another; that is, the stages through which raw materials gradually move to become finished products. Operation refers to the discrete stage at which a worker may work on different products; i.e., a human temporal and spatial flow that consistently centres on the worker"*

In the construction industry, flow-based theories can either emerge from the analysis and transfer of conceptual and theoretical theories from other industries (e.g. Hopp & Spearman, 1996; Womack et al., 1991) or when the particularity of its environment, as described in 2.4.1, are such that there is a need to for the industry to develop its own theories (for example, Koskela, 2000; O'Brien et al., 2002).

Many studies that address production management in construction are based on the thinking developed in Womack and Jones' *Lean Thinking* which is based on the TPS. Continuous flow is the underlying goal that all these studies aim at, which can be reached by:

> *"producing and moving one item at a time, or a small and consistent bath of items, through a series of processing steps as continuously as possible, with each step making just what is requested by the next step" (LEI 2003, p. 9).*

For Hopp and Spearman (2008), the issue arises from that where variability in a manufacturing production setting come from two sources: (1) the time for a given task to be executed at a workstation, and (2) the arrival rate of the tasks at a workstation. Various types of variability, including those mentioned by Hopp and Spearman, impact task workflow in the construction industry and impose a challenge to project teams in managing workflows, especially during the design stage, which comprises iterative processes fluctuating between the owner's value proposition and various design alternatives (Ballard 2000b; Ballard, 2002).

Through increasingly more literature, the differences in the process approach and environments, as well as the similarities of the lean approach in construction and in the manufacturing industries, are better apprehended. However, Koskela, (1992) warning in his analysis of the construction production systems that these systems are anything but smooth and continuous still stands. Koskela argued that the waste and sub-optimal uses of resources in the construction industry are responsible for many interruptions in the construction flow.

Lillrank (1995) later identified that translating the concepts and tools from the manufacturing to the construction industry requires great efforts of generalisation. Lillrank went to say that adapting and importing the concept of continuous flow to the construction industry involved a great challenge.

For Shingo (1988), the analysis of a system of production requires that the system of production in the manufacturing industry is structured on two pillars: process and operations, which should be treated differently.

> *"Process analysis examines the flow of material or product; operations analysis examines the work performed on products by worker and machine."*

The view of the construction industry's operation as a flow is a key concept originated and developed in the lean construction community. Ballard and Howell (1999) and Koskela (2000) proposed that a construction site was the physical expression of three types of flow: material flow, location flow and assembly flow. They contrasted these three types of flow with the two types of flow that can be observed in a manufacturing factory: material flow and assembly flow. Koskela (2000) developed the three types of flow from the construction industry and proposed three models of production:

> *"Production is a transformation of production factors into the product" "production is a flow of material through the production system" "production is value generation, fulfilling the customers» needs and wishes"*

2.6.3 Theory of constraints

According to the theory of constraints (Goldratt, 1990), overall manufacturing system throughput is strongly dependent on bottleneck scheduling and the bottleneck production rate. Goldratt (1997) proposed the drum-buffer-rope scheduling technique for entire job shop scheduling. The overall duration of a project is directly dependent on the set of tasks that comprise the critical chain, considering both resource and precedence dependencies.

Once the critical chain activities (bottlenecks) are identified and duly scheduled, non-bottleneck tasks can be planned backwards and forwards, depending on the limited capacity or productivity of the bottleneck.

According to Brodetskaia (2007), production processes in construction have a *floating* bottleneck. At any stage of project progress, any trade that slows down its production rate or lingers at any location may become a flow bottleneck. Therefore, under the bottleneck scheduling approach, effective stabilisation of construction flow depends on the ability of the works manager to identify or predict which activity is the bottleneck in the process at any time and to schedule or manage it properly to ensure continuous workflow.

2.6.4 Takt time planning

Takt is a German word that originates from the music world. It can be translated and simplified as *rhythm*. In an industrial world, this notion has been used to indicate the division of the work sequence, timed per shift, that is allotted for a single available piece of work based on customer demand, at a precise rate per shift (Rother & Shook, 1998). Liker (2004) later proposed a simplified definition:

> *"The rate at which the customer demands the product and, hence, dictates the rate at which production should take place to meet those demands exactly on time without generating unnecessary inventory."*

Licker (2004) claims *takt is the heartbeat of one-piece flow*. Designing and addressing a production line with the application of takt eases meeting the customer demand as each piece flow can be seen separately (Liker 2004). Translated into the construction industry, takt time can be seen as the overall progress rate that should dictate the work's pace. Each activity should have the same allotted time, tracked to move at the same pace and reduce, or virtually erase, any variability for constant demand.

For Kenley et al. (2009), the impact in the construction industry would be a decrease in the overall duration of the site and, consequently, a decrease in the costs of the project. However, in the real world, given the heterogeneity of the activities, contractors and environments (or situations), the application of takt time requires that production rates are balanced between one activity to the next so that products do not accumulate on site or that there is no discontinuity in the flow of work (Hopp & Spearman, 2008).

The concept of takt when applied to construction has not yet been widely investigated. It was first presented at IGLC conferences on production system design using takt time. Frandson et al. (2013) proposed a refined definition of takt time:

> *"The maximum number of days allowed to complete work at each location."*

Takt time-based planning, or takt planning, has been tested on a daily application on the Sutter Health Women's and Children's Center (WCC) construction site. The study by Linnik et al. (2013) presented a very encouraging result: the project was completed in half the forecasted time. In their case study, Evinger et al. (2013) compared the productivity of a traditional as soon as possible approach and a location-based management system that could be assimilated with a takt-based approach.

The study, which was conducted in the same building with the same crew, reported 18% improvement in the productivity and 10% in the production rates in favour of the application of takt planning.

2.7 Lean Construction research on SMEs

While Sections (2.3), *Pull system and production flow stability*, through to (2.6) *Linking manufacturing and construction flows*, presented the rise of production flow theories in the context of the manufacturing and construction industries, Section (2.7), *Lean Construction research on SMEs*, narrows the literature review to address the context of SMEs in the construction industry, which are in the centre of the approach developed in the research undertaken in the context of this thesis. Section (2.7) closes the literature review.

2.7.1 Originality of the research: the context of SMEs in the lean construction research is largely under investigated

In 2017, Tezel pointed out that even if SMEs often constitute the largest group in construction supply chains, discussions have rarely focused on the application of lean construction in the context of construction sites they operate. Sector-level analyses are even scarcer. Tezel (2017) claims that for an extended dissemination and deployment of lean construction across the construction supply chains in different sectors, it is essential to gain a better understanding of the issue from the SMEs' point of view.

Tezel et al. (2019) made a systematic literature review on the research on applying lean construction and BIM in SMEs in construction. They found that the current discussion on the adoption of lean construction from the SMEs' perspective is very limited. They showed how the number of publications was stable year after year and that there was no significant difference between the UK, Swedish, Italian, American, and Brazilian institutions in terms of research output. It should be remembered that the IGLC annual conference and the Lean Construction Institute's Lean Construction Journal are together responsible for half of the publications. Tezel et al. (2019) recalled that, although there were no barriers to entry for the larger research community, such an implicit, closed community feeling in the LC research scene had been subject to criticism before (Green 1999; Green et al. 2005; Jørgensen and Emmitt 2008). More diversity in the publication media is deemed useful for further dissemination of this research focus.

It is to be noted that at the start of this research in 2011, not a single paper had been issued in francophone papers on the application of lean in the SME world and that, nine years later, little more has been published in French. The dissemination of lean construction in the French-speaking countries (mainly in France, Luxembourg, Belgium, Switzerland and Mauritius) has been pioneered by the promotion of specialised consultants who have made certain tools and approaches available to SMEs. Of course, the bias of a consultant should be considered here and will be discussed in Chapter 3.3.1.3.

It should also be highlighted that, although some client-driven contractual LC obligations imposed on construction supply chains do exist (e.g., highway supply chains in the UK) (Tezel et al. 2018), currently, there are no government-driven mandates and no large-scale support groups targeting specifically SMEs for LC implementations like the BIM implementation scene in the UK (Tezel et al. 2019). Some other initiatives exist in lean construction supported by clients in French-speaking countries but most of them are driven by consultancies on very large-scale construction sites made by very large companies/international groups. These include the European Parliament Office in Luxembourg (450,000 sqm, €500 million works turnover), the Pullman Hotel and shopping centre, Montparnasse in Paris (150,000 sqm, €200 million works turnover), and the Olympics real housing project in Paris (200,000 sqm, €150 million works turnover).

It is to be noted that in most of these large construction sites, a BIM approach either was promoted or adopted well before the lean construction approach was brought to anyone's attention. In brief, neither the clients nor the SMEs seem to be mature enough regarding lean construction to adopt the approach and generalise it, as has happened with BIM.

Alves et al. (2012) argue in favour of self-promotion of the lean construction community based on successful case studies that can reflect the benefits that all the stakeholders can get from such an approach at various stages of the project, whatever the size of the contractor(s). For Alves, it can be useful to promote lean construction for SMEs at the sectoral or national level but it is also down to the LC community to create this attention by demonstrating business cases and activating diffusion mechanisms.

With fewer than five papers yearly (two-thirds published in conference papers and one-third published in journals), the *SME and Lean* topic seems largely under-represented in the research bibliography (Tables from Tezel, 2019).

Publication type	SMEs and Lean
Conference paper	23
Journal paper	11
Grand total	34

Year and publication type	SMEs and Lean
2004	1
Conference paper	1
2005	1
Journal paper	1
2006	1
Conference paper	1
2007	2
Conference paper	1
Journal paper	1
2009	
Conference paper	
2010	4
Conference paper	2
Journal paper	2
2011	2
Conference paper	2
Journal paper	
2012	3
Conference paper	2
Journal paper	1
2013	4
Conference paper	2
Journal paper	2
2014	3
Conference paper	3
Journal paper	
2015	3
Conference paper	3
Journal paper	
2016	4
Conference paper	4
Journal paper	
2017	4
Conference paper	2
Journal paper	2
2018	2
Journal paper	2
Grand total	34

Figure 2.7.1-1 "SME and Lean" topic largely underrepresented in the research bibliography (tables from Tezel, 2019)

The researcher then investigated the papers presented in Tezel (2019) in search for previous research on the concept of stability in the context of SME as developed within the present research. It was found that none treated the concept of stability.

Year and publication type	SMEs and Lean	***Stability*** *(as the concept developed in this research)*
2004	1	***0***
Conference paper	1	***0***
2005	1	***0***
Journal paper	1	***0***
2006	1	***0***
Conference paper	1	***0***
2007	2	***0***
Conference paper	1	***0***
Journal paper	1	***0***
2009		
Conference paper		
2010	4	***0***
Conference paper	2	***0***
Journal paper	2	***0***
2011	2	***0***
Conference paper	2	***0***
Journal paper		
2012	3	***0***
Conference paper	2	***0***
Journal paper	1	***0***
2013	4	***0***
Conference paper	2	***0***
Journal paper	2	***0***
2014	3	***0***
Conference paper	3	***0***
Journal paper		
2015	3	***0***
Conference paper	3	***0***
Journal paper		
2016	4	***0***
Conference paper	4	***0***
Journal paper		
2017	4	***0***
Conference paper	2	***0***
Journal paper	2	***0***
2018	2	***0***
Journal paper	2	***0***
Grand total	34	***0***

It was also found that despite that some academic articles such as Björnfot (2007), Sachs et al (2009), Mota et al (2013), Sousa et al (2020) relate to the concept of stability, none of them either address this concept as works synchronization by SMEs.

2.7.2 Critique of the state of literature

Tezel (2009) recognises that the vast majority of the literature, even if quite limited as shown above, involves demonstration of the implementation of lean construction techniques at SMEs through pilot implementations and case studies, focused on operational aspects of the approach. Green et al. (2005), Jørgensen and Emmitt (2008), Alves et al. (2012), Wandahl (2014) and Cano et al. (2015) have already pointed out the insufficient theoretical exploration and the positive bias when the lean construction approach is addressed to SMEs. Most research focusses on organisational, procurement, training, and project governance issues to be addressed by lean construction tools within the context of academic research..

As a consequence of this state of the art, one could argue that the lack of scope in the research, the limited number of publications and the limited dissemination of the lean construction approach in SMEs, has narrowed the research focus and negatively affected the access of SMEs to lean construction research.

In conclusion, although lean construction has gained credence in large companies and large projects, this is far from the case with SMEs. Lean construction research and project cases have been mainly iconic and beyond the reach of the vast majority of the regular construction industry: the SMEs. This situation will most certainly change as important stakeholders and/or clients impose lean approaches in their operations. Then, the issue of training will emerge, something which is not considered here. Tezel (2017, 2019) advocates that a more critical and SME-focused research area is now required. This thesis, fully centred on applying lean construction approaches to SMEs, seeks to fill this gap.

3 Research methodology

Given the context of the research, which is mainly based on human factors, the choice for a research methodology has not been a straight path. This chapter helps the reader understand how the methodology of the research has been chosen and then developed and adapted, and how data were collected on the three blocks of real estate development over a 4-year period.

The concepts of action research and design science that are the two main relevant approaches in the context of this research are first presented and detailed. After having discussed and compared the two, they are linked with the case study approach that has proved to be appropriate here.

- The first section (3.1), *Introduction*, introduces the chapter as covering the research methodology and provides the general frame of the research.
- Section (3.2), *The choice of research method*, presents the choices for the research method (action research and design science research), then Section (3.3), *Recent research into the search for consensus*, reports on the recent literature in a search for a consensus in those two approaches.
- Section (3.4), *Conclusion*, presents the findings and, based on these, Section (3.5), Justification for the choice of research method, justifies the choice of the research method.
- Section (3.6), Proposed method: multiple-case study from design science research, introduces how the method has been applied in the context of this research and (3.7), Data collection, describes how the data were collected for the thesis.

Chapter (4), *Research processes*, then develops the process based on the research method developed here.

3.1 Introduction

This section introduces the research methodology used in this research. The following sections of this chapter develop the path that the researcher has followed, how the data were collected and why this research process was chosen.

According to Kerlinger (1973):

> *"The basic purpose of scientific research is to produce a theory (i.e. to understand and explain phenomena). Theory relates to a set of interrelated constructs (concepts), definitions, and propositions that present a systematic view of phenomena specifying relations among variables, with the purpose of explaining and predicting the phenomena."*

Kerlinger (1977) goes on to say that:

> *"a scientific study is systematic, controlled, empirical, and critical investigation of hypothetical propositions about the presumed relations among natural phenomena." A hypothesis is a "conjectural statement, a tentative proposition, about the relation between two or more phenomena or variables." In other words, in the academic world, a hypothesis should be understood as A propositional form, almost Boolean: "if, then, else" that helps structure and provide predictions for future research.*

Buckley et al. (1975) insisted on the importance of meeting certain criteria to conduct quality research:

- an orderly investigation of a defined problem
- the use of appropriate scientific methods
- adequate and representative evidence
- logical reasoning, uncoloured by bias, employed to draw conclusions
- a demonstration of the validity or reasonableness of the conclusions
- the generation of general principles or laws that may be applied with confidence under similar conditions in the future, yielded from the cumulative results

While the aim of the research and the scientific discipline can orient the choice of an appropriate research method, finding it remains a long, though key, journey for any researcher. For Remenyi et al. (1998), the two main drivers should be the topic to be researched and the specific research question. Van Aken (2004) proposed three scientific disciplines and corresponding missions:

- *The formal sciences, such as philosophy and mathematics*, aims at building systems in their own eco-system that can be tested internally and in the theoretical field. Theories play a central role in the approaches developed in the formal sciences, that, one could say, auto-generate and auto-feed new theories in a single, closed environment.
- *The explanatory sciences, such as the natural sciences and the major chapters of the social sciences*, aims at explaining the world as we see it. Observation, description, explanation, and prediction are fundamental steps of the explanatory sciences. Following these steps should lead the researcher to *true* propositions that, on the basis of the evidence provided and on the rigour of the analysis, can be accepted as true by the scientific community. Explanatory science is sometimes regarded as soft science as opposed to formal science, which are considered to be hard science.
- *Design sciences include the engineering sciences, medical sciences and modern psychotherapy*. Design science may be seen as a soft science with a hard core or as a hard science with a soft core. Design science aims to develop solutions to be tested through the reaction of artefacts. An artefact is a problem (or a constraint) that has been identified in the practical world that needs more than intuition and *make do* to be solved, captured and integrated into the body of knowledge, and then disseminated.

A large proportion of the research conducted so far in the field of lean construction has addressed large sites made by very large contractors and with a design supported by BIM. In the US, Sutter Health (private healthcare operator) and DPR (general contractor) were pioneers in the use of lean management in the Camino Medical Centre project in 2003, a process further developed in the Castro Valley project. As noted by Dave et al. (2013), in the UK, the Heathrow Terminal 5 project, Network Rail’s Borough Viaduct project and the Highways Agency’s Bidston Moss (Costain) and M4/M5 Automation (Balfour Beatty) projects are other large-scale construction projects which made use of lean construction principles. Laing O’Rourke (UK), Morgan and Sindall (UK), Skanska (Finland and UK), and BAM Nuttall (UK) are notable construction companies that have already at least experimented or integrated lean principles. Examples of small or medium projects conducted according to lean construction principles by SMEs remain limited, however.

The scope of the research has been narrowed to address a gap in the body of knowledge: understanding the effects of the application of flow-based management systems on medium-size sites (€2−50 million work turnover) made by medium-sized companies (20–200 employees), which represents most of the construction sites in Europe.

Finding, justifying, testing, developing, implementing, and closing research methodology is a key sequence in the doctoral research process. The researcher should take care of and account for the entire process of a doctoral path: from understanding the grounding concepts and theories to proposing the development of new solutions through data collection and analysis of the problems investigated. Research methodology focusses on grounding the sequences of the research in the problem that will be investigated. Thus, although a range of research methodologies coexist in the academic world, only a few will fit any researcher’s project. Wedawatta (2013) claimed that the researcher should pay special attention when identifying the research methodology that best suits the selected topic, the problem, the environment and the category of science to be addressed for at least two reasons: to achieve the objective of the research and develop new knowledge and, perhaps most importantly, to establish the credibility of the work.

As developed in the following chapter, this thesis has been built on the development of a hybrid approach, the combination of design science and action research. Subsection (3.2.1), *The action research approach (differentiated from consultancy)*, explains the action research and (3.2.2), *Design science research*, design science. Section (3.4), *Justification for the choice of research method*, presents a justification for their application in the present research context and (3.6), *Proposed method: multiple-case study from design science research*, describes the mixed research methodology.

3.2 The choice of research method

3.2.1 The action research approach (differentiated from consultancy)

"Action research is a method of learning from changing one parameter or more in a structured learning process from the real world."

> *"Action research aims to contribute both to the practical concerns of people in an immediately problematic situation and to the goals of social science by collaboration within a mutually acceptable ethical framework." (Rapoport, 1970).*

Blum (1955) saw action research as a two-stage approach. First the researcher should conduct a diagnostic that involves *a collaborative analysis of the social situation* that leads to the formulation of hypotheses based on the nature of the research domain.

The second stage is to *care*: collaborative experiments are conducted by introducing changes and the effects are studied. The concept of scientific rigour was introduced by Susman and Evered (1978), who detailed a five-phase cyclical process for science.

> *"The approach first requires the establishment of a client-system infrastructure or research environment. Then, five identifiable phases are iterated: (1) diagnosing, (2) action planning, (3) action-taking, (4) evaluating and (5) specifying learning. The figure below is a diagram of this action research structural cycle." Evered (1978)*

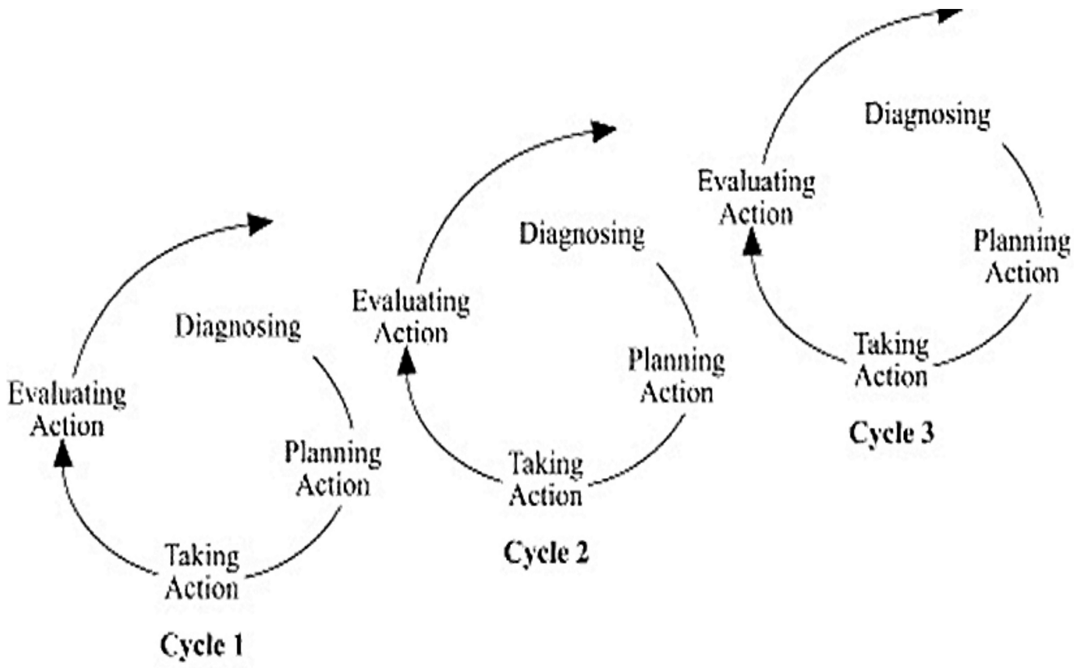


Figure 3.2.1-1 Adapted from Coghlan and Brannick (2001, p. 19).

As recalled by Lungo (2003), the *client-system infrastructure* is the specification and agreement that constitutes the research environment. Baskerville (1997) argues that the undertaking is a collaborative act in essence, which is a key aspect of the infrastructure.

The researchers work within the environment and eco-system of the practitioners, within the client-system. The practitioners know best their environment and the subject to be studied within the knowledge system. They have a deep knowledge of the insight that is necessary to investigate the issues that should be addressed as part of the study. To clarify, Baskerville (1997) advocates that the practitioners can be considered:

> *"as part of a set of actors who are oriented to the solution of practical problems, who are essentially organisational scientists rather than academic scientists."*

In the case of the research, the client-system infrastructure is given, and the boundaries of the actions that can be conducted are determined by the contract that links the Client and the company. The contract and the scope of actions were jointly decided upon with the Client, and the plan was to work on three development blocks consecutively and to build iterative knowledge and experience, exploring further improvement opportunities at each stage. Hence, Block 1 would be used to initiate a lean culture supported by fundamental tools such as LPS and 5S (the two first Ss: seiri and seiton). Block 2 would present an opportunity to capitalise on the experience and knowledge gained from Block 1 and to decrease tolerance in the respect of the fundamental tools (increase PPC) and secure the three first Ss from the 5S approach (i.e. seiri, seiton, and seiso). Block 3 would allow a consolidation of the good practices gained from the first two blocks and initiation of the integrated project delivery (collaborative design).

Given the time allocated to the research (three years), the research made on each of the three blocks would itself be made up of successive action research cycles. The research, therefore, comprises three distinct action projects within which cycles would be undertaken.

One difficulty in this situation was the external position of the Author of the thesis, not as a researcher but as a consultant. Consultancy is commonly viewed as a temporary activity, one which brings external expertise, objective analysis, specialist knowledge, or the benefits of cross-organisational experience while keeping a constant level of permanent employees (Steele 1975). A scholarly work made by a consultant is often seen as part of the regular organisational development process. Many management fields have adopted the support of these specialists to grow new expertise internally (Kubr 1986). Lippit and Lippit (1978) describe the process of organisational consultation as one of successive phases: 1) engagement, 2) analysis, 3) action, and 4) disengagement.

(1) A consultant is introduced into the organisation under a formal contractual agreement. The consultant is thus linked to the organisation in the search for the deliverable, which is the critical output.

(2) During the analysis phase, the consultant studies the organisational elements to identify problem areas and possible solutions, concluding with the presentation to the management of the organisation of a consultancy report. This report typically proposes various actions to be undertaken to bring concrete answers in the search for the deliverable.
(3) The action phase is the concrete part of the consultancy, where the organisation undertakes actions. According to the roadmap and depending on the subjects that have been discussed by the management, the consultant implements the ad hoc actions, which mainly originate in his/her experience.
(4) The disengagement phase is determined when either the deliverable is delivered, or the mission (temporally fixed) has come to an end.

Bakersville (1997) argues that:

> *"consultancy is a form of participative case study, but a case study in which the authors make no strong claims to being objective or uninvolved observers. Rather, the case describers very often have a pronounced and understandable bias in promoting their claims to having identified actions leading to successful outcomes."*

In essence, a consultant is not necessarily interested in maintaining strong academic rigour since the result (the delivery of which allows fees to be claimed) is of more importance than the path followed to attain it. A consultancy is managed like any profit-based company: Profit is generated by the difference between the price sold for the mission and the operational costs to deliver the mission. The price sold is most generally a lump sum (fixed). So, in order to maximise profits, a consultant must decrease operational costs, generate immediate biased results and be results-focused; this is mostly incompatible with academic rigour.

Seashore (1976) first noticed and warned about the natural bias that can exist between being a researcher and being a consultant. Seahore (1976) points out that the rational link between action (consultancy) and research should be particularly investigated to avoid the natural tendency of professionals to *act* as researchers. Eric Trist (1976) also pointed out that

> *"there is a great difference between simply acting as a consultant and acting as a researcher in a role where both professional and scientific responsibility are accepted. In the first case, there is no commitment to the advancement of scientific knowledge, either on the part of the consultant or on the part of those for whom the inquiry is being made. In the second case, this commitment is fundamental and must be explicitly accepted by both sides. It is this that makes the relationship collaborative."*

For Warmington (1980), it is a trap for those action researchers who want to gain credit to pretend to have found some definitive techniques or packaged methods and to be able to make their own recommendations to the organisation concerned. For Warmington (1980), a good position in the research act for those researchers is to stand as if they were fellow students, collaborators and investigators, in other words, of equal status with the other stakeholders of the research environment. This position would be best to avoid distorting the reality. In reality though, this may prove more difficult and ambiguous than this picture would suggest.

As an answer to Trist (1976) and Warmington (1980), Gummesson (1988) proposed four factors of rigour that should be followed by either a consultant or by a researcher to avoid ambiguity and professional bias in the definition of the position of the scientist.

For Gummesson (1988), researchers need to be more rigorous than consultants in the following aspects:

(a) documentary records,
(b) theoretical justifications in the action research process that is a cyclical process,
(c) consultants require less rigorous (often undetailed) empirical justifications
(d) clients often set the limit of the rigour (attached to the price paid for the time of the consultant),
(e) the mission of a consultant is often linear: engage, analyse, act, disengage (from Lippit and Lippit 1978).

Baskerville (1997) summarised the key distinctions between consulting and action research as follows:

	Action Research	Consulting
Motivation	Scientific knowledge, publication	Profit, proprietary knowledge
Commitment	Dual: research community, client	Client only
Approach	Collaboration	External, independent study
Foundation for recommendations	Theoretical framework	Empirical tradition
Essential source of understanding	Experimentation	Critical analysis
Explanations	Idiographic solutions	Universal solutions
Client's side benefits	Contingent learning	Knowledge transfer

Table 3.2.1-1 Key distinctions between consulting and action research

From all the above, the consulting researcher (or researching consultant) should take extra care to focus on the research and treat the consultancy as secondary. The research conducted here should, hence, for the stake of scientific rigour, follow the academic rule while allowing the generation of some profit to ensure the consultancy is viability. The motivation is clearly based on the quest for scientific knowledge that is not incompatible with profit, profit generated through making a client happy by having improved operations and knowledge, not profit generated as a priority. The knowledge and experience gained in this regard is then shared with the academic world to be disseminated, a fundamental difference from a classic consultancy approach.

I am, therefore, committed to both the academic and practical world, with the approach of the researcher based on collaboration with the Client, who is deeply involved in the research. The recommendations come mainly from the theoretical framework, although some empirical experience has helped in choosing the actions to be tested. The explanations of the findings are constructed within the action research framework, and their validity and possible generalisation will be assessed by the scientific community. It is most probable that more research on the topic will be necessary, capitalising on the learning gained in this case, before dissemination.

From the above, it is clear that, although the researcher is a consultant and that the Client first contracted me as such, changing into a researcher was necessary to guarantee the academic rigour and scientific validity of the findings. From the above, it also appears that one can be a researcher and a consultant, although a consultant cannot necessarily be a researcher.

3.2.2 Design science research

Brady (2014) states that research based on design science is largely described as research applied to the development of innovations that solves existing practical problems and makes contributions to a body of knowledge. Lukka (2003) advocates that when the research aims at the production of innovative constructions, a research approach by design science is appropriate; especially if the intent is to bring concrete solutions to solve problems that practitioners face in the real world and seek to expand the body of knowledge and theories of the discipline under investigation. With the growth of human science and sociology, March and Smith (1995) describe the main purpose of design science as a way to address problems created by humans and find solutions that will help them. March & Smith, (1995) divided the outcomes of design science into four categories: constructs or concepts, models, methods and instantiations. The relationships between each are defined below (March & Smith, 1995).

3.2.2.1 Construct or concept

A construct is an idea or theory, typically one considered to be subjective and not based on empirical evidence, comprising various conceptual elements (Wood, 1986).

Given the singularity of the environment of the research (each design science process operates in a dedicated zone), it is necessary to define a construct (or a concept) that defines and sets the vocabulary for the observed domain. The construct will help in conceptualising and describing the issues to be addressed in the domain and anticipate the solutions to be developed. As proposed by Hull & King (1987), constructs can vary in forms and formats, from the most formalised as in semantic data modelling (entities, attributes, relationships, identifiers, and constraints) to the most informal forms, as in cooperative work. In brief, the environment (technicity, complexity, pluralisms, etc.) will define the level of formalism required for the research. Of course, a construct can be seen at a micro-level (individual, small group) to a macro-level (an organisation as a whole or society) and interdependencies between constructs should be identified (Smith, 1995).

3.2.2.2 Model

The formal interdependencies between constructs constitute a model expressed in the form of a set of propositions or statements that can be either descriptive (a representation of how things are) or prescriptive (a statement of how things should be). Formalising the model will help the researcher to map the construct and better understand the environment of the research field, should the researcher have only a limited knowledge or understanding of the domain. Modelling can then be very limited, leaving more room for intuition, which can later be justified in the light of the results as part of the iterative process that is inherent in design science.

3.2.2.3 Method

The model provides a representation of the space in which stands the problem and, perhaps, the solution, and the constructs of a language. Both the model and the constructs together form the base on which the method can be drawn. March & Smith, (1995) define a method as a set of steps that can be highly formalised (e.g., an algorithm or guideline) and which are used to perform a given task. A model can indicate a method as inputs can be taken from the steps of the model. Solving a problem in a different environment can then ask the researcher to provide a broader view of the problem and use methods to convert one model to another by retaining the original method.

3.2.2.4 Instantiation

Instantiating means realising an artefact in its environment where the methods are operationalised. Vaishnavi and Kuechler (2007) developed the concept of instantiation and argued that design science supports better theorisation in two ways.

First, design science can address a problem that may affect many people and communities in different environments. Developing a piece of design science research (DSR) may provide theorising for many communities, and it can offer experimental proof of method by essence, or even an experimental exploration of a method that is being developed as the research is continuing (as part of the iterative process).

Second, defining (refining, understanding, formalising, conceptualising, detailing) the artefact can be an output of instantiation by an exploration into the relationships between its elements. This can be achieved by better explaining the elements of the artefact and making them more visible. The refined artefact can then be used to question previously theorised relationships (Vaishnavi & Kuechler, 2007).
Van Aken (2004, p. 228) describes the outcome of design science as a technological rule: ”a chunk of general knowledge” which emphasises the importance of the outcome in the design research process as a desired outcome or performance in a certain field of application that can be found from an intervention or by an artefact.

Lukka (2003) explained the design science approach and restated its core features. For Lukka (2003), a design science approach should:

- focus on a real-world issue that can be either expressed or shared by the practitioners or identified by the research itself as part of the iterative process
- provide innovative solutions that should (at least partly) solve the initial practitioner’s real-world problems
- test the developed solution and validated its practical applicability
- create a research environment that encourages close involvement and co-operation between the researcher and practitioners as key to developing the

conditions of experiential learning that will later lead to the construction of the artefact

- ensure the link with prior theoretical knowledge that should explicitly appear in the research method to ground legitimacy for the creation of new knowledge of the application in the field observed
- Practise close research by linking the empirical findings within the concomitant theories as a way of providing areas for further research

Hence, a DSR approach is both experimental and iterative by nature. The aim is to develop and implement new artefacts (solutions to a given problem) that should be regarded as a test instrument in an attempt to illustrate, test or refine a theory, or develop an entirely new one (Lukka, 2003).

While much scientific research starts with theories and tests them in practice (or in modelling the reality), DSR engages reality the other way around. Lukka (2003) recalls that DSR originates from a more pragmatic philosophy of science, one that advocates that by a profound analysis of what works (or does not work) in practice, one can make a significant contribution to theory.

Henver et al. (2004) described design science as a rigorous process of:

- designing artefacts to solve observed problems,
- making research contributions,
- evaluating designs and,
- communicating the results to appropriate audiences.

For Venable (2006), DSR is a rigorous inventive problem-solving process that focusses on developing and producing artefacts and artificial systems with desired properties that will then be further implemented, tested and refined to bring new artefacts to the practical world and extract new theories, thus feeding the body of knowledge. Kasanen et al. (1993) and Peffers et al. (2007) highlight that DRS has been widely used in the technical sciences such as mathematics, engineering and clinical medicine, but that it has also been tested in softer sciences and has become an important activity in fields like architecture, engineering and urban planning.

Brady (2014) points out that the construction industry started to use DSR as a research method, construction being directly linked with people. While in other industries, most processes involve machinery (and, therefore, can be easily copied), the construction industry processes still rely a lot on human interventions (and, thus, bias). Barker et al. (2004) were the first to test the application of DSR in the construction industry; they proposed a model of time compression for construction projects. Da Rocha (2011) later developed a framework for customisation strategies for the housing industry, and then Rooke (2012) proposed guidelines to improve wayfinding in hospital environments. Another example is the research carried out by Oyegoke (2011) on the development of a specialised task-organisation procurement approach.

To conclude, as Van Haken (2004) states, it is important to understand and keep in mind that, contrary to more traditional research processes, the research in design science aims to produce and apply knowledge of tasks or situations to create effective artefacts in the form of new applied solutions rather than produce general theoretical knowledge.

3.2.3 Design science steps

The main issue in DSR concerns the ability of the researcher to build the above concepts, models, methods and instantiations at an academic level, or in a format that is innovative and valuable enough to be recognised by a scientific community, who are used to more traditional approaches and justifications.

March and Smith (1995) proposed a new way of conducting research in the form of combining the real world and the academic world, with the former providing concrete issues that the latter would address and propose artefacts for. From this, design science was born. Design science is oriented to create things that serve human purposes, which is also called the building phase; the performance of the solutions created should then be tested and validated back in the real world. This phase is called the evaluating phase.

> *" Building is the process of constructing an artefact for a specific purpose; evaluation is the process of determining how well the artefact performs." March and Smith (1995)*

Peffers et al. (2006) proposed the figure below, providing a research process model for DSR. This DSR process model presents the iterations loops:

(1) problem identification and motivation,

(2) the objectives of a solution,

(3) design and development,

(4) demonstration,

(5) evaluation and

(6) communication.

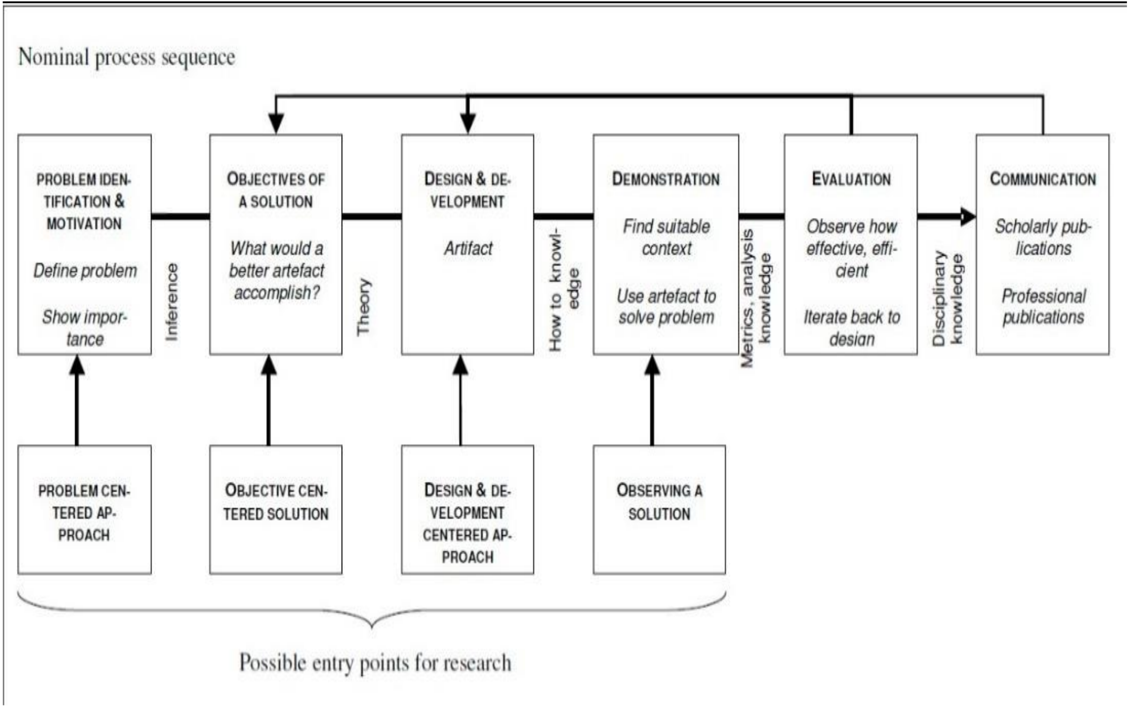


Figure 3.2.3-1 Design science research process model (Peffers et al., 2006:93)

3.2.3.1 Step 1: Problem identification and motivation

This first step aims to define the research problem and validate the significance of the proposed solution. In this way, the readers will better understand the origin, the context, and the reasoning of the researcher in seeking a solution to the proposed problem. Peffers et al. (2007) argue that, in the development of effective artefacts, two important aspects of the design science approach must be particularly developed and justified: defining the problem and justifying the value of the solution. The links between the problem, its justification, its value and context help to capture the complexity of the problem and build a justification for the value of the solution. Identifying the problem is a critical step in understanding what the problem is and, therefore, being able to affirm the value of the solution for it.

The solution will then have to be accepted by the audience of the research. The researcher assesses, validates, and justifies the value of the solution that will help the solution and the results to be accepted and explain the reasoning associated with the researcher's understanding of the problem (Peffers et al. 2007).

3.2.3.2 Step 2: Objectives of a solution

For Peffers et al. (2007), once the problem has clearly been identified and motivated, the objectives of a solution can be developed, arising from the problem definition and from the knowledge of what is possible and feasible. The approach can be either quantitative and/or qualitative when addressing the objective. When the literature review shows one solution can be considered better than the others currently presented in the body of knowledge, the quantitative approach is appropriate. The qualitative approach develops how a new artefact is expected to support solutions to problems that have not yet been addressed in the literature. Then, from the problem specification, the researcher sets the objectives and the resources required to achieve them. The research will further develop what the problem is, as well as what current resolutions have already been developed and validated for the problem, along with their efficacy.

3.2.3.3 Step 3: Design development

Step 3 is devoted to developing the artefact's (i.e. the concept's, model's, method's, or instantiation's) functionality, design and architecture before creating it for the practical component of the study. Theories surrounding the research problem should be well known at this point so the researcher can design a valuable solution based on accepted wisdom. The link between the objectives and design development is made through different investigations regarding the knowledge of theory and its applicability to the current problem in the search for a solution (Peffers et al. 2007).

3.2.3.4 Step 4: Demonstration

In Step 4, experimentation, simulation, case studies or other appropriate activities may be conducted to demonstrate that the solution developed as a concrete answer to the problem is appropriate and complements the body of knowledge concerning the application of the artefact and the possibility for future researchers to continue growing the knowledge. The researcher demonstrates how effectively the created artefact addresses the research problem.

3.2.3.5 Step 5: Evaluation

For Peffers et al., (2007), the evaluation step assesses the efficiency of the solution to the research problem by observing and measuring its impact in the real world. The evaluation is conducted by the difference between the quantitative objectives and the situation (results) as observed after the use of the solution (artefact). Evaluation can take various forms: surveys, user feedback and satisfaction questionnaires, assessment of whether the objectives have been met by the application of the artefact as an answer to the objectives, or the measure of quantitative indicators to assess the performance of the system, such as response time or availability.

Another iteration of the DSR cycle may prove necessary from the analysis of the results of the evaluation phase to solve the identified research problem. Of course, in this evaluation of the artefact phase, the researcher needs knowledge of relevant metrics and analysis techniques that can be complemented and/or confronted by ground experience to consolidate or expend the evaluation.

3.2.3.6 Step 6: Communication

The final step closes the cycle when it has been confirmed from the above that the artefact solved the research problem. The researcher can then communicate on the relevance (utility and novelty) of the artefact, advocate the rigour of its design, and communicate on the effectiveness of the findings. Diverse audiences may find interest such as researchers in sake of growing future knowledge and professionals in search for applicable solutions to concrete problems they face (Peffers el al., 2007). Research papers commonly achieve this final step, as do lectures or conferences, sharing new knowledge with both the academic and professional worlds.

Ultimately, the research problem and its significance are exposed, and the artefact (innovativeness, effectiveness, design objectivity and usefulness) is made available to be challenged, criticised and, if possible, further developed by the research community.

Diverse audiences may find interest such as researchers in sake of growing future knowledge and professionals in search for applicable solutions to concrete problems they face (Peffers el al., 2007).

3.2.4 The case study approach

For Stake (1998), while it is tempting to consider the methods of investigation a crucial aspect of the research in case study research, is the case in question:

> *"As a form of research, a case study is defined by interest in individual cases, not by the methods of inquiry used."*

On the other hand, for some other researchers (e.g., Robert Yin (1994)), the method and the techniques that constitute the case study are of most importance. Yin (2003b) later refined his view of a case study as:

> *"an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident."*

Johanson (2003) completes Jin's view by restating that, unlike many research fields, in a case study several approaches are combined in pursuit of analysing the problem, investigating different facets and observing from different angles. Johanson (2003) sought to summarise the case study approach by a triangulation effort that combined several methodologies, some of which even being antagonistic.

3.2.4.1 Determining the study strategy

Architectural Research Methods (Groat & Wang, 2002) describes how research can be conducted in the field of architecture and the relationship between different strategies. They illustrated the similarities in a diagram, presented here, where the closer the approaches are, the more similarities they share (see Fig. 3.2). Starting from the real world, an "empirical world in full complexity", they propose three directions to follow. cases

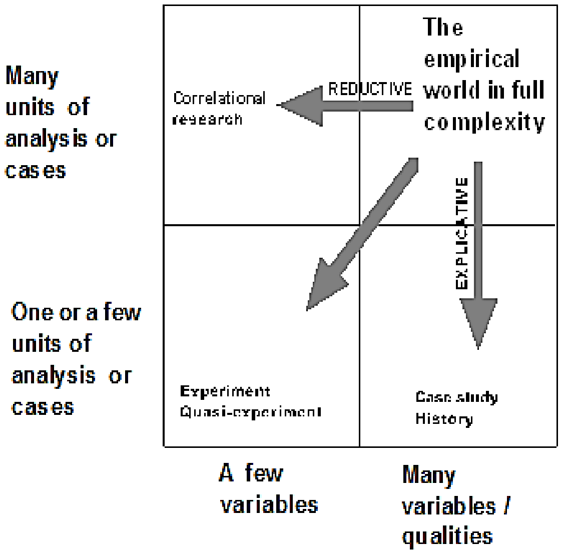


Figure 3.2.4-1 The empirical world in full complexity (Johansson, 2013).

The first method, if there are enough units of analysis or to allow a probabilistic approach, is reductive in that it would lead to correlational research.

The second method is relevant either when the researcher is left with only one or a small number of units of analysis or cases with few variables. In this latter case, the research would mainly be oriented toward experiment or quasi-experiment. The third method, explicative, is imposed when the researcher must cope with (too) many variables, making the case study approach appropriate. For Groat & Wang (2002), on the one hand, and although their timelines are different, both qualitative and interpretive research are based on a holistic approach to the research subject. On the other hand, despite the highly volatile level of quantitative data available to the researcher; qualitative and correlational research share the same focus on the analyse of the naturally occurring circumstances. When manipulating isolated variables (such as in simulation) is possible, the choice of an experimental approach is relevant. Johanson, (2003) supports the latter and argues that an interpretive-historical research approach is based on a structured logic of interpretation of the historical facts that is highly dependent on the level of data available.

From the above, the case study approach seems perfectly adapted to the present research. The case would be the building construction, enabling in-depth observation and analysis over a long period of time (two to three years). Triangulation would be made possible by analysing each block from a different angle, based on experimental and simulation and correlational strategies. Experimentation is intrinsic to the field of research that is investigated here, and the correlational aspect would be fed by the three-block scope of the study and the simulation by the planning, namely the forecasted site organisation.

Doing a case study allowed the documentation of an empirical investigation of a real-world and actual issue that could be observed within the professional environment of the researcher. These investigations helped me to attain the objectives of the doctoral research and answer the research questions posed by the problematic of the thesis. Based on Wedawatta (2013), Brady (2014) claims the following:

> *"a case study strategy will contribute to addressing the call for improved methodological pluralism in construction management research, enhancing*

the understanding of the complex network of relationships pertinent to the industry and the phenomenon being studied"

Johansson (2014) further argues that a case study approach is particularly appropriate in practice-oriented fields of research, such as architecture and planning.

Contrary to other fields where modelling and simulating is predominant, the construction-related field of research offers the possibility of impacting professional practice in real time, incrementally growing the knowledge by the construction of a repertoire of action-documented cases. Johansson's views support the argument in favour of a case study based on experimental strategy as the number of units in the cases was limited, and only a few variables were to be observed.

3.2.4.2 Determining the type of case study

Case studies have been categorised by Yin into three compartments: explanatory, exploratory and descriptive. In this categorisation, each category can be either single or holistic (i.e., involve multiple-case studies). Stake proposes three categories: intrinsic, instrumental and collective. Table 3.2.4-1 Definitions and published examples of kinds of case studies (Baxter 2008; Brady 2014).below presents definitions and published examples of these types of case studies (adapted from Baxter (2008) and Brady (2014)).

Type	**Definition**	**Published Study Example**
Explanatory	"Answering a question that sought to explain the presumed causal links in real-life interventions that are too complex for the survey or experimental strategies. In evaluative language, the explanations would link program implementation with program effects" (Yin, 2003).	Joia (2002). Analysing a web-based e-commerce learning community: A case study in Brazil". *Internet Research*, 12, 305–317.

Type	Definition	Published Study Example
Exploratory	"Exploring those situations in which the intervention being evaluated has no clear single set of outcomes" (Yin, 2003).	Lotzkar & Bottorff (2001). An observational study of the development of a nurse-patient relationship. *Clinical Nursing Research*, 10, 275–294.
Descriptive	"Describing an intervention or phenomenon and the real-life context in which it occurred" (Yin, 2003).	Tolson, Fleming, & Schartau (2002). Coping with menstruation: Understanding the needs of women with Parkinson's disease. *Journal of Advanced Nursing*, 40.
Multiple-case studies	"Exploring differences within and between cases. The goal is to replicate findings across cases. Because comparisons will be drawn, it is imperative that the cases are chosen carefully so that the researcher can predict similar results across cases, or predict contrasting results based on a theory" (Yin, 2003).	Campbell & Ahrens (1998). Innovative community services for rape victims: An application of multiple-case study methodology. *American Journal of Community Psychology*, 26, 537–571.
Intrinsic	"Stake (1995) uses the term *intrinsic* and suggests that researchers who have a genuine interest in the case should use this approach when the intent is to better understand the case. It was not undertaken here primarily because the case represents other cases or because it illustrates a particular trait or problem, but because in all its particularity and ordinariness, the case itself is of interest. The purpose is not to come to understand some abstract construct or generic phenomenon. The purpose is not to build theory" (although that is an option; Stake, 1995).	Hellström, Nolan, & Lundh (2005). "We do things together" A case study of couplehood in dementia. Dementia, 4(1), 7–22.

Type	Definition	Published Study Example
Instrumental	"This type aims to accomplish something other than understanding a particular situation. It provides insight into an issue or helps to refine a theory. The case is of secondary interest; it plays a supportive role, facilitating our understanding of something else. The case is often looked at in depth, its contexts scrutinised, and its ordinary activities detailed because it helps the researcher pursue an external interest. The case may or may not be seen as typical of other cases" (Stake, 1995).	Luck, Jackson, & Usher (2007). STAMP: Components of observable behaviour that indicate potential for patient violence in emergency departments. Journal of Advanced Nursing, 59, 11–19.
Collective	"Collective case studies are similar in nature and description to multiple case studies" (Yin, 2003)	Scheib (2003). Role stress in the professional life of the school music teacher: A collective case study. Journal of Research in Music Education, 51.

Table 3.2.4-1 Definitions and published examples of kinds of case studies (Baxter 2008; Brady 2014).

This research addressed real-life construction sites in which the researcher was professionally engaged and about which the researcher had a genuine interest in better understanding. The circumstances suggest that the appropriate type of case study would be intrinsic. However, if we consider that the case was comprised of three apartment blocks, that exploration of the differences within and between sub-cases (each apartment block) could be possible, and that replication of the findings across cases could be made, the appropriate type of approach would seem to be multiple case studies. In a multiple case study, one examines several cases to understand the similarities and differences between them. Yin (2003) describes how multiple-case studies can be used: a multiple-case study either (a) predicts similar results literal replication or (b) predicts contrasting results but for predictable reasons (theoretical replication). The types explanatory, exploratory, descriptive, instrumental, or collective do not seem appropriate here.

3.2.4.3 Generalising the findings

Once the case has been understood, the question of generalisation of the findings must be addressed. Depending upon the findings, the generalisation would either be made by dissemination via audiences or by intrinsic relevance. The audiences themselves can validate and generalise the findings of the case (those selected within a representational sample strategy used in correlational research (Stake, 1995; Patton, 1990)), or the generalisation can be intrinsically generated when a case is purposefully selected by virtue of being information-rich, critical, revelatory, unique, or extreme.

The case observed here was purposefully selected, as the property blocks to be built were a typical property development of standard apartments in a European capital suburb made by classically selected SMEs with no particular technical or architectural idiosyncrasies. Generalisation is expected to be validated through the intrinsic characteristics of the selected case. Generalisation can then be built on the deductive principle (i.e., a hypothesis is formulated, and testable consequences are derived by deduction), through induction (i.e., theory-generation based on the data of the case), or by abduction (i.e., through particular cases). Ginzburg (1989) refers to these kinds of generalisation as occurring within the evidential paradigm.

Procedure	**Mode of reasoning**	**Result**	**Generalisation**
HYPOTHESIS TESTING A theory (hypothesis) is tested in a case, and validated or falsified	Deductive	The establishment of the domain of the theory	From a hypothesis and facts to the validation of a *theory*
THEORY GENERATING A principle (theory) is generated from facts in the case	Inductive	A theory (Conceptualisation)	From facts in a case to *theory*
NATURALISTIC GENERALISATION An actual problem situation is compared with known cases	Abductive	Ability to act based on the conception of a case	From cases to a *case*
SYNTHESISING A CASE A case is synthesised from facts in the case and a principle (theory)	Abductive	The (re)construction of a case	From facts and a theory to a *case*

Table 3.2.4-2 Modes of generalization and reasoning within case study methodology (Johansson, 2012).

From table 3.2.4.2 in the previous page, two main generalisation approaches seem valid: deductive and inductive. The deductive approach has been considered appropriate since the research here aimed to test the applicability of the lean approach for the organisation (scheduling) of construction sites made by SMEs in mid-sized sites, and the inductive because the approach proposed to be tested is not yet a theory. In essence, the conclusion was unknown in the early stages of the research and, in a case study, the different modes of generalisation are often combined. Layder argues that theory-testing and theory-generating are combined in practice. He names this combined approach the *adaptive theory approach*. I shall retain the latter terminology, as it best fits the duality and complexity of the case study of the author of this thesis.

3.2.5 Discussion between action research and design science research

This chapter discusses the two mainstream approaches applicable to practically conducting the research in the context of the three-block site observed by the researcher.

Interest from scholars in the field of action research and design science, two main approaches in information systems, has been growing in the academic world. Although Kock and Lau (2001), Baskerville and Myers (2004), and Kock (2006) have provided legitimacy to action research, March and Smith (1995), Hevner et al. (2004) and others have proposed articulations of design research in information systems, hence the development of another (yet complementary) research approach. While action research has been the research approach when dealing with observing, modifying and learning from concrete actions in practical circumstances through iterative steps, design science has also emerged.

Action research and design research originate in different scientific traditions. Action research has mainly been pioneered in social science (Dewey (1938) and, later, Kurt Lewin (1947)). Design science, on the other hand, introduced the concept of *sciences of the artificial*, taken from engineering science (Simon 1996). Both traditions have found their way into the information systems discipline. Many authors have proposed attempts to understand the relationships between action research and design science, such as Burstein and Gregor (1999), van Aken (2004), Cole et al. (2005), Andriessen (2007), Lee (2007), Järvinen (2007), Figueiredo and Cunha (2007), Baskerville et al. (2009), Iivari and Venable (2009), Sein et al. (2011), Papas et al. (2012), Wieringa and Morali (2012), Alturki et al. (2012) and, more recently, Goldkuhl (2013), who proposed using practice as a lens for comparison and integration between action and design research.

3.2.6 Comparing action research with design science research

As Goldkuhl (2013) noted, it is interesting to note that action research and design science differ, and that even though some strong resemblances can be found (e.g. Cole et al., 2005; Järvinen, 2007), some researchers claim that the approaches are decisively dissimilar (Iivari & Venable 2009). Goldkuhl (2013) notes that others argue that the two research approaches have been integrated into a single, coherent approach (Lee 2007; Baskerville et al. 2009; Sein et al. 2011; Wieringa & Morali, 2012). Cole et al. (2005) and Iivari and Venable (2009) have proposed paradigmatic comparisons between action research and design science, while Järvinen (2007) has based his comparison on process descriptions.

Ivari and Venable (2009) have proposed a comparison between action research and DSR. They suggest there is more variety in paradigmatic assumptions in DSR than in action research and that, paradigmatically, action research can be considered a special case of DSR. They argue that, despite being unlike action research, DSR also builds new innovative artefacts, and that there is not necessarily any paradigmatic incommensurability between it and action research. Both appear to be mutually compatible. Further developments, based on Venable (2006) and Johnstone and Venable (2008), suggest that if the DSR activities of building an artefact and its evaluation are separate, a researcher can apply action research in the evaluation. Ivari and Venable (2009) propose the following table to classify action research and DSR:

Paradigmatic dimension	Action Research	Design Science Research
Ontology	Anti-realism	Realism or anti-realism
Epistemology	Mainly anti-positivist	Mainly positivist, but also anti-positivist, especially in evaluation
Methodology	Idiographic	Constructive (building) Nomothetic (evaluation) Idiographic (evaluation)
Ethics	Means-end Possibly interpretive Unlikely critical	Means-end Possibly interpretive Possibly critical

Table 3.2.6-1 Summary of the paradigmatic assumptions of action research and DSR (adapted from Livari & Venable, 2009)

3.2.6.1 Similarities

Based on a conceptual analysis, Järvinen (2007) argues that action research and DSR are similar approaches. He compares the previous work on action research from Susman and Evered (1978) and Nunamaker et al. (1991), and the work on design research from March and Smith (1995) and van Aken (2004). Searching for shared characteristics, he found seven fundamental similarities. Goldkuhl (2013) has proposed a categorisation of the similarities based on Järvinen (2007): (a) striving for utility, (b) producing useful knowledge, (c) combining building or acting and evaluation, (d) collaborating between researchers and practitioners, (e) aiming for development and improvement, (f) intervening in a local practice and (g) creating knowledge and testing it during the process.

The following table, adapted from Järvinen (2005), presents the similarities of the fundamental characteristics of action research and design science.

Action research	Design science
Action research emphasises the utility aspect of the future system from the people’s point of view.	Design science’s products are assessed against the criteria of value or utility.
Action research produces knowledge to guide practice in modification.	Design science produces design knowledge (concepts, constructs, models and methods).
Action research means both action-taking and action-evaluating.	Building and evaluation are the two main activities of design science.
Action research is carried out in collaboration between action researcher and the client-system.	DSR is initiated by those researchers interested in developing technological rules for a certain type of issue. Each case is primarily oriented at solving the local problem in close collaboration with the local people.
Action research modifies a given reality or develops new systems.	Design science solves construction problems (producing innovations) and improvement problems (improving the performance of existing entities).
The researcher intervenes in the problem setting.	DSR is initiated by those researchers interested in developing technological rules for a certain type of issue. Each individual case is primarily oriented to solving the local problem in close collaboration with the local people.
Knowledge is generated, used, tested and modified in the course of the action research project.	Knowledge is generated, used and evaluated through the building action.

Table 3.2.6-2 Differences between AR & DSR (adapted from Livari & Venable (2009) and Raimo Hälinen (2012))

After comparing the important characteristics (concepts and paths) of both action research and design science, there seem to be important overlaps and similarities in the two approaches. On this basis, Järvinen (2007) claims that action research and design science should be considered similar research approaches.

3.2.6.2 Dissimilarities

Unlike Järvinen, who conducted a conceptual analysis, Iivari and Venable (2009) conducted a paradigm analysis. Although they found some similarities, they argue that the similarities they found are superficial and that the two approaches are decisively dissimilar. Similarities and differences were found in their comparison, based on ontological, epistemological, methodological, and ethical assumptions.

They claim that there are no similarities between action research and design research in the cases of an action research case made with no technical design or a design research case with purely technical problem-solving or a design research case without any local practice intervention (Goldkuhl, 2013).

The aim of action research and design research can also diverge from study to study. While the major contribution of design research is to create new means for achieving some general (unsituated) goal and [while it] demands innovation and novel technology, action research seeks a general practical contribution and not for any local practice contribution linked to normal design practice.

Iivari and Venable (2009) conclude by orienting the design science toward the field of cutting-edge technologies and action research toward the field of safe solutions based on robust technology (Goldkuhl, 2013).

3.2.6.3 Combination of action and design science research approaches

Burstein and Gregor (1999) have proposed an analysis of the two approaches in relation to each other. Their case study was not conducted following the guidelines of action research or design science, but according to general scientific criteria. They introduced a new term of system development based on the terminology from Nunamaker et al. (1991) and concluded:

> *”The iterative nature of [system development] research, with the intention of generating new knowledge and improving social acceptance of the system under construction, makes it also quite distinct from computer science research, where the main purpose is the creation of new methods or programs – not the application of the methods in real-life”.*

While some authors claim that action research and design science are similar approaches (e.g., Järvinen, 2007), others claim that they are quite different (e.g., Iivari & Venable, 2009). Yet others, such as Cole et al. (2005), favour combining the two approaches rather than perceiving them as opposites. Based on a cross-criteria analysis, they compared design science criteria (from Hevner et al., 2004) and action research criteria (from Davison et al., 2004).

They discovered that, despite claims that the approaches were different, they fulfilled criteria from each other’s research approach. Cole et al. (2009) used a down-to-earth paradigmatic analysis and outlined an integrated research approach. They found that a common area could be found since ” the process models of both approaches are like a degree that we can form a common process model for them”.

Papas et al. (2012) experimented with the approaches. They conducted their study both from an action research and design science approach. The paradigm analysis of the two approaches revealed many similarities, but also some differences. In the light of this experience, Papas et al. (2012) claimed that it was possible and valuable to combine action research and design science and to use both criteria.

3.2.6.4 Integration of action and design science research

The above sections describe important similarities that have been found between action research and DSR and how several integrative approaches combining the two have been created. In the search for a combined approach, as revisited by Goldkuhl

(2013), Cole et al. (2005) proposed a four-stage process: (a) problem identification, (b) intervention, (c) evaluation and (d) reflection and learning, where intervention (Step 2) is a combination of action planning and action-taking (from action research) and building (from DSR).

Later, in 2007, Lee argued:

> *”action research and design science have the potential to bring about greater rigour and greater relevance by acting together than by acting alone”*.

Capitalising on the framework from March and Smith (1995), Lee (2007) combined the four types of activities and the four types of artefact, respectively build, evaluate, theorise, and justify with construct, model, method, and instantiation. The dialogical action research from Mårtensson and Lee (2004) helped him map on this DR framework and take a step forward from the previous publications by including theorise and justify in DSR, hence completing March and Smith’s (1995) and Hevner et al.’s (2004) work. Lee (2007) then separated the activities conducted by the researcher and the practitioner, claiming that the researcher should not be participating in the building of the instantiation.

Baskerville et al. (2009) later integrated action research and design research by combining them with another action research approach described by Checkland in 1981, soft systems methodology. The combination of specific problems and solutions, on the one side, and generalised problems and solutions, on the other, was tackled by problem-solving logic: from a specific problem to adaptation of specific solution through generalised problem and general design requirements and solutions.

A later development by Cole et al. (2005) has been proposed by Sein et al. (2011), namely an integrated approach: action design research (ADR), which further integrates intervention and evaluation. The inception of ADR is the formulation of an organisational problem to be treated by a research process that leads to the generation of design principles. Almost in parallel to Sein et al. (2011), Wieringa and Morali (2012) worked on a combined action research and DSR approach. Contrary to the above examples, which are mainly problem-driven, the main idea defended by Sein et al. (2011) is that it is possible to bring about concrete solutions through a researcher-driven approach working on an idealised design. Wieringa and Morali (2012) have proposed a new approach called technical action research. As Goldkuhl (2013) reminds us, this sort of research is based on two engineering cycles: (a) the artefact cycle, where a researcher aims at improving a class of problem through artefact design and a complementary empirical research cycle, and (b) helping a client by improving a particular problem. An empirical research cycle that aims at answering research questions through making investigations completes the approach.

While Sein et al. (2011) start with a problem to drive the research, Wieringa and Morali (2012) argue that technical action research is more appropriate when ” the researcher has identified a class of problems and aims to develop an artefact to mitigate those problems” (ibid. p. 234).

Goldkuhl (2013) capitalised on the previous work presented above and stated that, while DSR aims to create new and innovative ways of solving a class or classes of problems, and create a new reality, action research is primarily focused on understanding reality.
Goldkuhl et al. (2013) base their comparison analysis of action research and DSR on the model of DSR activities presented in Venable (2006) and *Framework and Context for design science research* (Venable, 2006) adapted by Jeffrey Bagraim.

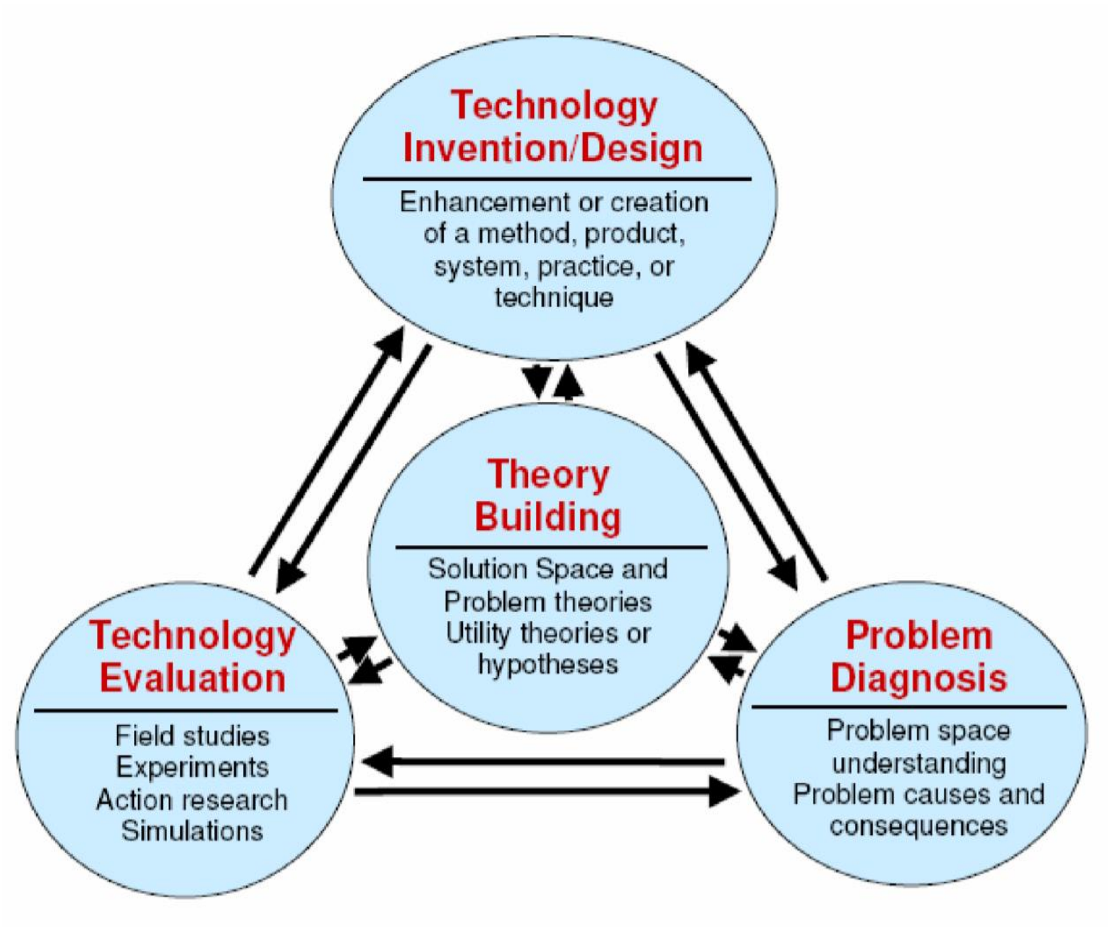


Figure 3.2.6-1 Framework and context for design science research (Venable, 2006). Adapted by Jeffrey Bagraim

From the above figure, Goldkuhl (2013) identified three different cases where action research and DSR have differing relationships with one another:

Completely non-overlapping: Action research is not concerned at all with the DSR interest of building and evaluating innovative artefacts. This situation may appear when solving the client's problem requires no technology and is possible through the application of existing solutions without innovation. This situation may also appear when design science research is applied to solve a purely technical or a socio-technical problem.

Slightly overlapping (using action research *to evaluate DSR):* This situation may appear if the researcher does not devote enough effort to defining and justifying the aim of his research (which should be to develop a new, innovative artefact or any solution technology) and when his activity could be considered as aiming to assess an existing solution. Then, it is tempting for the researcher to develop biased evaluations of the artefacts formerly developed by other researchers or practitioners.

Significantly overlapping (action research conducted with DSR): This situation may appear when a researcher is tempted to design innovative artefacts only to provide a solution to the client and solve the problem in general. In this case, the evaluation of the solution may be biased as it is only based on a specific environment where the evaluation of the results can be biased by a distortion in the measures of the reality.

Goldkuhl (2013) summarises the three cases in the table below:

Case	**Action research interest**	**Design science research interest**	**Design science research**
No overlap	"Understanding reality in an organisational context"	None	None
	None	"Solving a purely technical problem by developing and evaluating a new solution technology"	"Theory building, solution technology invention, and artificial
	None	"Solving a socio-technical problem in a non-action research context by developing a new solution technology, but evaluating it by means other than action research"	"Theory building, solution technology invention, and artificial or naturalistic evaluation, or both"
Slight overlap	"Evaluating an existing solution technology in an organisational context"	"Evaluation of a solution technology developed separately"	"Naturalistic evaluation only"
Significant overlap	"Solving a socio-technical problem by developing and a new solution technology and evaluating it in an organisational context"	"Solving a socio-technical problem by developing and a new solution technology and evaluating it in an organisational context"	"Theory building, solution technology invention, and naturalistic evaluation"

Table 3.2.6-3 Overlaps in activities between action research and DSR (adapted from Goldkuhl, 2013)

3.2.6.5 Problem-centred approach

The design science approach can be a nonlinear process that may evolve in different ways (Peffers et al., 2007). Research would start with a problem and begin at Step 1 in the case of a problem-centred approach, or if the research resulted from the observation of a problem (Peffers et al., 2007).

3.2.6.6 Design and development-centred approach

In the case of an objective-centred solution, the process could also begin at Step 2. The objective can emerge from a research or industry need that can be addressed by developing an artefact. Experience can also motivate a research idea concerning the processes of an artefact not yet formally contemplated as a solution for an explicit problem domain. For Peffers et al. (2007), this process is a design-and-development-centred approach.

3.2.6.7 Consulting or client context-centred approach

As Brady (2014) recalls, a client or context can also offer a practical solution developed in practice and proven to be effective. In this case, the researcher is working backwards to apply rigour to the process. (Peffers et al., 2007) proposes the following:

> *”A problem-centred approach is the basis of the nominal sequence, starting with activity one. Researchers might proceed in this sequence if the idea for the research resulted from observation of the problem or from suggested future research in a paper from a prior project. An objective-centred solution, starting with activity two, could be triggered by an industry or research need that can be addressed by developing an artefact. A design-and-development-centred approach would start with activity three. It would result from the existence of an artefact that has not yet been formally thought through as a solution for the explicit problem domain in which it will be used. Such an artefact might have come from another research domain, it might have already been used to solve a different problem, or it might have appeared as an analogical idea. Finally, a client/context-initiated solution may be based on observing a practical solution that worked; it starts with activity four, resulting in a design science solution if researchers work backwards to apply rigour to the process retroactively. This could be the by-product of a consulting.”*

3.3 Recent research into the search for consensus

Maccani (2015) advocates that DSR can assume a variety of positions, while action research is more limited in this way but can be applied as part of the evaluation stages of DSR projects. For Maccani (2015) action research can be a special case of DSR. The following chapter develops the above.

Maccani (2015) contributed to the ongoing academic conversation regarding the investigation on how to incorporate action in DSR. Maccani (2015) developed Ivari and Venable's (2009) contextualisation of Burrel and Morgan's (1979) paradigmatic framework to explore and understand the similarities and differences in the two methodologies at the philosophical level. Their conclusions are presented in the table below:

Paradigmatic dimension	Action Research	Design Science Research
Ontology	Anti-realism	Realism or anti-realism
Epistemology	Mainly anti-positivism	Mainly positivism, but also anti-positivism especially in evaluation
Methodology	Idiographic	Constructive (building) Nomothetic (evaluation) Idiographic (evaluation)
Ethics	Means-end Possibly interpretive Unlikely critical	Means-end Possibly interpretive Possibly critical

Table 3.3.1 Paradigmatic assumptions of action research and DSR

Maccani (2015) further expanded the paradigmatic framework with philosophical assumptions and showed that the same philosophical underpinnings were covered by action research and DSR. He suggests that action research can be considered to be a particular case of DSR, rather than a methodology close to it, considering the scope of action research projects, i.e. "building and evaluating ensemble IT artefacts" (Sein, 2011).

Maccani (2015) further develops, by extending Ivari and Venable's (2009) and points out that from ontological, methodological, and ethical points of view, the two approaches are very similar. The substantial difference comes from the epistemological difference between the two methods.

"Design Science aims at the design of general solution concepts which are applicable not just to a specific organisational context. In other words, in the so-called "build and then evaluate" path of Design Science, *the first stage involves a positivistic epistemology (especially in the engineering field), while anti-positivistic assumptions are likely to emerge when the artefact is instantiated. On the other hand, because of the nature of Action Research, the design process within it is more likely to have as underlying assumptions anti-positivistic positions. In fact, in a typical Action Research project, the problem as well as the artefact are conceived from the point of view of the individuals who are directly involved in the activities which are to be studied. Thus, the design stage (or stages) is (unlike Design Science) underpinned by anti-positivistic paradigmatic assumptions. The positivistic side of the methodology emerges in both the ongoing Reflection and Learning stage, and the Formalisation of Learning one, when the specific organisational-related solution is related to a broader class of solutions, or, in other words, to a generalised outcome. We believe that an explanation for this epistemological difference that exists between Action Research and Design Science is given by the different role that the organisations play in the two approaches. In detail, while in Design Science the organisational intervention is considered secondary, in Action Research projects the organisation is part of the Design Science team since the beginning and the design process is highly participatory. As a result, the ADR artefact is 'socially constructed', thus not consistently with positivistic epistemology."*

3.4 Conclusion

At this point, it appears that, regarding the boundaries and similarities of action research and DSR, research and discussions have been long ongoing in a search for a consensus. The essence of the research and approach driven by the client or by the researcher, or both, can be oriented differently. In the case of this research, action research and design science approaches have been applied at different stages of the project (block 1, block 2 and block 3) depending on the specific context of the research and on the understanding of the project at each stage of it.

3.5 Justification for the choice of research method

In 2007, Peffers et al. argued that that the application field of DSR was broad and that its problem-solving approach could be adopted for a research study in various ways, dictated by the client context, and mainly centred on a problem or on an objective or on a design issue.

Sever critics then arose in the academic world regarding research in construction management (Azhar et al. 2009; Alsehaimi et al. 2013) . Both considered the approach to be too descriptive and explanatory because of the use of quantitative surveys or case studies. Managerial problems experienced in construction should not be addressed with tangible and applicable answers. Taking this objection into account, it became important that the output for a piece of so-called action research would be applicable to the gemba and grounded in practice. That the implementation of the solution should be developed in relation to the practical world was an initial given in the choice of the research method.

The main weakness in recent studies such as by Macconi (2015) and Alsehaimi et al., (2013) is the lack of concreteness in the solution proposed by the researchers. Although planning and control are often found to be ineffective, and solutions are only partially (if simply not) recommended, the necessary tools needed to overcome the problem fail to be proposed or investigated thoroughly enough.

It has long been argued that existing approaches need to be developed and completed to strengthen the link between the research and practical worlds. Although there is no doubt that developing a theory that should then be tested and confronted by reality to extract outputs and build knowledge is needed, the research could more deeply focus on the applicability and validity of the output that is allowed by DSR, in addition to the historical approaches (Simon,1969, 1996; Simon 1973; Klahr & Simon 1999; Holmström 2009).

Thus, to fit the client context of the research and ground it in the practical world, but also to develop a site-based output that would be as applicable and as duplicable as possible, design science was also adopted for this research. As a pioneer in consultancy activities, specialised in lean applied to the construction industry with the aim of reducing delays and costs by creating reliable and stable production flows on site, the researcher has developed a first version of an improved approach.

According to Peffers et al. (2007), the identification of a problem should be the starting point of a DSR approach; however, developing and applying a solution in practice could also be considered a research study. The initial research cycle was used to validate the capacity of the researcher to conduct site research, capture results, and identify new issues that would lead to the next research cycle in the queue. The initial problematic (client need) was to improve daily planning and control of the construction works.

Iterative improvements in weekly and daily planning were captured in the first research cycle that comprised of the implementation of LPS on site, which allowed the development and the application of new approaches within the context of this PhD. Similar to Brady (2014), who also worked for a consultancy practice on the development of a tailored site-based approach for their client; the researcher has worked backwards to apply rigour to the process:

> *"Design science can result from the existence of an artefact that had not yet been formally thought through." (Peffers et al. 2007, p. 14).*

The three case studies and the action cycles undertaken in this research took four years to present, analyse and evaluate and for the outputs to be further developed to determine and validate the contribution to practice and theory. The development of the research on site required rigour and the frame provided by action research was particularly adapted to ease this and initiate the research cycles on block 1. However, given the nature of the consultancy and the need to bring a concrete answer to the client, the research cycles were adapted to DSR from block 2.

The above advocates action research and DSR as both rigour and output provider approaches; while action research focusses on the rigour the researcher should follow, design science emphasises the applicability of the output. Again, the design-science approach has been chosen for block 2 out of respect to the nature of the research. As with Brady (2014), the present research aims to provide a clear and practical solution to be applied on site. In this case, a large body of literature (March & Smith 1995; Lukka 2003; Hevner et al. 2004; Van Aken 2004; Venable 2006) is in favour of applying design research as Brady (2014) did, whose aim was to “improve current practice in production planning and control and to clarify the theoretical significance of this solution”.

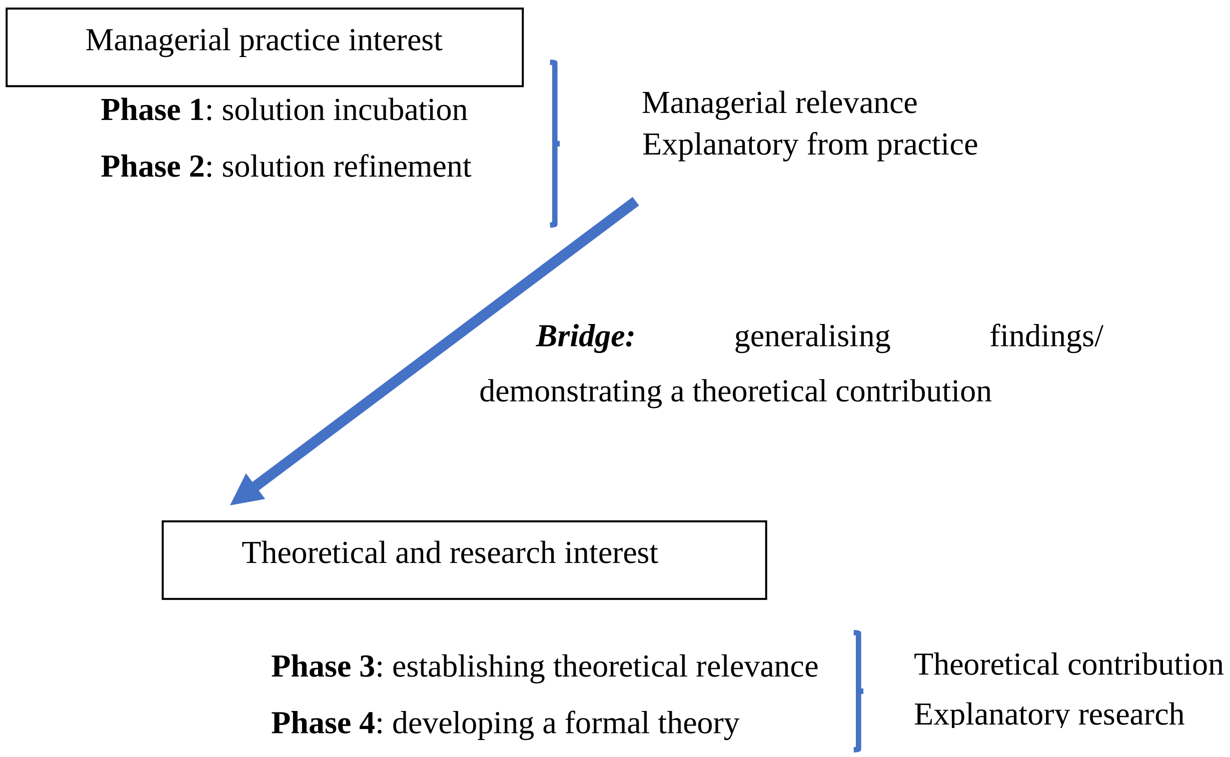
Focus on Design Science: an attempt to bridge academia and the practical world

Design science has ambitions to provide academic research with theoretical understanding and practical outputs that the practical world could apply and that could be pulled from it by extending practical solutions. It seeks a stronger alignment between the theoretical and research interests and the interests of managerial practice (Holmström & Ketokivi, 2009; Lukka, 2003).

As developed in the above paragraphs and chapter, design science focusses on changing the practice world by addressing real, identified and quantified problems. Design science brings prescriptive answers to these artefacts, once the theoretical significance of the problem and its solution has been validated, and then develops research to build current knowledge (March & Smith 1995).

Holmström and Ketokivi (2009) observe that design science links practice to theory, not the reverse, to actually ground the research in the practical world. This can be summarised by 2x2 research phases: solution incubation and solution refinement, which are explanatory from practice, and establishing theoretical relevance and developing formal theory, which are explanatory research. An issue stands in the fact that addressing a practical world-based issue that is shared by a professional (or a client, as in this research) cannot necessarily be a contribution to the body of knowledge.

The graphic below illustrates how Holmström and Ketokivi (2009) emphasised the importance of linking phases 2 and 3 in the path from phases 1 to 3, leveraging theory from practice.



However, despite ambitious initiatives in recent years in the academic world, providing academic research that would be relevant, usable and duplicable to the practitioners remains elusive (Holmström & Ketokivi, 2009).

3.6 Proposed method: multiple-case study from design science research

From the above sections, it clearly appears that finding the most appropriate method can prove difficult given the wide range of situations, contexts, objectives, and the vision of the research. The present research is neither solely a case study, as the position of the researcher as a consultant requires me to act on site, nor is it solely an exercise in action research, as the theoretical part of the findings should emerge from the analysis of the case. The ambition of this research is to test the applicability of a new flow theory in the construction industry and draw conclusions from the research approach used.

It is proposed in this thesis to build a case study by following action research and design science approaches on site to develop and experiment with a new flow theory in the 3-block building project before validating and generalising a new theory. The figure below illustrates the duality of the research.

"Experimental Multiple Case Study" (Longitudinal): cycle of learning

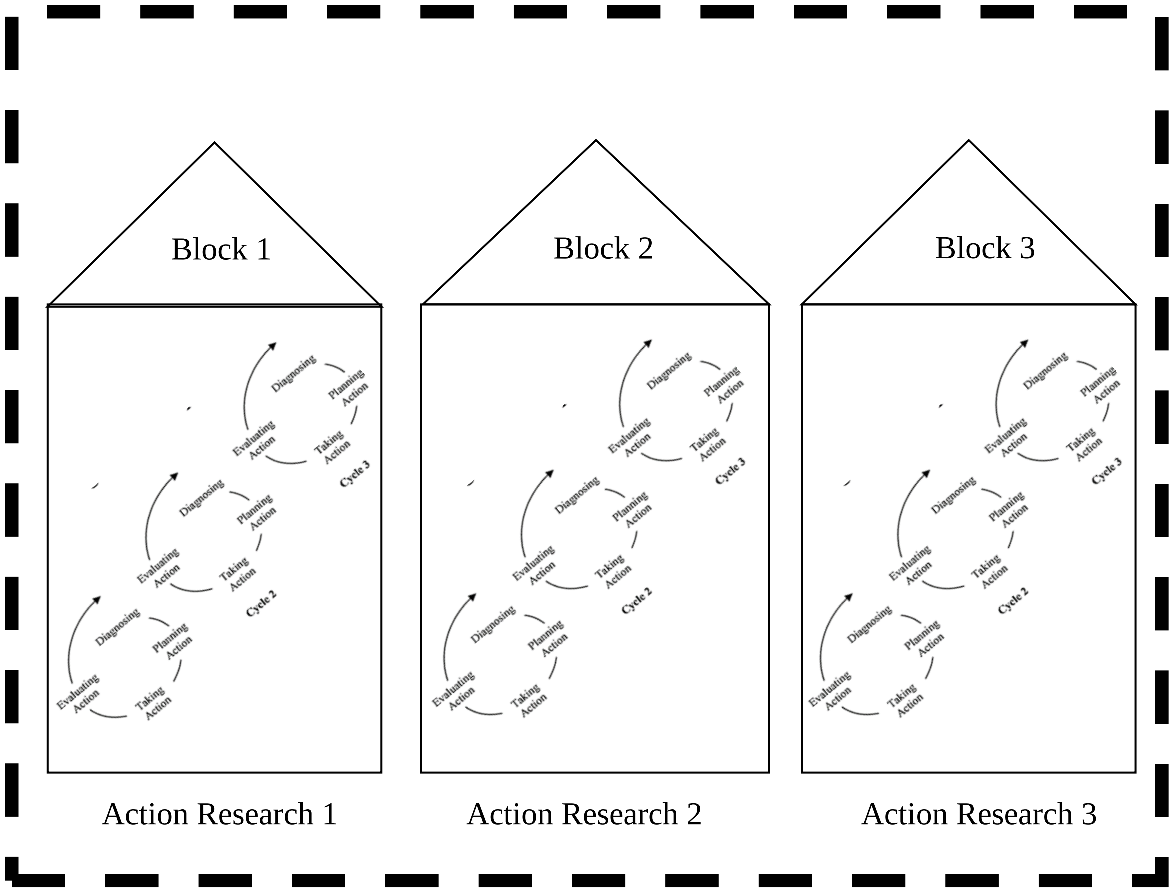


Figure 3.2.6-1 Representation of the action and case study research building, adapted from the spiral of action research cycles (Coghlan & Brannick 2001).

3.7 Data collection

Data were regularly collected during the research from different sources: workflow indicators, documentation, semi-structured interviews, and direct and participant observation.

3.7.1 Workflow stability indicators

Measuring the workflow stability (or reliability) on the construction site has been done by evaluating the PPC on a regular basis.

3.7.2 Documentation

Documenting a research thesis is core to a researcher's doctoral journey. In finding various sources of data to aliment the research, diaries, letters, agendas, minutes of meetings, personal notes, field notes and reports, images, sounds and objects, and computerised records may be investigated (Bryman 2001; Yin 2003; Finnegan 2006). Once gathered, the researcher must then cross-check the information, validate the pertinence of the data to the research field and explain how the retained documents are appropriate through corroboration (Yin 2003).

The documentation used in this research was as follows:

- diaries recording the on-site situation and difficulties; weekly observations and recollections (from workmen and foremen) of the work done, of how it had been completed, and of difficulties met in fulfilling the job (planning not addressed at this point, focus is on the output).
- agendas covering the main interior construction milestones (slab casting, window installation and waterproofing, plastering and equipping); initial and revised master plans, detailed works planning "as is" at the beginning of the research. No judgement was made or shared at this point to avoid biasing the perception of the documentation provided.
- minutes of site meetings (including PPC): measuring the progress and works promises on site from one week to the next. Understanding the root causes of delays and difficulties met on site.
- personal and field notes of actions taken: keeping a weekly log of the actions asked, realised, and their impact as measured on site on the progress rate, promise reliability, stress level.
- images and computerised records: keeping a weekly tangible record.

3.7.3 Semi-structured interviews

Initiated once the measures had been taken on site, this part of the research comprised interviews with the site management team (site foremen and team leaders) about their understanding of the approach developed and of the effect they felt and had measured at their level. An interview can be viewed as a managed verbal exchange where all communication biases, from the thinking of the idea to the understanding of the message through the expression of the message, the medium used to the reception and treatment of the message in context, can significantly affect the output (Ritchie & Lewis 2003; Gillham 2000). Hence, the effectiveness of an interview can largely depend on the communication skills of the interviewer (Clough & Nutbrown, 2007). In order to capture valid information, the ability of the interviewer should be developed around being able to:

- pause, probe or prompt appropriately (Ritchie & Lewis, 2003, p. 141);
- clearly structure the questions, (Cohenet et al., 2007);
- listen attentively (Clough & Nutbrown, 2007);
- encourage the interviewee to talk freely, to ”make it easy for them to respond”

3.7.4 Observation

Hancock (1998) describes observation as a technique that can be used when data collected through other means may be of limited value or is difficult to validate. Observation can be further defined as a systematic method of data collection that relies on a researcher’s ability to gather data through his or her senses (O’Leary 2004). Hussey et al. (1997) and Saunders et al. (2007) divide observation into two categories: direct (non-participant) and participant.

In direct observation, people or experiments are observed and recorded while the researcher’s role is only to be an observer, as is often the case during a site visit.
In participant observation, observing and recording are not enough. The researcher could be involved in the field and may even have interactions with the subjects observed and, thus, interfere with the situation being observed (Yin 2003; Easterby-Smith et al., 2002; Bryman, 2001).

4 Research processes

While Chapter 3, *Research methodology*, presented the choice and justification for the methodology to be followed in the context of this research, this chapter presents the research process followed by the researcher from the diagnostics of the actual state through to the formalisation of the research process.

Chapter 4, *Research processes*, describes the process as follows:

- Section (4.1), Problem diagnostic and , introduces the problem
- Section (4.2), *Evaluating the action*, explains how the action can be evaluated from a doctoral research point of view
- Section (4.3), *Formalising the research process*, closes the chapter and proposes a step-by-step process to duplicate the path initiated by the researcher in the field of this research

The research covers a 3-year period involving the construction of a 3-block project of a total of 144 apartments; Each block is considered to be a separate case study. The blocks are named block 1, 2 and 3, in chronological order.

4.1 Problem diagnostic and development

This section presents the problem upon which the research is grounded and how the it has been refined and the solution built into the frame of doctoral research. The difficulty of being both a consultant and a researcher in this context has been developed in (3.2.1), *The action research approach (differentiated from consultancy)*. The process of structuring the research started with defining the problem. The client (developer) appointed the researcher on a lean construction consultancy contract. The aim of this mission was twofold. It was not only to improve the scheduling system and provide different output (100% of the previous blocks of the previous phases of this 10-year project where delivered 12% to 18% late according to the initial contractual programme) but also to improve the quality of the works delivered by the contractors (15 snagging works were noticed at the delivery of apartments to their owners).

Although the delivery of the works fulfilled the construction classics, both in terms of completion delays and snagging works (common standards for this do not exist in Belgium), the client had ambitions to change the current state and improve their process in the course of this consultancy mission. The client accepted that the researcher could ground his research in this context so that the method could be formalised, the output duly measured, and the process replicated in future projects. The agreement made the researcher totally free regarding the approach to be implemented, the tools to be developed and tested and the data to be collected and then shared in the context of a doctoral study that would lead to a PhD thesis.

It is to be noted that full support was then provided by the client in the path followed and in communicating the importance of changing the system in the first months of the mission. Looking back, in the light of the entire 3-year process of the research, the researcher believes that this initial support and positive communication facilitated much of the application of the first tool (the weekly work plan); at least, this was so in the initial adoption of the tool by the contractor. Because literature on the topic of the success factors relating to lean construction approaches is scarce (Nelder (2006); Ward (2015); Davies (2002); Cano (2015)), further research would be needed on the initial conditions of success in the context of SMEs in small real estate sites to validate the researcher's post-research intuitions.

Once the problem was identified, in general terms, from the initial discussions with the developer, the researcher had to investigate it in practice and grow his understanding of it . Although each situation is unique, it was possible, through reading the literature related to the problem, to refine it, develop it and then test solutions. The effects of the solutions in resolving the problem were later measured. However, before that, the next loop of iterative improvement processes had been carried until a satisfactory improvement level been reached (in relation to the aim of the client).

The first task the researcher was given was to provide a diagnostic of the current situation. This analysis was made on the first building block, where the works had already started, in the form of identifying any waste and starting a waste reduction journey, as described in the TPS, with the aim of improving the construction processes and generating tangible impacts (collateral effects) on safety, on-time reduction and quality improvement.

The research process began with an initial search of a solution to a problem perceived in practice: the site works were highly unstable and desynchronised, and there was little evidence of the structural work schedule. A deeper understanding of the practical problem was the first step of in Case Study 1, so to speak. As a consultant, I was called upon to provide immediate solutions to immediate issues. As a researcher, however, I had to make the switch from consulting to consider the distinctness and causes of the problem from a theoretical perspective. The theoretical part was to be investigated in the existing literature.

At the time of the inception of the research, Hamzeh et al. (2009), Björnfot (2012) and Zimina et al. (2012) had already pointed out that there was a lack of research in the application of lean construction in SMEs. Alves et al. 2012 and, later, Tauriainen et al. (2016) argued that it was down to the LC community to draw attention to SMEs by demonstrating successful business cases and diffusing the mechanisms for LC at SME level. Other authors later claimed that special attention should be given to SMEs given the lack of lean construction (and BIM) literature from the SMEs perspective (Upstill-Goddard et al. (2016); Dainty et al. (2017); Lam et al. (2017); Tezel et al. (2018)).

Tezel et al. (2019) had been first to perform a systematic literature review on lean construction and BIM in SMEs. They pointed out that:

- There was no significant difference between the UK, Swedish, Italian, American, and Brazilian research in terms of research with SME and lean construction focus.
- An overwhelming majority of the publications on SME and LC are concerned with construction SMEs rather than design SMEs.
- The current discussion on LC adoption from the design SMEs’ perspective is very limited.

- Almost one-half of publications have been presented at the IGLC annual conference and through the Lean Construction Institute's Lean Construction Journal.
- The LC literature that exists mostly overlooks organisational, procurement, training, and project governance-related parameters in LC implementations (Green et al. 2005; Jørgensen and Emmitt 2008; Alves et al. 2012; Wandahl 2014; Cano et al. 2015).
- Discussions concerning LC training and diffusion mechanisms at SMEs are currently very limited.
- There are only a few pieces concerned with the theoretical exploration of LC and SMEs.

Hence, at the beginning of the research in 2013, only a limited amount of information was found in the residential development field made by SMEs to gain a deeper understanding both problem and of the theoretical background that could provide a basis for addressing it. The issues, problems, and solutions applicable to a large hospital project in California erected by multinational lean leader construction companies had some limited applicability to the small 35-apartment block development in a Brussels suburb, made by small SMEs who had never heard about lean construction. This was the basis of Case Study 1.

The literature review focused on the principle of flow stability, scheduling, lean production, lean construction, and the deficiencies of classical project management.

Once the problem had been duly identified and its effects measured, Step 2 consisted of defining the objectives of a solution that could be implemented; in other words, the expected results or effects of Step 1. The data gathered in Step 1 were reviewed and analysed. This step was necessary to detail how the objectives for a solution were expected to afford concrete answers to the problems observed in practice. Reviewing the important concepts in the literature and drawing on the researcher's practical experience with the application of lean tools and flow production tools developed prior to the current research helped to refine the possible objectives and solutions.

The main objective of the research was to stabilise production flow on site, and to seek a reduction in delays, perceived stress, and costs, together with an increase in motivation, quality and health and safety.

4.2 Evaluating the action

While Section 4.1, *Problem diagnostic and development*, developed the context and the formalisation of the problem, this section focusses on how the action can be evaluated.

After the action research is completed, it is crucial to determine whether a real-world problem has been solved and assess what impact has been created by the implementation of a new artefact. The researcher can then estimate the contribution from both practical and theoretical points of view (Lukka, 2003).

In order to validate the value of new artefacts and benchmark the new solution to existing solutions and ideas, Kasanen (1986) proposes three market tests: weak, semi-strong and strong. A market test is considered weak if the interest of the practitioners is solely based on the results that the solution has achieved. A market test is considered semi-strong on the basis of how much the adoption of the artefact within the companies has been spread. A strong market test reflects how the results have been improved in practice by the companies that systematically applied the artefact in comparison to those who have not. As Brady (2014) outlines, the benefit of evaluating the model across the research is twofold:

- to contribute to the development of the model and ease further development, and
- to validate the practical applicability and industry effectiveness of the model (i.e., the market testing of the artefact). In this way, both formative and summative evaluations are achieved.

Smithson and Hirschheim (1998) and Remenyi (1999) later identified the two most important antagonistic approaches to evaluating DSR: formative and summative evaluation on one side, and *ex-ante* or *ex-post* evaluation on the other. These approaches were later developed by Stefanou (2001), Irani and Love (2002) and Klecun and Cornford (2005). Remenyi (1999) categorised the distinctions between approaches and techniques. For Remenyi, an approach can be either quantitative or qualitative, and a technique can either be subjective or objective. Categorising both approach and technique helps to define evaluation in the following ways: (a) why to evaluate, (b) when to evaluate, (c) how to evaluate, and (d) what to evaluate (from Stufflebeam 2003).

Peffers (2008) summarises the choices of evaluation methods and argues they should be driven by the nature of the artefacts: particular artefacts lend themselves to evaluation by particular methods:

Logical argument	**"An argument with face validity"**
Expert evaluation	"Assessment of an artefact by one or more experts (e.g., Delphi study)"
Technical experiment	"A performance evaluation of an algorithm implementation using real-world data, synthetic data, or no data, designed to evaluate technical performance rather than performance in relation to the real world"
Subject-based experiment	"A test involving subjects to evaluate whether an assertion is true"
Action research	"Use of an artefact in a real-world situation as part of a research intervention, evaluating its effect on the real-world situation"
Prototype	"Implementation of an artefact aimed at demonstrating the utility or suitability of the artefact"
Case study	"Application of an artefact to a real-world situation, evaluating its effect on the real-world situation"

Logical argument	**“An argument with face validity”**
Illustrative scenario	“Application of an artefact to a synthetic or real-world situation aimed at illustrating the suitability or utility of the artefact”

Table 3.7.4-1 Summary of the choices of evaluation methods (adapted from Peffers, 2008)

Venable (2012) insist on the importance of the evaluation phase to achieve rigour in DSR. He points out that there is little guidance concerning formulating the evaluation activity of DSR. He proposes an extended framework of DSR evaluation which he coupled together with a DSR design to guide design science researchers in the choice and justification of the evaluation phase. The DSR researchers can now validate both designs (artefacts and theories) in the production of output.

Venable (2012) capitalises on Pries-Heje et al. (2008), who proposed a strategic DSR evaluation framework comprising a simple but efficient 2X2 framework. This table provides strategies for evaluation in DSR and helps the researcher choose between them.

The researcher should choose whether the evaluation should be made based on an artificial or naturalistic approach, and then whether the evaluation is made *ex-ante* or *ex-post*. An *ex-post* evaluation relates to an instantiated artefact (i.e. an instantiation) and *ex-ante* to an instantiated artefact such as a design or a model as presented in the following page.

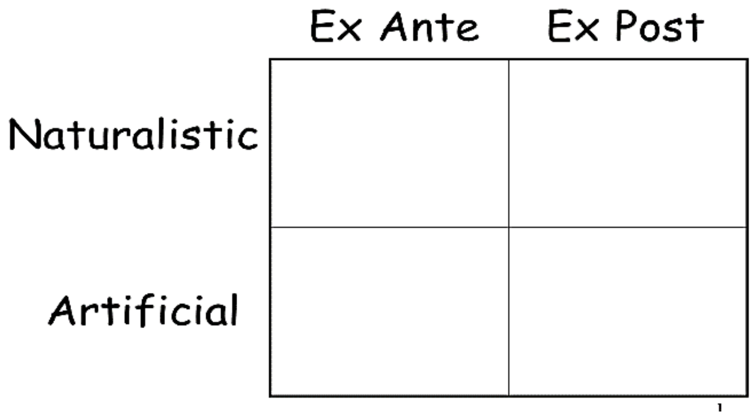


Figure 3.7.4-1 Research Quadrants (Venable, 2012)

(1) The distinctions of *ex-ante* versus *ex-post* and artificial versus naturalistic evaluations reflect a variety of ways in which evaluation might be conducted.
(2) *Ex-ante* evaluation is possible without building an instantiation of an artefact (at least, initially).
(3) Artefact evaluation in artificial settings could include imaginary or simulated settings.
(4) Naturalistic evaluation can be designed by choosing from among multiple realities and multiple levels of granularity for measurements or metrics.
(5) Multiple evaluations, combining multiple evaluation strategies, may be useful.
(6) The specific evaluation criteria, measurements, or metrics depend on the type of artefact (product or process) and the intended goals or improvements.

Venable (2012) later proposed a four-step method for the evaluation research design of DSR: first, analyse the requirements for the evaluation to be designed; second, map the requirements to one or more of the dimensions and quadrants in the framework using Figure 4.2-1; third, select an appropriate evaluation method or methods that align with the chosen strategy quadrant(s) using Figure 4.4.1; and fourth, design the evaluation in more detail.

(1) Analyse the context of the evaluation - the evaluation requirements.
   - "Determine what the evaluands are: concepts, models, methods, instantiations,

or design theories, or some combination.”

- “Determine the nature of the artefacts or evaluands. Are the artefacts to be produced products, processes, or both? Are the artefacts to be produced purely technically or socio-technically? Will they be safety-critical or not?”
- “Determine what properties need to be evaluated: Which of these (or other properties) will be evaluated? Does utility or effectiveness, efficiency, efficacy, ethicality, or some other quality (and which) need to be evaluated?”
- “Determine the goal/purpose of the evaluation. Will a single or main artefact be evaluated against goals? Does the developed artefact need to be compared against other artefacts?”
- “Identify and analyse the constraints in the research environment. What resources are available: time, people, budget, research site, and so forth? What resources are in short supply and must be used sparingly?”
- “Consider the required rigour of the evaluation. How rigorous must the evaluation be? Can it be just a preliminary evaluation, or is a detailed and rigorous evaluation required? Can some parts of the evaluation be done following the conclusion of the project?”
- “Prioritise the above contextual factors to determine which aspects are essential, more important, less important, nice to have, and irrelevant.”

(2) “Match the needed contextual factors (goals, artefact properties, etc.) of the evaluation (from Step 1) to the criteria in Figure 2, looking at the criteria in both white portions relating to a single dimension and the blue areas relating to a single quadrant. The criteria statement that matches the contextual features of the DSR project will determine which quadrants apply most or are most needed. It may well be that more than one quadrant applies, indicating the need for a hybrid-methods evaluation design”.

(3) “Select the appropriate evaluation methods from those listed in the selected, corresponding quadrants in Figure 4.1-2. If more than one box is indicated, selecting a method present in more than one box may be helpful. The resulting selection of evaluation methods, together with the strategies (i.e. quadrants), constitutes a high-level design for the evaluation research.”

(4) “Design the DSR evaluation in detail. An *ex-ante* evaluation will precede *ex-post* evaluation, but more than one evaluation may be performed, and more than one method used, in which case the order of their use and how the different evaluations will fit together must be decided. Also, the specific detailed evaluations must be designed (e.g. design of surveys or experiments). This generally will follow the extant research methods literature.”

Venable, Pries-Heje and Baskerville (2015) further developed and refined the above evaluation models into what has been called the framework for evaluation in design science. This framework aims to:

> *“guide design science researchers in developing a strategy for evaluating the artefacts they develop within a DSR project.”*

Evaluation can be achieved by following the four steps below (from Venable, Pries-Heje and Baskerville (2015)):

1) “Explicate the goals of the evaluation
   - “Rigour: It is essential at the beginning of the evaluation strategy to check that it is the artefact, and only it (the instantiation), that causes an observed outcome (artificial evaluation), and that the artefact instantiation works in a real situation (naturalistic evaluation).”
   - “Uncertainty and risk reduction: Risks may originate from different factors, such as human or technical error. Formative evaluations should be conducted as early as practicable to identify the difficulties and areas for improvement to influence and improve the design of the artefact. Higher quality artefacts (more effective, efficient, etc.) can hence be attained.”

- “Ethics: The evaluation should address potential risks to animals, people, organisations, or the public, including future generations. Summative evaluation is the best way to ensure the rigour that reduces risk to the eventual users of the artefacts and knowledge resulting from DSR.”
- “Efficiency: Efficient evaluation represents a trade-off between high levels of rigour, low risk and high ethics on the one side, and the resources necessary to meet the artefact (financial and temporal) on the other. A naturalistic evaluation is more often less efficient than an artificial evaluation, and non-empirical (artificial) evaluation approaches generally need the fewest resources.”

2) Choose the evaluation strategy or strategies for the evaluation, including:
   - Evaluation and prioritisation of the design risks, and understanding of the potential problems that the design may face;
   - Evaluation of the costs of using real users and systems in the setting;
   - Evaluation of the category of the artefact (e.g. technical, not used by or affecting people) or whether the need or problem addressed by the design exists today or will only be relevant in the future; and
   - Evaluation of whether the construction of the design is small and simple or large and complex.

3) Determine the properties to evaluate, including:
   - *Framing* of potential evaluands;
   - Alignment of candidate evaluands with the goals explicated in Step 1;
   - Alignment of evaluands to the chosen strategy; and
   - Choice of evaluands based on the above heuristics.

4) Design the individual evaluation episode(s), including:
   - Identification and analysis of the constraints in the environment;
   - Prioritisation of the above to contextual factors; and
   - Decision on a plan.”

4.3 Formalising the research process

While Section 4.1, *Problem diagnostic and development*, developed the context and the development of the formalisation of the problem and Section 4.2*, Evaluating the action*, focused on how the action was evaluated, this section provides the reader with a synthesis of the steps that have been followed in the research.

The link with the related section from this thesis eases the reading process and the understanding of the path followed from step 1 to step 10 so that the approach developed in the thesis can be replicated. This slightly differs from the actual path followed by the researcher as it has been formalised after the research having been undertaken considering the experience gained by the researcher throughout the research.

The following steps need future research and on-site implementation so that the proposed approach can be refined, improved and developed.

The following steps provide a formalisation of the experience of the researcher in the hope of easing a future researcher's work with SMEs in the same context.

1.	Identify the problem of the research

The need for research or application of a new approach must be validated. This first step helps to get the sponsor on-board. The path is long and requires support. See 5.2 Problem of the practitioner (a real estate developer)

2.	Validate the real engagement to change the system

A sponsor alone, even the client, is not sufficient to impact the production site in the context of SMEs. It is important that most (if not all) of the team gets engaged in the search for improvement. In the context of the research, this step has been made later in the process to avoid offending the feelings of the site crew. From the experience gained, it is proposed to validate engagement as early as possible; this phase can be related to the "elimination of burdens" in *The Machine That Changed the World* (Daniel T. Jones and Daniel Roos 1990). See 6.1.4.3 *Creating a sense of urgency and engaging the crew*.

3. Diagnose the situation

From perception to improvement, by measuring the actual situation. On the basis of “bad news early is good information”, a measurement of the actual situation helps lower passions and human perception bias. See 6.1.2 *Diagnostics: clarification of the problem*.

4. Create a favourable environment

From the researcher’s experience gained through this research, the application of a 5 S approach (see 6.2 5Ss on site: development of research Stage 1.2) is a must as the first operational step. The actual action research started with the implementation of the LPS as a scheduling tool. It is proposed to move to this step after the site has been made more readable and organised, not to mention H&S approved, by the application of 5S to maximise the tangibility of the results of the following steps.

5. Create a learning process with the application of the LPS

Through the implementation of a weekly work plan, the focus can be made on the flow of works and on the weekly engagement with the shop floor and on understanding the actual difficulties by measuring the scheduling performance on site. Learning from mistakes becomes a weekly routine and an improvement approach can be promoted. See (6.1) Beginning with LPS: development of research Stage 1.1 . This step was undertaken first based on the experience gained in this research; it is proposed to first start with 5S and then to focus on the scheduling.

6. Make tasks and activities ready

Once the environment on site has improved and is readable and the schedule is stabilized, the tasks or activities comprising the schedule must be thoroughly anticipated and prepared. The application of a make-ready approach helps stabilise the schedule by reducing the probability of making do on site from lack of resources. See 6.3 Focus on make ready: development of research Stage 1.3. The importance of a rigorous spatial organisation and procurement routine is highlighted by the implementation of the approach.

7. Design and technical improvements

When procurement and production flow on site have improved through the steps below, if the technical possibility still exists, the design can be questioned from an operational point of view See 7.1 Raisers technical improvements: development of research Stage 2.1. From the experience gained from this research, the importance of improving the design is crucial not only to ease the work of the workmen but also to get the engineers, architect and the client on board and be part of the solution. The effect of seeking improvements in the drawings destabilised a team that was not used to being questioned. The crew mentioned in step 2 Validation of the real engagement to change or make the system evolve is consequently enlarged for a larger effect.

8. Create a steady production pace

The adoption of takt time coupled with kanban helps maintain a controlled flow of work that can be designed to be as steady as possible in a search for the stability of production on the site. See 7.3 *Takt planning:* Development *of research Stage 2.3* and 8.1 Human *factor bias: introduction of discipline* and kanban, respectively.

9. Stability indicators (index) and learning

Improvements in the production flow can then be better followed and more precisely measured. Weekly physical progress is a simple and immediate measure that can be initiated on site. The exploitation of these measures provides tangible insights into the works stability. See 7.2.3 *Developed solution – weekly progress stability indicator*. The effects of the actions on site can then be better followed up and the learning curve can be fed by the feedback.

10. Prepare for the next iteration cycle

The whole experience can then be implemented in a management dashboard and the approach closed as a first top-down/bottom-up iteration cycle; top-down as the approach has been triggered by the client and bottom-up as the approach is fed at the highest level by shop floor information.

The following chart is a summary of the proposed approach, adapted with the researcher's experience gained throughout this research into improving the production workflow on real estate development construction sites made by SMEs.

1. Identify the problem of the research

2. Validate the real engagement to change the system

3. Diagnose the situation

4. Create a favourable environment

5. Create a learning process with the application LPS

6. Make tasks and activities ready

7. Design and technical improvements

8. Create a steady production pace

9. Stability indicators (index) and learning

10. Prepare for the next iteration cycle

5 Complements

From Chapter (1), *Introduction*, through to Chapter (4), *Research processes*, the thesis increases the readers understanding of the context of the problem and how it has been addressed in the context of this doctoral approach.

This chapter complements the latter and helps the reader fully understand the research undertaken in the context of this thesis, from the background of the construction projects to the research summary through the problem of the client (a real estate developer) and the source of the research (3 blocks of real estate development). This chapter is constructed as follows:

- Section (5.1), Background *of the project* , presents the main elements of the three phases of a 3-block real estate development project that started 10 years ago, on which the researcher has based the research presented in this thesis.
- Section (5.2), *Problem of the practitioner (a real estate developer)*, introduces and develops the problem shared by the client and the reason for seeking help in searching for an improvement in the current situation.
- Section (5.3), *Grounds of the research: focus on the 3-block real estate development site*, narrows and presents the three blocks where the research was undertaken and provides the reader with a context and understanding of the sites.
- Section (5.4), *Research summary*, summarises the approach followed by the researcher and concludes the chapter.

This chapter is followed by Chapter (6), *Case Study of block 1: inception of lean*, Chapter (7), *Case Study on block 2: Development of the solution* and Chapter (8) *Case Study on block 3: further development of a pull flow system*, which develop the research and findings made on the three blocks.

5.1 Background of the project

This section complements the presentation of the project made earlier in the thesis to provide the reader with more context of the research. The project, which is the focus of this case study, involved the construction of three blocks of a total of 140 apartments in a suburb of Brussels in Belgium. This 3-block phase (representing Phase 3) was the last of a 10-year development project; hence, a previous sample of 200 apartments had been erected the traditional way in two phases (Phase 1 and Phase 2).

Picture 3.7.4-1 Aerial view of the 3-phase project

The real estate developer, the Client, is a subsidiary of a large renowned Swedish developer (2.500 employees, €1,500 k turnover) that operates across Scandinavia and has an extensive track record of successful project completion. Their quality, costs and planning indicators are well above the average in the construction industry, with a mean of 70% of apartments delivered snag-less. The table of the following page illustrates this.

totaux et pourcentages remarques			**manque** inachevé nombre remarques	nombre appts concernés	**défaut** achevé mais refusé nombre remarques	nombre appts concernés	**dégât** achevé, réceptionnable mais endommagé nombre remarques	nombre appts concernés
châssis	5%	25	3	3	17	13	5	5
façade	1%	7	0	0	4	4	3	3
terrasse	1%	3	1	1	1	1	1	1
garde-corps	0%	2	1	1	0	0	1	1
électricité	16%	89	48	19	41	15	0	0
chauffage	4%	20	15	10	4	4	1	1
ventilation	1%	5	3	2	2	2	0	0
sanitaire	21%	116	44	20	63	25	9	8
cuisine	11%	62	27	19	26	14	9	8
carrelage	8%	44	28	18	11	8	5	4
parquet	9%	47	35	19	8	8	4	3
porte	10%	54	9	8	31	16	14	12
plafonnage	13%	71	21	14	49	22	1	1
nettoyage	2%	11	3	3	7	6	1	1
conception	0%	2	2	2	0	0	0	0
		545	235		257		53	
			43%		47%		10%	

Table 3.7.4-1 Number of snag works per apartment per phase

The real estate developer kept track of the incomplete apartments at completion (i.e. works yet to be completed at the due date) and of the imperfect apartments (i.e. with snagging works to be completed after delivery to the owner). The average, per apartment, of works still to be completed (unfinished at completion date) was 7.6 and the average of unsatisfactory works (snagging) was 8.3. Thus, the number of works to be either completed or made good before handover to the owner was > 15. From the interview with 10 real estate developers acting in the same area and business as the Client, with the same kind of contractors, this measure was considered an industry-classic mean. Most of the developers interviewed considered this low-quality standard as inevitable, intrinsically grounded within the construction industry.

5.2 Problem of the practitioner (a real estate developer)

While Section 5.1, ‚Background of the *project* complemented the context of the project, this section complements the problem presented earlier in (4.1), *Problem diagnostic and development*, and provides the reader with more context of the research.

In 2015, on Phase 2, the Client chose to go beyond the prevailing that’s-the-way-it-goes mentality in the construction industry and initiated an anticipated snag-detection system. This system consisted of systematically searching for faults and incomplete works (pre-pre-snag) three months before the completion date and doing the same again two months later (pre-snag), so that the snag list would be as limited as possible at completion. This system decreased the number of snags at completion to 2.3 per apartment, which was considered a success in comparison to the average of 15 commonly accepted previously. The downside of the system was the high cost of human resources that the developer had to allocate to obtain the results. Two engineers had to work full time to achieve the aim; their costs brought down the overall benefit of the result.

The developer then sought a more systematic, structured way to achieve better quality, lower costs and reduced time and discovered the lean philosophy. I was subsequently appointed as a consultant to develop a model that would help them deliver the apartments with outstanding performance (i.e. beyond current standards) in terms of cost, time and quality. The final three blocks (Phase 3) were used as a living laboratory for the doctoral research of the author. The lean theories would be applied on site, and the site measures would feed the research in iterative cycles.

5.3 Grounds of the research: focus on the 3-block real estate development site

While the previous sections of this section have provided complements to the context of the research and to the 10-year real estate project, this section focusses on and develops the reader’s understanding of the final phase of the three blocks where the doctoral study is grounded, time and quality time were to be improved.

The last phase of the 10-year construction project comprised the construction of three consecutive blocks, planned from 2013 to 2018, as presented below:

- Phase 1 Block 1: 35 apartments, from 2013 to 2015
- Phase 2 Block 2 : 65 apartments, from 2015 to 2017
- Phase 3 Block 3: 40 apartments, from 2016 to 2018

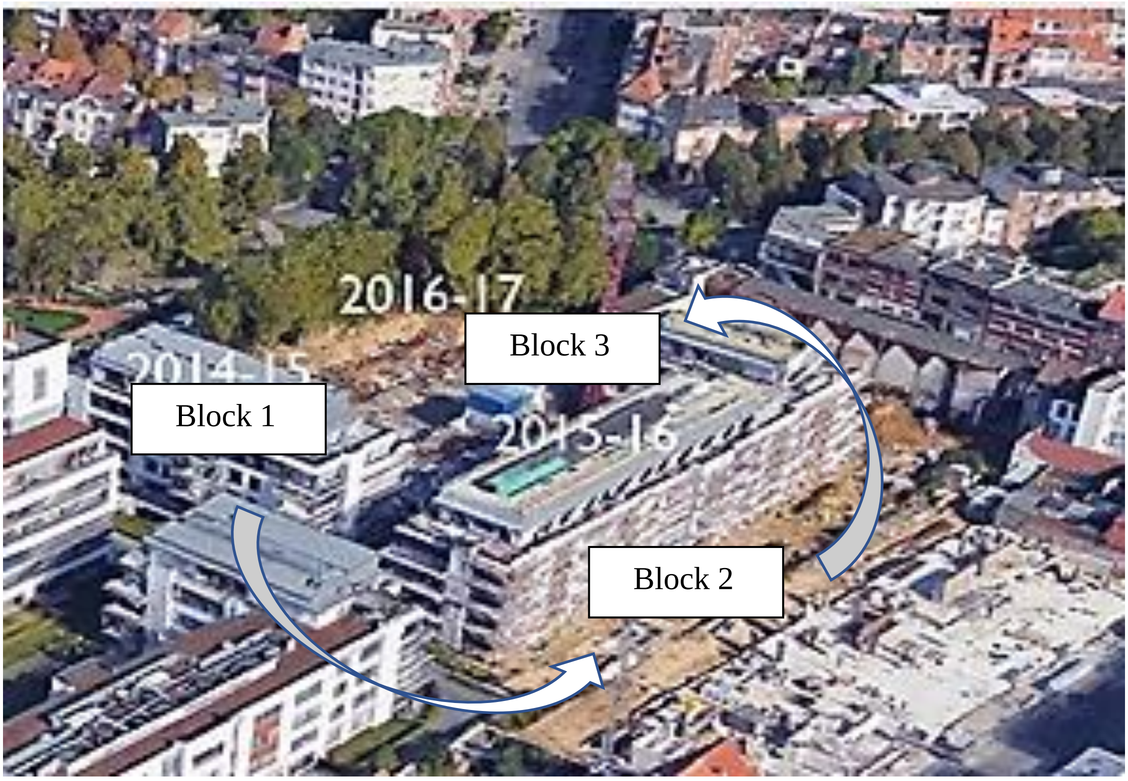


Figure 3.7.4-1 Aerial view of the three blocks of Phase 3

As part of the mission of the researcher as a consultant, I was challenged to design and build a practical solution to address the problem of poor construction efficiency (extended delays, additional amendments, quality issues and extra cost). The client had the intuition that this would be made possible through better planning and an optimised building process. The researcher was appointed for this project from phase to phase, over a period of more than three years: from April 2014–July 2017. The works in block 1 had already started by the time of the researcher's appointment as a consultant. The concrete works (elevation walls) were in progress on the 4th floor research inception.

5.4 Research summary

While the previous sections of this chapters have provided complements on the context and problem of the client, this section summarises the research to provide the reader with a global understanding of the path followed by the researcher over the construction of the three blocks of real estate development.

On each block, the research followed the following cycles:

- 1. diagnostic,
- 2. action planned,
- 3. action taken, and
- 4. evaluation of the action.

To link each block and grow the chain of evidence, two steps were added at the end of the cycle:

- 5. learning and
- 6. questioning to initiate the next action research cycle.

Thus, the researcher based the actions of a long-term lean construction consultancy mission on a scientific approach under the direction of doctoral studies. This format helped bridge the two worlds of academia and practice, the former with the latter's inputs and data and the latter with the former's structured and scientific approach in the search for an answer to the shared problem.

The tables on the following pages, *Table 3.7.4-1 Action research cycles made in Block* , Table 3.7.4-2 Action *research cycles made in Block 2* and *Table 3.7.4-3 Action research cycles made in block 3*, present the logical path and steps undertaken from the diagnostic of the first action research in Block 1 (*Action Research 1.1*) to the question that introduces the third action research (*Action Research 3.1*)

Block 1	Research 1.1	Research 1.2	Research 1.2 bis	Research 1.4
(1) Diagnostic	Site works highly unstable and desynchronised, low visibility of the structural works schedule	Delays (and root of lower PPC) mainly due to labour congestion on site	PPC fluctuates and should be stabilised to ensure works stability	Lack of activity fathers work desynchronisation despite high PPC
(2) Action planned	Start the implementation of LPS by weekly work plan (WWP) meetings	Initiate 5S on site	Analyse the root causes	Continue the implementation of LPS to the next step
(3) Action taken	2-hour training in lean construction with the foremen, setting of the rules of the WWP meetings	Start 5S with the first S: evacuate the waste	Systematic questioning of the site foremen, 'five whys' analysis when possible/appropriate	Introduction and implementation of 'make ready' to the trade project managers and determination of the theoretical works sequence and unit time.
(4) Evaluation of the action	Works commitment on site (PPC) doubled in the first month, continued to grow thereafter	PPC continued to rise, though unstable from one week to another	PPC levelled	PPC kept high, works stability improved
(5) Learning	A clear understanding of the 'why' and favourable meeting conditions are key to first lure the foremen, who will then come naturally to the meetings, which are kept short and useful for their daily organisation	A clear working area helps the foremen be aware of their own issues and that of the others, which eases mutual help.	Immediate answers hide real difficulties faced by the foremen. A natural tendency to not present the constraints and bad news early. The most accurate and usable answers (in a continuous improvement goal) came from the foremen, not from the project managers.	The works can be desynchronised despite a high PPC
(6) Question to initiate the next action research cycle	What prevents site commitment (PPC) from rising?	Why is PPC unstable?	Why is work running late vs schedule despite a high and levelled PPC?	What can be improved in the next block (Chopin) that has slowed work in this block?

Table 3.7.4-1 Action research cycles made in Block 1

Block 2	Research 2.1	Research 2.2	Research 2.3	Research 2.4
(1) Diagnostic	Work in the raisers has been a bottleneck at the start of the work and has delayed the whole progress of Block 1.	The work is still unstable despite a high PPC and technical anticipations.	Accelerations and decelerations in the pace of the work is measured from one apartment to the next, from one week to the next; last planner is not enough	The pull system based on takt time requires discipline. Despite that, flow consistency improves, site congestion becomes again an issue.
(2) Action planned	Technical optimisation and micro-planning of the works in the raisers	Compare the theoretical and actual works progress.	Determine a pace to align all trades to and develop a complementary pull system.	Develop further the pull system by integrating a kanban system (discipline by visual management).
(3) Action taken	Special collaborative meeting with the M&E+ structural trade foremen and project managers	Determine a model to calculate the theoretical weekly progress for each apartment in a stable flow vs weekly progress measurement on site	Calculated a takt time that should allow each trade to complete its works in a single apartment. Initiate takt planning following Frandsen's 5 steps	Develop a table displayed on the wall of the site meeting room with sticky vignettes (kanban) for the next trade in the queue, mainly a communication tool
(4) Evaluation of the action	A truly collaborative spirit has allowed trade-offs. The raisers work was optimised and prepared well in advance.	Permitted to find distortions between theory and actual physical progress	Measured works stability, doubled	Individual and collective improvement on the state of the site and self-commitment to follow the rules. Work stability doubled.
(5) Learning	The project managers are not used to addressing issues well in advance; a trade-dedicated preparation could have eased the process.	A high and stable PPC does not necessarily stabilise works.	It is somehow possible to apply takt time to the construction industry: early key success factors identified.	Discipline can be eased by a simple effective visual management system.
(6) Question to initiate next action research cycle	Technical optimisations enough to stabilise the works?	Can the trade workers progress in a continuous and constant (stable) flow on site, such as the cars in a factory?	How to ease the managerial process of keeping the takt system?	Is this system duplicable in the next block? (Block 3)

Table 3.7.4-2 Action research cycles made in Block 2

Block 3	Action Research 3.1
(1) Diagnostic	Lack of discipline and human bias inserts lack of reliability on site
(2) Action planned	Test the application of a visual and simple tool that would enforce discipline (insert a constraint into the system)
(3) Action taken	Test the application of a visual kanban
(4) Evaluation of the action	Variability decreased
(5) Learning	Kanban can be successfully applied
(6) Question to initiate next action research cycle	How can kanban be generalised to the other stakeholders (architects, technical specialists, etc.) to improve upstream information flow stability?

Table 3.7.4-3 Action research cycles made in block 3

The next sections detail the above table and focus on the developments and instantiations of the model developed by this research. They are structured to follow the five steps by Peffer et al. (2007): namely (a) problem identification, (b) definition of the objectives for a solution, (c) design and development, (d) demonstration, and (e) evaluation. As part of a sixth step, (f) communication (of the artefact to relevant audiences such as researchers and practicing professionals), this thesis and publication of the findings in academic papers will help disseminate the information into the research community, and the industry conferences held in 2015, 2016 and 2017 in Paris (FFB Conference), Brussels (CCI Conference), Wallonia (Chambre des Metiers Conferences), Bordeaux (FFB Conference), Melun (FFB Conference), Luxembourg (LIST Conference) and Geneva (Induni Conference), giving professionals concrete examples of achievable results. For the sake of clarification, and to ease the reader in following the demonstration, the author has added three paragraphs for each chapter (instantiation): introduction, data collection and demonstration of the solution.

The next chapters (6), (7) and (8), follow the same eight steps path (where relevant):

- 1) Introduction,
- 2) Diagnostics, clarification of the problem,
- 3) Definition of objectives for the solution,
- 4) Develop solution,
- 5) Action taken,
- 7) Demonstration of solution,
- 8) Evaluation of the research solution.

The following chapters, Chapter (6), *Case Study on block 1: inception of lean*, Chapter (7), *Case Study on block 2: Development of the solution*, and Chapter (8), *Case Study on block 3: further development of a pull flow system*, develop the research and findings made on the three blocks.

6 Case Study of block 1: inception of lean

This Chapter is composed of four sections.

- Section (6.1), *Beginning with LPS: development of research Stage 1.1,* presents the inception of the research with the introduction of the weekly work plan of the LPS as a first step in the search for a solution to the client's problem as presented in Section (4.1), *Problem diagnostic and* .
- As the Last Planner™ System through the application of the weekly work plan was not sufficient in itself in the latter stage, the research was continued. Section (6.2), *5Ss on site: development of research Stage 1.2*, introduces how the 5S approach has been applied on site.
- As the 5S and WWP were not sufficient and procurement issues were detected, the research was oriented to the anticipation of their delivery on site. Section (6.3), *Focus on make ready: development of research Stage 1.3*, presents the development of the application of the make-ready phase of the LPS
- Section (6.4), *Section summary*, summarises the chapter on the research carried out on block 1.

Then, Chapter (7), *Case Study on block 3: further development of a pull flow system*, and Chapter (8), *Case Study on block 2: Development of the solution*, develop the research in the two blocks which follow.

The research has been grounded on a real estate development project that comprised three blocks: block 1, block 2 and block 3. This chapter describes the research that has been undertaken on block 1.

The aims of this chapter are as follows:

- To better understand the root causes of the problem when looking to improve work synchronisation in the construction process;
- To develop how the research has been implemented in practice while being linked to the fundamental academic methods and identify the main foundational concepts that would help grow an understanding of the current situation and of the models to be applied;
- To describe and justify how the methods have been tested, given the very limited literature on the application of the approach on a real estate construction site run by SMEs;
- To explain and describe the limits of the application of 5S and LPS and, hence, the need to further develop visual and flow management.

The picture in the next page illustrates the end product of block 1 as handed over to the owners of the apartments/

Picture 3.7.4-1: Block 1 building completed

6.1 Beginning with LPS: development of research Stage 1.1

6.1.1 Introduction

The following sub-sections show how the lean journey started and how the move toward flow stability was carried out by the researcher from a situation where the site had already started (the structural works were ongoing at the 4th floor at the beginning of the action research) to a new system based on takt planning and kanban methods through action and DSR cycles from block 1 to block 3.

Block 1 construction was carried out between September 2014 and December 2015. As the initial research stage, research on Block 1 focused on testing an existing flow management tool (i.e. LPS) as a means of stabilising the production flow. Block 1 involved the construction of a block of 35 residential apartments. The project was managed by the property developers themselves, performing the role of project managers, with whom each contractor had a separate contract (i.e. no general contractor oversaw the site management). Eight principal subcontractors were appointed to build most of the building block. Brady's (2014) research field and environment are quite similar to those in which this research has been undertaken (mid-size sites made by SMEs). Brady (2014) advocated that the project could be completed under the target cost through better coordination between the contractors and through an optimised planning and building process.

6.1.2 Diagnostics: clarification of the problem

The research process started with an attempt to identify the original problem which was perceived to be a lack of work planning leading to low quality and increased costs at delivery or handover. The first step was to develop an understanding of the current situation and link the observed reality to a theoretical perspective. A first review of the literature that addresses the problems was carried out, but only a limited part of the extended literature applied to the relevant environment which was real estate development sites run by SMEs with direct contracts with the owner: no general contractor or external project manager to oversee the construction process and take responsibility for the time, quality, costs, and H&S performances. The literature review focused on work synchronisation, flow theories and work-levelling methods.

While the literature review helped better understand the theoretical aspects of the problem and gain insight from previous research, an important step was to analyse the first data gathered on the initial state of the site. Indeed, when I started working on the site, the concrete work had already begun, and a structure of three of five floors was already erected. Other data were collected from the construction site (photos, interviews, measures of waste, daily coordination problems, etc.) and later reviewed to link the observed reality to the theoretical issues or past documented experiences. The literature review, in the light of the practice as audited (and vice versa), helped identify the first layer of the problems that the construction site faced. As Tezel (2019) pointed, the vast majority of the literature on LC made by SME is still related to the operational aspects of a lack of work synchronisation and of adequate site layout.

6.1.2.1 Poor master planning optimisation, lack of activity overlaps

The WWP was drawn up following the recommendation of the LPS. Only the tasks that started and ended the planned day were noted as completed promises. In this case, and only in this case, the figure "1" was inserted for the line of work. Although this figure was normally used to signify that a task had been started or had ended earlier or later or not started or completed, the researcher used it to indicate that the promise was completed. The works were collaboratively noted as completed or not completed by the contractor in charge and the company next in sequence and by the client. A task, when noted "1", or completed, met all the criteria required to avoid snagging works that would result in the misallocation of the task as having been completed. This task was considered "done, done" to indicate that it had been 100% completed. The status of any promise scheduled in the WWP could only be considered as 0 or 1 in a binary system: completed or not completed. These only two scenarios are illustrated below:

CLOS YSAYE

Weekly Work Plan: Anticipation 15 jours E: 46 PPC 18%

	Apt	Lot	Activité de la semaine	Je 19/6	Ve 20/6	Sa 21/6	Lu 23/6	Ma 24/6	Me 25/6	Promesse Tenue ?
1	A2	Elec	Tracage implantations appartements bloc A (fin)	X X	X X		X	X		0
1	A2	Elec	Réalisation des saignées et percements (fin)	X X	X X		X	X		0
1	A2	Elec	Evacuation des crasses / déchets	X X	X X		X	X	X	0
1	A0	Elec	Tubes alimentations tableaux		X X					1
1	A0	Elec	Réalisations éventuels changements (plans)		X		X X			0
1	A2	Elec	Pose des blochets				X X	X	X	0
1	A21	Elec	Cablage					X	X X	0
1	A22	Elec	Cablage					X	X X	0
1	B2	Elec	Tubage					X	X	0
1	A21	Plombier	Décharges		X X		X			0
1	A22	Plombier	Décharges		X X		X			0
1	A24	Plombier	Décharges		X X		X			0
1	B21	Plombier	Tuyautage				X X	X X		1
1	B22	Plombier	Tuyautage				X	X X		0

Figure 6.1.2-1 Example of weekly work plan in block 1-A

- The red highlight in the graphic above illustrates a task promised to start on 19/06 and to last for two consecutive days (see the upper crosses in the calendar box of the highlighted line). The task started on 20/06 and continued until 24/06 (see the lower crosses in the calendar box of the same line). So, although the task was completed in the course of the week, the promise could not be considered "completed" and, therefore, it was annotated "0" in the table (red circles).

- The green highlight illustrates a task promised to start on 23/06 and to last for two consecutive days (see the upper crosses in the calendar box of the highlighted line). The task did start on the 23/06, continued and then ended on 24/06 (see the lower crosses in the calendar box of the same line). Given that the next trade was happy with the works done, the promise was considered "completed" and, therefore, the task was noted "1" in the table.

The first measures showed that the works on site were highly unstable and desynchronised, and the existing planning for the structural workers lacked visibility: the first three measures of the promises made under the inception of the LPS, completed by the site foremen before its implementation, showed levels between 10–20% of PPC.

Such a level indicates that the vast majority (80–90%) of the work undertaken in a day was not planned for that day during the previous week. The overall planning was following the CPM, but that planning was four months old and needed to be updated to take into consideration the actual constraints of the project and their impact on the synchronisation of the works.

Picture 6.1.2-1 Illustration of the initial state of the works environment of block 1 as audited by the researcher – Unsafe, congestion, overloaded of unused materials and wastes

It is to be noted that the site was largely congested by materials, tools and over-storage and that safety needed to be improved. The lack of transparent planning had led the developer (acting as project manager) to focus on the physical progress made weekly following the well-disseminated view in the construction industry: ”All that is done, is done”, a typical push site-management system.

While the structural work was almost done on the fourth floor, the M&E works could not start, given the installation of the windows and waterproofing (even temporary) works were not anticipated. Hence, the mason was almost alone on site, with the M&E works planned to start in the next sequence. This lack of activity overlap prevented the site from increasing the level of productivity, even though the ground floor, the first floor and the second floor were ready for the next tradespeople.

Picture 6.1.2-2 Illustration of one the one-trade-at-a-time works planning in the previous phases

According to the client (acting as project manager): “The crews would show up at the area of work according to macro-sequences, very often finding that other trades had already taken possession of the area or that they were blocked (with the materials left in place) because another trade should finish its works first before the next in the queue could start his”. As illustrated above, the macro-planning was so poorly defined (sequences of macro-sequences of the concrete works with limited inputs on the second trades) they were open to interpretation for most contractors, who were working “wherever”, without following any flow on-site. The subcontractors were mainly working in areas ” where it was possible”, or ”where it is convenient today regarding the resources on site” rather than where they should have been work with the proper materials.

From his own assessment, the client, acting as project manager, was then putting great effort into making the contractors do ”some” jobs based on daily coordination, flexibility and the rearrangement of activities. It is clear that the master plan was of a limited use, and created more confusion than unity.

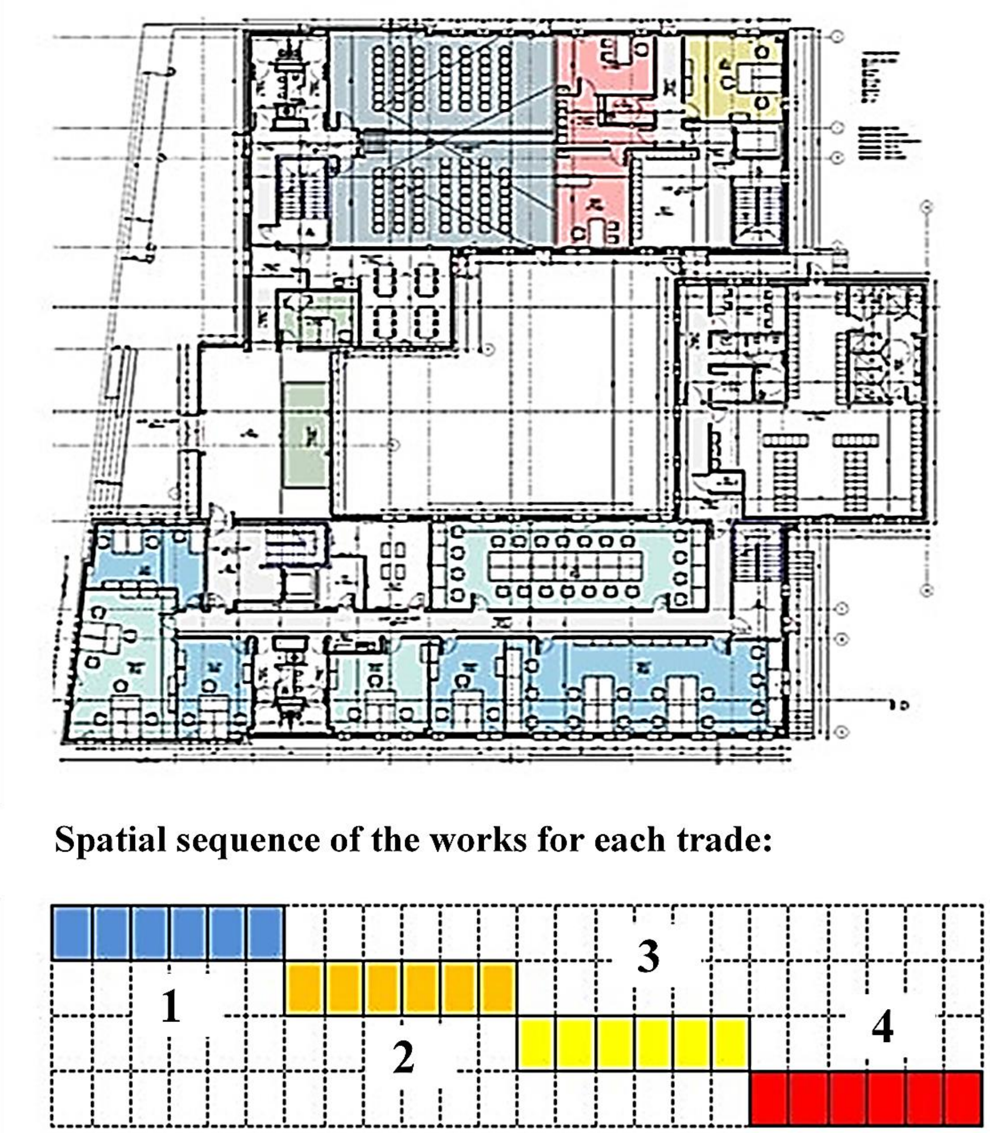


Figure 6.1.2-2 Illustration of the sequence of the works thought as “one-trade-at-a-time” in the previous phases

Interestingly, the master plan remained the only contractual document for determining whether a contractor was early or late in their works and, of course, in these conditions, the delivery date was uncertain at this stage. Notably, the whole project management team (the client, the architect, the engineers, and the contractors' site managers) spent more than half a day each week in a so-called coordination meeting. Each player offered feedback on the current situation and the constraints for the following period (usually, a month), reviewed the master plan, pointed out the delays and outlined mid-term milestones (two to three months ahead). The developer's team had a central role in organising and coordinating the works and in keeping track of the delays of each trade as they related to the master plan. Despite these recurrent meetings and efforts, site management still had a limited understanding of the work being done on site and how to coordinate the next steps to deliver on time.

6.1.2.2 Desynchronised works

At the beginning of the mission (and research), the data from the master plan were reviewed together by the researcher and the client, comparing where companies were planning to work and establishing whether they were carrying out the work as planned. The researcher made a visually detailed audit of the current situation, noting for each task (or activity) whether the works as seen on site were being done too early, on time, or too late.

Measuring the difference between the planning of the macro tasks and the reality of the progress on site helped better understand the level of desynchronisation. The illustrated plan (see below) shows that of the 113 tasks measured on site (13 typical macro tasks per floor), 84 were late (4 weeks, on average), 8 were ahead of schedule (3 weeks, on average) and 21 were progressing on time (+/- 1 week). Next page presents the actual document on which the Client based the follow up of the progress made on site. For sake of authenticity, and despite much unreadable, it has been kept as it is. This illustrates the low attention that was given to the works follow up in the context of the beginning of this research by the Client.

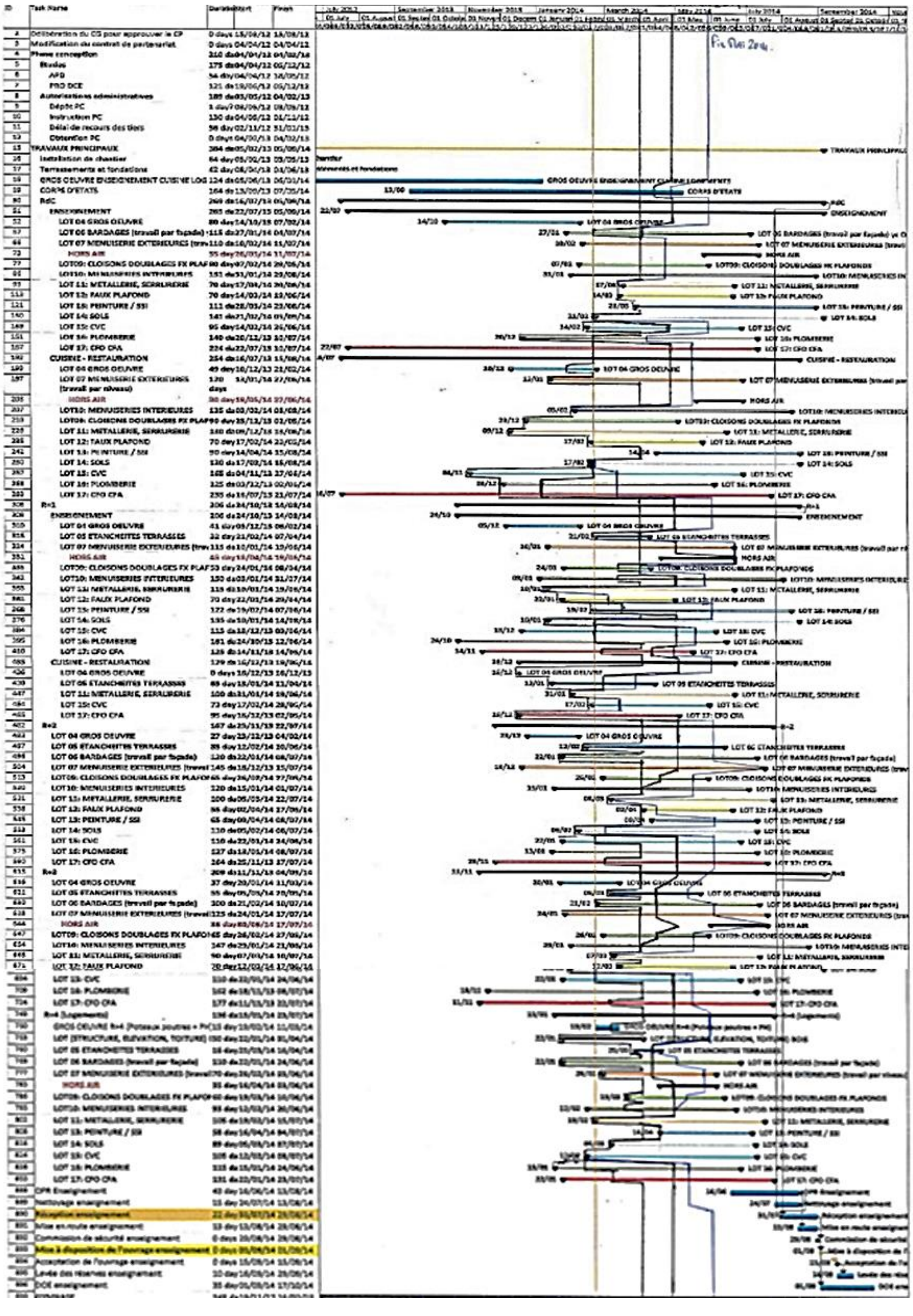


Figure 6.1.2-3 Illustration of the measure of progress of each macro task.

- *The actual document is not more readable, kept as is for sake of authenticity. Illustrates the un-readability of the planning - -*

6.1.2.3 Lack of engagement to improve the current situation

- From the latter data, it can be seen that a relatively small number of the tasks were being carried out according to plan: Percentage of activities too early: 7%
- Percentage of activities on time: 19%
- Percentage of activities too late: 74%.

Some activities were more than 40 working days late, no rework of the sequence had been made, nor any identification of the critical path. The impact of the tasks which were too early or too late was not measured; hence, the works in progress on site were desynchronised, with each contractor working mainly ”where they could”.

6.1.2.4 Serious safety issues

The push system observed in place forced the site foremen to focus on production, leaving safety aside from their own assessments. During the initial audit, the researcher noticed many dangerous situations (several on each floor) that could have led to lethal consequences. The greater risks mainly originated in holes and missing handrails across the whole of the 5-floor building site, as illustrated in the following pictures.

Picture 6.1.2-3 Safety issue noticed in Block 1 at beginning of the research., 3rd floor

Picture 6.1.2-4 Safety issue noticed in Block 1 at beginning of the research (handrail missing)

Picture 6.1.2-5 Safety issue noticed in Block 1 at beginning of the research (handrail missing,. 4th floor

Picture 6.1.2-6 Safety issue noticed in Block 1 at beginning of the research (handrail missing), 4th floor

Picture 6.1.2-7 Safety issue noticed in Block 1 (anti-fall protection missing), 5th floor

The client had appointed an independent health and safety officer and inspector on site, who paid weekly visits to the site. These visits could be compared to gemba walks in that the inspector went on site, sought out dangerous situations that could be improved, gave verbal and written recommendations, and provided a report after each site visit. The reports for the three months preceding the start of this study contained, an average, 14.5 remarks, amongst which 3.2 were very urgent or critical. No improvement was observed nor noted by the inspector, despite his reports. This record confirmed the severity of the safety issues detected by the researcher.

6.1.2.5 Low visibility of site layout and inventory

Despite the high volume of human resources (35 workers solely for the concrete works on a 35-apartment block was considered high by the project manager for such a project), the majority of the tasks were late. The workmen interviewed on site shared the difficulty of finding materials and tools to execute the works they were allocated in the morning. There was neither a clear site layout nor a storage area.

Picture 6.1.2-8 Safety issue noticed in Block 1 at beginning of the research: no pathway, iron bars unprotected, busy floor, risk of fall, ground level

Picture 6.1.2-9 Safety issue noticed in Block 1 at beginning of the research: no pathway, iron bars unprotected, busy floor, risk of fall, ground level

Picture 6.1.2-10 Safety issue noticed in Block 1 at beginning of the research: no pathway, iron bars unprotected, busy floor, risk of fall, ground level

Picture 6.1.2-11 Safety issue noticed in Block 1 at beginning of the research: no pathway, iron bars unprotected, busy floor, risk of fall, ground level

Some materials were used as tools (plaster blocks are being used as props in the picture below), increasing confusion on site and preventing the workers from working with the needed resources.

Figure 6.1.2-4 Safety issue noticed in Block 1 at beginning of the research. Risk of collapse, 3rd floor

Other measures of distances walked by a worker performed at the beginning of the research showed that a worker walked 17 minutes without any apparent or shared reason. The researcher went up the crane and observed, kept a log and interviewed a workman who seemed lost on his own site while looking for something. The result of his route has been drawn on the picture of the floor to illustrate the walk. When asked what he was looking for, he admitted he had forgotten.

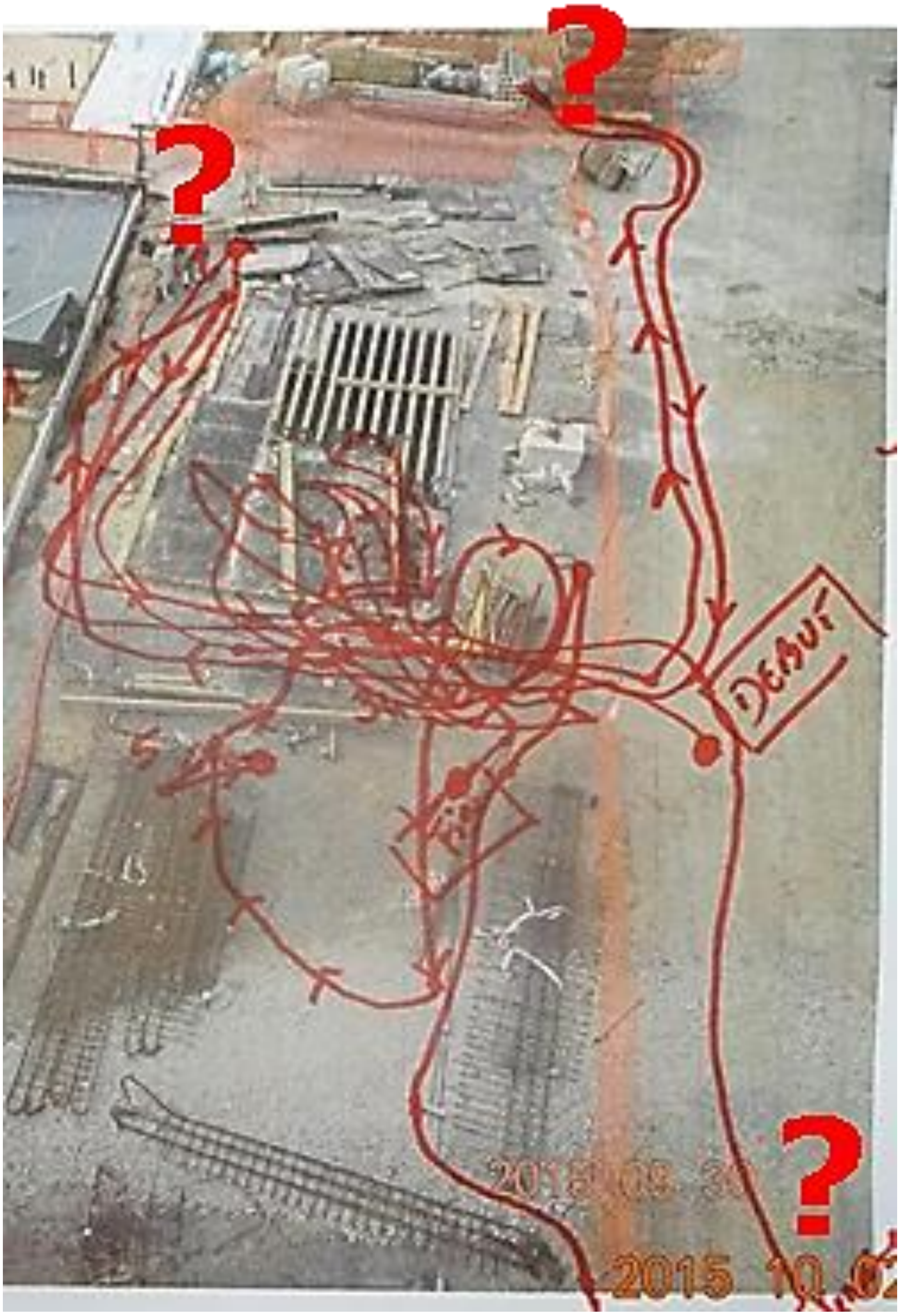


Figure 6.1.2-5 Illustration of the movement made by a workman in 17 minutes (spaghetti diagram)

6.1.2.6 Quality issues

A site visit revealed many non-quality issues that, if not treated as soon as possible, would increase work desynchronisation, and increase the need to go back to previous zones. Windows were too narrow (see photo below), drilling was not centred, and concrete columns had to be remade after the plaster-boarding had already been fixed, as shown in the pictures.

Figure 6.1.2-7 Example of non-quality fathered by "making do" on Block 1)

Figure 6.1.2-6 Examples of non-quality fathered by "making do" on Block 1

6.1.2.7 Clarification and summary of the practical problems found at the inception of the observation/ research

Based on the observations, measures and information gathered from the feedback of the companies as described in the previous chapter, the main issues identified at the inception of the research can be summarised as follows:

- **Lack of clarity in the trade interfaces**: The work was mainly done in a push system, with each worker doing ”whatever was possible’.
- **No flow of work**: The sequence of the work was too macroscopic to direct the crews on site. The work was done ”whenever possible”. From the above, it is clear that the whole team (from the workers to the project manager) was putting forth their ”best possible” effort, which suggested deeper concerns, as represented in the subsequent items of this list.
- **No sense of urgency or need to improve the status quo**: Only the real estate developer had decided to change and test new methods based on lean. No contractor on site was willing to discuss that the construction industry suffered from a poor performance. The current status quo from the contractors interviewed demonstrated that the foremen perceived themselves as “giving the best they could”.
- **No challenge in the performance**: The work was monitored from a highly microscopic perspective, which prevented fine-tuning and challenging each contractor who, by default, was making ”the best possible” effort.
- **Serious safety issues**: Although helmets and safety shoes were worn, passive safety (fences, hole blockages, iron protection, etc.) were limited. The probability of a serious accident was very high.
- **No general site organisation, visible spatial layout**: The site was organised with no vision of spatial optimisation. No visual signs indicated the different zones, and storage was sited ”wherever possible”.
- **Lack of quality monitoring**: The many quality non-conformities were clear consequences of the above issues; treating them would address these non-conformities. The work was being done ”as well as possible”.
- **Poor logistics**: The materials and tools were ordered by the foreman based on the

work to be done during the following month or beyond in a delivery cost-saving strategy. Hence, materials and heavy tools (timbers, metal formwork, etc.) were delivered on site in quantities of ”as much as possible”.

6.1.3 Definition of the possible objectives for the solution

The above paragraphs detail the objectives for the solution to be developed in Stage 1. Not all could be addressed in the first iteration; the aim of the information presented in this chapter was to help me to decide what objectives were to be addressed first.

6.1.3.1 Improve works scheduling and transparency

The first problem noticed, as summarised in Chapter 7.1.2.1, was the poor implementation and relevance of the master plan. This problem was reflected in the poor overall organisation of the site (Chapter 7.2.2.3). Coordination meetings traditionally took place each Wednesday for at least the whole afternoon (some pre-meetings even started late morning) and so, despite spending more than half a day per week in coordination meetings, the site management still had a limited understanding of the work being done on site and how to coordinate the next steps to deliver on time. The project was considered to be in the hands of the developer.

To achieve better scheduling, it is important to integrate the contractors in the overall planning of the operation. Disconnecting the developer from the central role provides the possibility for contractors to express themselves. In the pursuit of achieving overall transparency, Brady (2014) recalls :

> *“in the construction process, the concepts of transparency and the value stream are important. Transparency provides people with a clear understanding of different aspects of the current system’s performance and status, giving them feedback on performed activities and helping them to make decisions, letting them recognise interdependencies and, as a result, enabling higher levels of improvement.” (Bauch 2004). The value stream is concerned with understanding the physical flows of people and information (Liker 2004). To achieve transparency in processes, visual management is key. Chapter 4.5.1, explains how a visual tool called the overall process map is used to make the overall process transparent in the early stages of the project.”*

6.1.3.2 Implement production flow management

This objective addressed the difficulty of managing the flow of work on site to increase the proportion of production made each day by each worker. The implementation of the LPS and the root cause analysis of the promises not kept showed that more than half of the works could not be started because the area was unavailable (materials from “others” were stored on the path or at the workstation) or previous work had not been completed, and so forth and, as an alternative, they the workers were working somewhere else. This ”somewhere else” was generally the most appropriate place from a sequence, synchronisation, or layout point of view. This deferral of work increased the probability of the next issue to be noticed: the lack of visibility of the site organisation as a whole. The site was in a heavy push system; the objective would be to reverse the stream and implement a production flow based on a pull system. A pull system would help to create a continuous and levelled flow, hence more predictability. Ideally maintained by the production actor, the production flow is a central concern in a lean system.

For Womack & Jones (1996, flow refers to “*achieving the optimal order of processes, by reducing variability and irregularity (such as bottlenecks) so that material and information may move in a predictable way within the supply chain*”. Pull is the approach of producing only what the next activity in the queue needs, while avoiding materials piling up and keeping the inventory level at a minimum (Liker, 2004). Transparency is key to the optimisation of the flows through the logical way the activities can be arranged. The problems become more visible and the solutions can arise more rapidly. Brady (2012) warns that a shift in the way work is carried out is necessary for the implementation of a flow-based management approach. Employees have to switch from focusing on large quantities of work that bring a large amount of invoicing (the short-term approach) to rethinking how the work and the activities should flow across the building in a specified sequence. The situation observed on this site confirmed Brady’s warning as the first contacts with the contractors reflected the same situation.

6.1.3.3 Create a sense of urgency to improve

A major issue was that, apart from the real estate developer (the client and the sponsor of this research), no one showed any sign of urgency. The interviews conducted as part of the initial diagnostic (each foreman interviewed separately after a site visit) showed a high level of apathy; the current situation of desynchronised work, safety issues, and disorganisation at the site were not considered abnormal.

Indications of understanding the current "normal poor performance" status quo

As variability undermines project performance and disrupts workflow in AEC processes, organisations working on site often strive to maintain consistency in the production flow and shield production from uncertainty in their in-house processes and their business environment (Hamzeh et al., 2007; Hopp & Spearman, 2008; Thompson, 1967), and end up accepting this situation as normal. Most companies either fail or only partially achieve lean production in its true form (Liker, 2004; Kotter, 1996; Ballard et al., 2007; Hamzeh, 2009). Viana et al. (2010) have studied LPS implementation in Brazilian companies and highlighted various implementation hurdles, including the following: (a) difficulty in adapting to the new culture, (b) incompatible personnel qualifications, (c) much time spent planning issues, (d) incomplete information, and (e) high interdependence between various processes. Hamzeh (2011) points out that the LPS as a lean method for production planning and control should be viewed as *"a first step towards creating a higher-performing, more competitive lean enterprise"*.

Initialising change of the current "normal poor performance" status quo

It is important to keep in mind that the application of the LPS is only one step, which is to initiate and facilitate the development of a new, more effective, more collaborative way to see the production of work schedules; lean is the much broader umbrella. While most companies only focus on tools and methods in their quest for operational efficiency, to successfully implement a lean approach (such as the LPS), the organisation must start, feed and improve key fundamentals: learning, changing, and focusing on people and philosophy, just as most companies tend to focus on tools and methods in their quest for operational efficiency (Liker, 2004). This combination should be integrated into the new model to ease adoption and maximise the chances of successful implementation.

6.1.3.4 Introduce performance measurements and indicators

This objective addresses the issue of the lack of objective and reliable measures of performance and, by extension, the lack of visibility in the planning. The progress on site was measured daily (which contractor worked where and on what) and monitored weekly (has the promise/plan been completed?). The log and conclusions (new unit time, new milestones, new constraints) helped collaboratively draw a leaner and updated master plan. The weekly coordination meeting integrated measures of delays but at the macroscopic level, which was too high to be operationally exploitable. According to the developer’s project manager, these logs were mainly made to back the contractual aspects up and keep track of the possible penalties that could be applied when the site was completed.

For Formoso et al. (2009), “*performance measurement plays an important role in terms of providing process transparency. It makes visible attributes that are usually invisible, and it helps employees to see how they are performing and creating conditions for decentralised control to be implemented*”. In relation to clarity and transparency, it is important that the new solution makes the issues visible and the actions, insights and feedback available and clear.

6.1.3.5 Improve safety on site

There is no doubt that the success of an effective health and safety approach depends on two pillars: a safe working infrastructure and a sound safety culture: *”The precursors of effective occupational health and safety risk management are both functional – e.g. involving formal management systems, and interpretative – e.g. social issues such as trust, blame, risk perception, learning, commitment and motivation”* (Peckitt et al., 2004: 22). For Rowlinson, a positive safety culture is achievable through the combination of an effective safety infrastructure and thought conditions on the construction site (2004: 5). *”It is important to realise that the construction site is a highly autonomous organisation. As such, it is very difficult for the head office to control what happens on the site on a day-to-day basis. In fact, on large construction sites, it is often difficult for the site agent to control what happens on a day-to-day or even hour-to-hour basis. Consequently, construction workers are expected to operate with a high degree of independence and initiative.”*

It is not sufficient to establish a safety infrastructure that will then be monitored by health and safety officers. Rowlinson (2004) expressed that ”*Workers progress around the site as the building works progress and each worker is expected to use his own judgement to ensure work proceeds in new and continually changing surroundings”*. Forman (2010) reminds us that in recent years, the safety focus has switched from planning to culture. Efforts have been made to make the construction industry acknowledge that safety can be defined and operationalised, and then systematically used as an approach or a tool in various daily practical situations. Peckitt (2004) concludes that, because of a lack of quantifiable parameters, a safety approach can be perceived as unachieved, incomplete or misunderstood. However, even if imperfect, a safety culture can contribute to the understanding of and a fall in both the frequency and gravity of accidents since this new culture involves aspects that have been overlooked by other paradigms. Forman (2010) adds that management and employees can be considered the two pillars of safety; the actions of the first and the perceptions of the second being important in designing, improving and disseminating a safety culture. Consequently, a safety culture proves highly compatible with a lean approach in that both parties (management and employees) should collaboratively take part in promoting a new model.

6.1.3.6 Improve general site organisation’s visibility

This objective addresses the problem of the lack of optimisation or understanding of the workplace in its environment. Unlike in a factory or manufacturing plant where, even if the production tool can evolve rapidly (e.g. through SMED methods), the production environment remains the same (lighting, paths, storage capacity, and work sequences), a construction site is in constant transition as the work progresses. The solution to be developed should provide a visual frame to the special environment on site and be flexible enough to be adapted as the work changes according to the shape of the site. Sharing the organisation principles, easing visual management and making flows visible are important aspects in assuring the sustainability of a new solution.

As noted by Brady (2014), Moser and Santos (2003) summarised the practical impacts of transparency in a work environment as follows:

> *"simplification of and greater coherence in decision-making, stimulation of informal contacts throughout different hierarchical levels, contributions to the introduction of decentralisation policies, assistance in broadening employees' participation and autonomy in management, more effective (overlapping) distribution of responsibilities, an increase in employee morale, greater effectiveness in production-scheduling, the simplification of production control systems, more rapid comprehension of and response to problems, increase in the motivation of workers for improvement and visibility of errors."*

Flexibility, versatility and mobility within work teams can also be included (Greif, 1991). Correct messaging providing visibility that helps people construct mental models and provides feedback on their actions are the essentials of user-centred design as well (Norman, 1998). Tezel, Koskela and Tzortzopoulos (2010) have emphasised the context of construction and the importance of visual management and transparency in the success of a production flow method. This importance should not be neglected in the development of the model and should be fully integrated into the solution.

6.1.3.7 Initiate a simple quality control system

From the observation and questioning of the daily routine from both the foremen and the project manager, the researcher noticed there was almost no (or if so, limited and sporadic that cannot be considered sufficient) control of the quality on site as the works were ongoing. This lack of consideration of the gemba did not help in detecting quality issues early. As Brady (2012) reminds us, the concept of quality is, on top of providing impeccable output, to reach for perfection in the processes (Liker, 2004). The concept of perfection is closely linked to the one of continuous improvement in that the latter strives to the former by identifying and solving problems continuously. The main idea is to involve the workers in the self-assessment of the situation and promote the possibility that the workers themselves may develop propositions and solutions. Hence, empowerment and engagement are two key values of the model developed in this thesis.

6.1.3.8 Improve logistics

This objective addresses the low-availability of materials and tools on site or their low-availability to the workman who would need them at a given time to complete a given task. This issue can arise from a lack of storage organisation (solution proposed above) or by an excess of demand on the supplier. In both cases, either the workman is not able to realise the activity assigned, or it will be achieved with incorrect materials or tools, creating quality, safety, delay, or cost issues. The new solution should integrate the logistics and supply chain optimisation to guarantee that any worker has all the needed resources (but not more) to complete the assigned task. Part of the solution may lie in applying the JIT concept in the management of site resources and logistics for each task on the master schedule and match the results to the physical constraints of the site (storage capacity, lift capacity, distances to carry, human resources, etc.).

6.1.4 Develop solution & Action taken

From the above, the problem appeared complex, consisting of no less than eight issues identified so far:

- lack of clarity in the trade interfaces,
- no flow of work,
- no sense of urgency or need to improve the status quo,
- no challenging of the team regarding the performance of the site,
- serious safety issues,
- no general site organisation or visible spatial layout,
- a lack of quality monitoring

The ambition of this research was not to bring an immediate and full solution to all the issues detected, but rather the strategy consisted of using all three blocks to apply a scientific approach: in brief, to identify and understand the problem, design a solution, test the solution, and improve the system, working in iterative cycles over a period of two to three years. Given that it would be unrealistic to address all eight issues in the scope of this study, the choice was made to start with the first four: lack of clarity in the trade interfaces, no flow of work, no sense of urgency or need to improve the status quo, and no challenge regarding the performance.

It was hence considered that, if part or all of the four first issues were addressed in Stage 1 of the development of the solution, the issues of safety, quality, general site organisation, and logistics could wait, and that hints and ideas for addressing these latter four issues may emerge.

6.1.4.1 Synchronising the works and promoting transparency

In 2008, Chinowsky et al. aimed to create a solution to promote communication across all the participants of a project and developed a social network model to ease this process. Chinowsky et al. (2008) stated that:

> *"it is time to recognise the key role of individuals within project networks, including the communication and trust that is the basis for achieving high-performance results" (Chinowsky et al., 2008, p. 811).*

They argue that transparency can be generated through efficient communication and social commitment that can lead to trust when a sound collaboration and active participation are shared. Plans can then be implemented by multiple trades through a tangible and shared planning process. For Fauchier (2013), better works synchronisation can be generated through a shift in the construction project management's focus from hard management by using tools (tool-reliability) and extensively detailed schedules (control-reliability) to a soft approach. The soft approach can be based on managing projects the same way as social collaborations.

Fauchier (2013) recalls that ”the *Last Planner™ System is the gateway to lean behaviours”* and argues that LPS can play a much broader role in a lean implementation strategy.

While traditional planning methods are grounded in the division of planning and pretending to tell us what to do, the LPS, by aggregating the “ground knowledgeable” (foremen, superintendents, and other stakeholders), tends to create a collaborative and participative dynamic. The LPS values the time spent by the productive crews to build up the planning and production plan, while in most traditional approaches, this time is considered a constraint, given that the operations will be managed on site directly. The time spent on site by the foremen is then as important as that spent by the managers having their weekly coordination meetings at the office (Shoet & Laufer, 1991). Wambeke et al. (2011) have demonstrated that the LPS improves the productivity of crews thanks to the involvement of the foremen and superintendents in the planning process.

Hence, better work synchronisation and transparency can be found by initiating the LPS, and a more integrated social environment can then be promoted by the system (Fauchier, 2013) fostering coaching, leadership, open participation (teamwork, collaboration, and transparency), and trust-building. The LPS appears to be the starting point to develop the application of lean management and bring concrete solutions to work synchronisation and transparency issues. Implementation of the LPS allows collaboration and trust that are further fostered thanks to a change in the environment/workplace paradigm.

A clear and visual workplace that promotes transparency and information-sharing eases the process of collaborating and eventually encourages trust among team members, which is the apex of the LPS. The LPS, then, may represent the gateway to solving or easing the process of solving other issues detected on site, like improving the general site organisation and visibility issues (see Chapter 7.1.2.7).

6.1.4.2 Initiating production flow management

The lean construction approach supports the practitioners in developing construction projects that could be seen as production systems. Koskela (2000) proposed that these systems could be designed and managed according to three dimensions: transformation, flow, and value. While transformation focusses on managing resources to complete tasks as expected, flow allows one to see the construction process not only as a sequence but as an array of interdependent activities. The activity should be managed and integrated into a system; following the network within the system would continuously generate value to the client. Each task could then be rethought, optimised or eliminated to bring value to the centre of the approach or, so to say, to deliver what the client expects from the project itself, as Fauchier claimed (2013).

In this context, the LPS as a production system works to shield production against variation and works against what might disrupt the flows of the construction work (Ballard & Howell, 1998). For Fauchier (2013), in a pull system that is intrinsically linked to the consideration and promotion of flow management, it is possible for multiple stakeholders to create plans in a collective and participative manner that is helped by real-time information, requirements and collective expertise sharing. The openness and clarity necessary for flow management, promoted by the LPS, are linked to the previous issue of promoting transparency.

6.1.4.3 Creating a sense of urgency and engaging the crew

In 1995, Kotter proposed a new sociological model for managing change in the organisations and tested an innovative approach to the management of the organisation, including those of the construction industry. The Kotter Model is intended to introduce a culture of change management into organisations. Kotter takes a broad look at organisational change and the forces necessary to make the change successful. Through examples of both successful and unsuccessful efforts, Kotter describes what needs to be in place for an organisation to accept change.

Kotter proposed a framework based on three phases: (1) Defrost the status quo, (2) take action to bring about change, and (3) anchor the changes in the corporate culture.

1) The first phase, defrost the status quo, comprises four distinct steps:
   a) The sponsors and leaders of change must create a sense of urgency to the actions and evolutions that the employee will notice or participate in. From Kotter's own experience in leading change in organisations, half of the failures are noticed at this initial step.
   b) Then, even if the sense of urgency has been created at local or individual levels, it is crucial to form a guiding coalition, composed of representatives of as many layers of the hierarchy as possible. The existing management alone cannot lead and give legitimacy to change, especially if the envisaged change touches a large part of the company's employees. Change is nurtured and supported internally by a representative group, influential enough to initiate change and legitimate enough to spread it across the organisation.
   c) Third, it is expected from the leaders that they develop and share an attractive vision of the future. The natural tendency is to follow a leader to achieve a vision and work out one's own position and future within this vision. A clear and shared vision is essential to align individual goals and behaviours; a weak vision or no vision would certainly result in a series of incompatible individual projects.
   d) Finally, the vision must be communicated across the company and, if possible, throughout the whole value stream. In brief, each individual who can be, either directly or indirectly, impacted by the change must be presented with the vision; he/she can then become part of the sponsor team and join the improvement effort. It is then important that the leaders give concrete and tangible signs of their vision through their actions to seal the dynamic for change.

2) The second phase consists of introducing change in practice; this phase comprises three steps:
   a) The first action is to empower the employees working on the vision. This first step is the seminal action step, by which the leaders must prepare the ground

for the employees and promote the emergence of new ideas and approaches and push the old habits away. Creativity can be encouraged at this step as a catalyst of change implementation;

b) Once the first action has been taken, it is important to foster the idea of detecting quick wins, however small they may be. Tangible positive results from change should be captured and disseminated across the company within 6 to 12 months to keep employees motivated in feeding the wind of change, to maintain both the level and the sense of urgency and to serve as validation of the relevance of the efforts. Then, as a logical consequence of the above, the leaders and the change group should consolidate the improvements gained so far, continue producing change and explore greater opportunities and bigger wins in line with the vision that drives the overall effort at each level of the company.

3) The third element involves anchoring the change in the corporate culture. Even if effective change has produced concrete and tangible effects, the new format is still highly fragile, and stability has not yet been established. To ease the change durably in the company, leaders must link corporate success with new behaviour and show the employees that the changed organisation is meant to stay and evolve and that there will be no return to the old times.

Changing an organisation through its leaders', managers' and employees' behaviour is a complex, uncertain and difficult task, that must be well anticipated and managed. Kotter's model for leading change helps design a framework to be followed and communicated to maximize the chances of success. The success of any change initiative within an organisation is directly linked to the team leading the change. Liker (2004) also emphasises the need for planning before any change is undertaken. With successful leadership and a clear plan for change, any organisation can be successful at changing.

As Forman (2010) claims, the empowerment of employees is often discussed as a development strategy in the sector due to industry-specific management challenges, such as complex products and processes, numerous actors, fragmented processes and tasks, etc. Bryman et al. (2005) explored employee perceptions of empowerment. They found that employees indicate two main ways that empowerment can be achieved: ”*through the demonstration of trust; and by allowing operatives to make their own decisions in relation to their work”* (Bryman et al., 2005: 362).

They also found that employees are very aware of the relationship between their competences (experience, knowledge, previous actions and training) and the work they are doing. They recognise that there are limits to their decision-making, and they will ask for assistance from a senior source if they think a decision transcends their experience. The consequences are described by the authors in this way: ”*they considered that by being empowered, they can be able to show themselves as individuals, and their individual achievements could then be recognised. Without the opportunity for empowerment, they feel that they are treated like robots…*” (Bryman et al., 2005: 364).

When management chooses to use the empowerment of employees as part of a management strategy, it is rarely easy. Several barriers are identified in the companies' implementation process of empowering employees. The roles of middle management are often mentioned as being a major barrier to the empowerment of employees due to the lack of a clear definition of the role and middle management's tendency to revert to old habits. Power relations between middle management and employees, and a lack of insight and skills among middle management to change their roles, are frequently mentioned explanations (Forman et al., 2001; Bryman et al., 2005).

It is a fact often forgotten that the empowerment of employees requires not only new tasks, lean processes and health and safety responsibilities, competencies, and so on for employees, but also organisational changes (Dainty et al., 2002; Forman et al., 2001). In the construction sector, this trend is even stronger. The geographic and perceptual distance between senior management at the company and the employee on site can hinder company strategies concerning empowerment being followed up on by local management or supervisors at the site (Bryman et al., 2005). Health and safety regulations are also mentioned as a barrier. The employees on the construction site feel that health and safety regulations can slow down processes and do not always provide safer working conditions (Bryman., 2005).

6.1.4.4 Introducing performance measurement

In *Improving performance through measurement: The application of lean production and organisational learning principles*, Lantelme and Formoso propose guidelines for the implementation of performance measurement:

- *Transparency:* Performance measurement is an essential component of the principle of improving process transparency, but its effectiveness also depends on whether other components of process transparency exist. This means that information must be shared, communicated, and presented in an easy-to-understand format, and a more autonomous, participatory decision-making process should be established.
- *Moments for reflection:* Formal moments defined at specific work times should be established to properly evaluate the results and develop new plans. These meetings should be held in an open and participatory climate, in which questioning, reflection and creativity can flourish.
- *Systematic thinking:* This way of thinking should always be practised so that the variables that influence the results are properly understood. Often, the causes of problems are separated in terms of space and time, and only by understanding the system's complexity and dynamics can organisations find leverage areas. Spending time and effort looking for blame and justification will not change bad results.
- *Reducing CT:* Processing time should be reduced to provide on-time information for improvement. In this specific matter, automated data collection and processing and the use of internal computer networks can play important roles.
- *Simplification:* This means, on the one hand, reducing the number of measures used and, on the other hand, using control systems and procedures that already exist in the firm. In addition, each measure should be analysed in a critical way and, if necessary, be modified to make it easy to understand by everyone in the company. Simplification results in cost reduction and increased reliability.

- *Benchmarking:* The continuous improvement of measurement systems depends on the linkage to the company's strategic objectives, as well as on the establishment of challenging goals. Benchmarking allows managers to constantly revise processes and compare the existing performance to that of competitors.

The following measures were implemented in Stage 1 to follow the guidelines proposed above:

- *Transparency*: The PPC was calculated weekly, contractor-by-contractor, together with the mean. These measures were shared at the beginning of the LPS meeting. Difficulties, such as missing supply or information, were shared at this point so that the whole audience, comprising the site foremen, were aware of the situation and would be able to fine-tune the plans for the following week. The whole team of site foremen met weekly, at 11:00 a.m., to maximise the chances of limiting the time spent in the meeting and orient the meeting in a performing way.

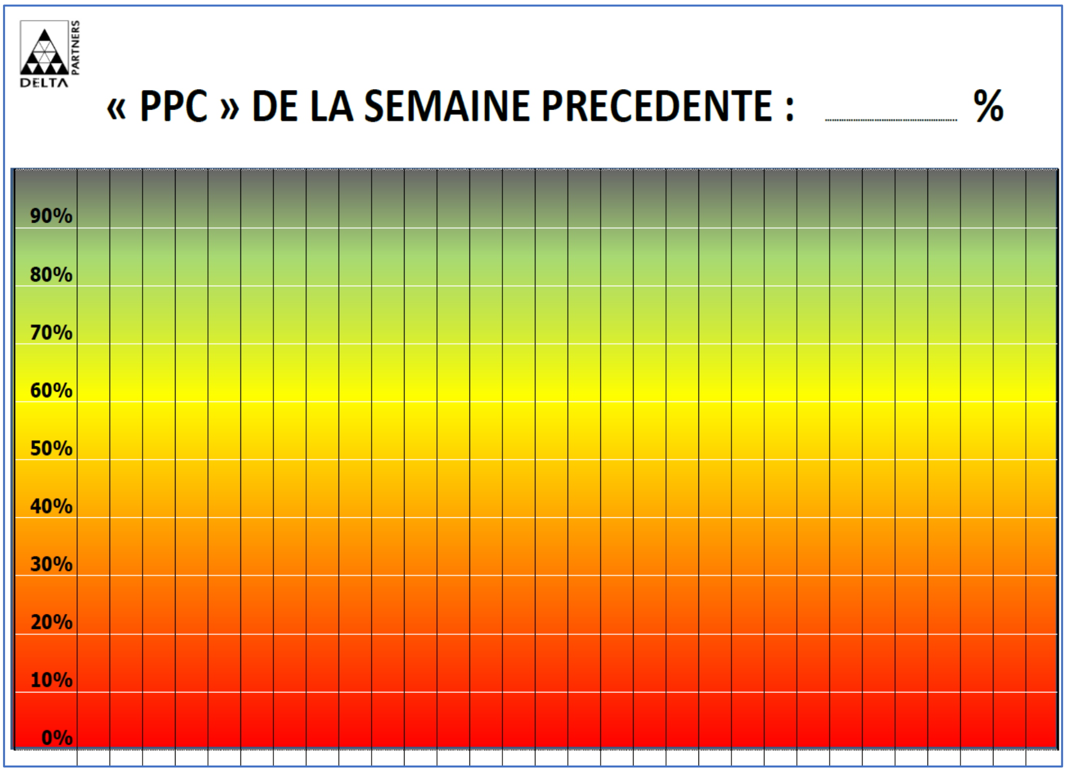


Figure 6.1.4-1 Template of PPC follow-up graph

- *Moments of reflection:* Fifteen-minute meetings were formally organised every two weeks with each foreman. The researcher asked how the system helped daily and how the system or site could be improved and checked with the other parties about how the situation could be improved. An action plan was agreed upon, to be completed within the following two weeks to keep the status quo challenged.

Figure 6.1.4-2   Illustration of a 5S team briefing on Block 1 (block1)

- *System thinking:* If the action undertaken following the above meeting showed positive results, the team started to check on how to integrate the action into the system to repeat it. If the action taken did not have a positive impact on the situation, or had a negative impact, the researcher, together with the main players of the action, met and sought reasons for the lack of success. This strategy initiated a learning process that would help in future steps.

Figure 6.1.4-3 Example of a 5S team training on Block 1 (block1)

- *Reducing CT:* Data collection on PPC was done daily by the client's site manager. The compilation and calculations of the data were done prior to the LPS weekly meeting with the foremen, and the room was prepared to host the foremen (having been cleaned and with heating, lighting, biscuits, a projector, paper blocks, and pens). The foremen were asked to prepare their views on what activities would be relevant for the following two weeks ready to discuss with the others. The information was shared on a screen via a projector, and the log and notes of the array of engagement were taken concurrently, each foreman being given a printed copy at the end of the meeting.

Hence, the meetings were guaranteed to last no more than 90 minutes, most running less than an hour. The meeting was planned to start at 11:00a.m., and was generally finished by 12:00, or 12:30 p.m., at the latest. This preparation (reduced CT and resolute efficiency) helped indicate to the foremen that discipline was a key factor in respecting everyone's time and assured the meetings were expedient. Experience showed that all the foremen showed up at 10:55 a.m. at the latest, to start the meeting at 11:00 a.m.

Figure 6.1.4-4 Example of a LPS Foremen meeting on Block 1 (block1)

- *Simplification:* The PPC was the only measure introduced at this point. It was the first time the foremen were asked to come to a coordination meeting with the power to say ”no I cannot…” or ”Yes I can if…”. From their own feedback, this was quite a revolution in contrast to the classical command-and-control system they had experienced for years.

Each foreman shared his daily ambitions (later transformed into promises) on the works that his team would be achieving each day (location, prerequisite if any, specific works). A table aggregating all the information was completed in real-time on the projector by the researcher. This table was designed to be as simple and readable as possible, with no discussion on technical points or issue-solving allowed during the meetings. If any of these were raised, it was noted and put ”in the fridge” to be addressed with the people concerned after the meeting.

CLOS VIVALDI		**Weekly Work Plan: Anticipation 15 jours**	E:		5	PPC		
Apt/Et	**Lot**	**Activité de la semaine**	**Ve** 9/12	**Sa** 10/12	**Lu** 12/12	**Ma** 13/12	**Me** 14/12	**Je** 15/12
ssol	Laurent	pose réduc pression EF	x					
4D	Laurent	livraison mobiler sani			x			
4D	Laurent	pose mob				x	x	x
3D	Eggo	pose cuisine	x					
C	Eggo	raccordements		x				
2C, 3C	Eggo	pose cuisines			x	x		
3D	Eggo	pose cuisines					x	x
RDC	GILLION	roofing sur dalle (général hors détail et zone lat.)	x					
RDC	GILLION	raccord pieds de mur roofing						x
TOIT	GILLION	pose Zinc	x		x	x	x	
FAC	GILLION	Bardage façade AR						

Table 6.1.4-1 Example of daily work plan

- *Benchmarking*: The PPC level was compared with other sites in Belgium (data from other clients of the researcher such as general contractors BPI, BCE, Section DeWahl) and in France (data from other clients of the researcher such as general contractors Vinci, Bouygues, Leon Grosse). The log curves generated of PPC were kept and pinned on the wall and each participant was able to estimate his or her own level of performance against others on the site and against other sites.

6.1.4.5 Linking site organisation with safety

Although it had been decided not to formally integrate safety in the first stage of development of the solution, the most urgent issues were reviewed, and actions were requested and integrated into the WWP. This consideration related to the lethal and dangerous aspects of the site, such as fixing fences against holes, edge skirtings, reinforcement of iron bar protections, and the like. Despite explanations and gemba walks on site, the site foreman of the structural works did not fully appreciate the high risk and severe consequences of an accident. He promised to arrange to address the detected safety issues, which he did, but sometimes with very little goodwill. In the next photo, safety was put in place on the balcony of the 4th floor. A close look reveals, however, that a large gap remains where someone could fall through; perhaps worse, no element is properly fixed - if any of the wooden elements were to be gently pushed, it would fall four floors.

Figure 6.1.4-5 Example of safety issue in Block 1 (block1): risk of fall in the staircase, 5th floor

This situation is typical of the difficulties faced on site and illustrates the gap that can be found between theory (any site should be properly safe) and practice. Changing this site foreman’s mind to lean practices required time. The following paragraphs and chapters present the research and how the new system helped to progressively solve all the issue identified initially, going beyond the search for production flow stability through the application of pull systems.

6.1.5 Evaluation of research solution on Stage 1.1: LPS

The five site foremen were made aware that their lean journey would collectively start. The two-hour on-site training followed the golden circles path described by Sineck (2009). After a brief introduction to me on site, the *Why* question was addressed, emphasising the opportunity to change the way site managers assure work scheduling and sharing the vision that it was possible to deliver more quickly, more cheaply and better. Examples from previous cases from the lean literature were briefly presented, creating a sense of urgency.

The *How* question was then addressed. The context and general mechanisms of the LPS were presented to provide the site managers with an understanding of the five different steps that would take place (master planning, milestone planning, making ready, WWP and learning). The *What* question logically ended the session. The first rules to follow during the WWP sessions were also shared: (a) discipline and (b) commitment: (a) ”If you can commit, engage yourself. If you cannot commit, do not. Do not promise if you are not convinced”; and (b) ”Arrive on time and prepared, and the meeting will stop on time after just an hour and a half, at the latest”.

The first rule was made to make all aware that the aim was not to get nice promises but commitments that can be kept and measured. The second rule was made to emphasise the importance of respect for people. I asked for a commitment from each of the foremen to the rules, and they verbally agreed. The promise I made was to keep the meetings short, provided that the foremen kept their commitment to arrive prepared and on time. The three first meetings did not start on time (20 minutes late). No site foremen were present on time (counted to the minute), but the meeting closed on time. This adherence to the end time put the foremen in a position in which they were the ones who did not keep their engagement, while I kept mine. The rate of engagement increased after the discovery phase (the first two weeks), and the PPC rose very rapidly (from 30 to more than 60 in the first month, as planned), as the site foremen understood there was no point in announcing overly optimistic promises.

The tendering process in the construction industry can be long and uncertain. The initial group of five foremen representing the companies already chosen were soon joined by other site managers from complementary trades.

On the fifth week, as the client had appointed two more trade contractors to join the team, two newly landed site foremen joined the site and the WWP meeting. Like the first five foremen, they had the two-hour on-site training, were made aware of the rules to follow and committed themselves to respect them. They came on time, which put the late ones in an uncomfortable situation; the group started to be formed. Using the sociological drivers from group-behaviour theories and human bias from game theory or the prisoner’s dilemma were powerful aids in achieving true commitment. The sociological studies showed that a group is composed of seven individuals. From seven on, the sum of individuals is not a sum of individualities but one single group. It is then each individual’s goal to stay in the group by respecting the simple rules. After six weeks, the majority of the site foremen arrived on time for the meeting (most often five minutes in advance), so the meeting could then start on time, the promises of the previous week were checked, and the reasons for not keeping a promise were analysed before starting to plan the following week.

The LPS was used at the WWP level to improve weekly work reliability. The WWP, through the enhanced communication it promotes, facilitates synchronisation among the trades at the site level. Very often, the foremen have very limited knowledge or interest in the work and the constraints of the other foremen on the site. Each foreman focusses on the work of his trade under the milestones given by the project manager in charge of coordinating the work. The WWP fostered openness in communication.

Communication is key to ensuring impeccable work synchronisation, one of the main pillars of LPS. The aim was to double the reliability (raising it from 20 - 40% PPC) in the first month. It is to be noted that, from the first meeting, much emphasis was put on offering a propitious environment in the meeting. The meeting room was clean, heated, ventilated, well-lit, and big, with comfortable chairs, biscuits, and good coffee to lure the site foremen and maximise the chances of their coming before they understood the deeper questions of why they had been asked to come. As a result, expectations were surpassed as the PPC did indeed double in the first month and continued to grow thereafter.

Data were gathered on Block 1 on a weekly basis and consisted of different forms of documentation, which included photos, interviews, PPC, percentage of works made in each apartment, descriptions of observations, examples of visual tools, presentations, and reports on presentations to the developer. The goals in collecting the data were twofold: first, it helped to keep the log of the micro-events current and to structure the learning, and second, it allowed the researcher to build an argument for how applicable the system being built was, and how it solved the issues in comparison with similar indicators as the system became more developed, complex and comprehensive.

6.2 5Ss on site: development of research Stage 1.2

While Section (6.1), *Beginning with LPS: development of research Stage 1.1*, introduced the research by the approach developed in block1, this Section develops the same but in block 2.

6.2.1 Introduction

The research presented in the previous chapter, even though it validated the applicability of LPS on this project, made the researcher aware that LPS alone would not be sufficient to bring flow reliability to the next level. Indeed, although the PPC rose from 20% to 40% in a month, 40% is not considered optimal and does not prove planning effectiveness. After another period of a month, where PPC found resistance at 65%, it was decided to tackle other issues that had not been addressed in Stage 1:

- Serious safety issues,
- No general site organisation or visible spatial layout,
- Lack of quality monitoring, and
- Poor logistics.

Because of the human risk factor, safety was considered non-negotiable in Stage 2. The quality of the works on site had improved (-40% snag or defects detected) as PPC went up; this rise was interpreted as a fortunate collateral consequence of the better coordination of the work and, hence, better knowledge of the work, which had led to a reduction in busy work.

However, this is only a supposition at this point, and further studies were needed to validate this hypothesis as very limited literature had been found on this correlation as applicable to this case (i.e. real estate work done by SMEs). The lack of quality monitoring could then be addressed later in the research, while logistics and general organisation were put aside. Considering organising the site layout and creating spatial visibility would be a prerequisite for optimising the logistics, it was decided that the health and safety would be coupled with the general problem of disorganisation for the next stage of research.

6.2.2 Diagnostic, clarification of the problem

The researcher first had to check that the general disorganisation was still an issue in Stage 2. It was noted that a large number of reasons for not keeping the site promises were based on site congestion (e.g. delay in the start of the task or the impossibility of starting it). Thirty-five percent of the causes of not keeping promises arose from the congestion of the area where the activity was to start.

Next was an issue of manpower (25%); the trade construction managers confessed that, with the labour shortage, resource allocation became an important issue. Consequently, the labour was distributed at the minimum levels, with no extra contingent workforce in the right quantity to execute the work that could be done on site. The trade project managers engaged themselves in bringing additional human resources if the site could absorb them. I seized this opportunity to introduce the notion of pull planning and demonstrated that the former push system was irrelevant.

6.2.3 Definition of objectives for the solution

Often considered as the first step to the other lean manufacturing practices and to creating a visual workplace (Hirano, 1995; Galsworth, 1997), the 5S method facilitates site visibility (transparency) through concrete action visible to anyone and eases the standardisation of the workplace in terms of classification (naming), location, quantity, type, and so forth. In the manufacturing industry, keeping the plant clean and orderly plays a key role in the reduction of variability. Disorder and dirt cause quality problems hinder problem-solving opportunities and may lead to undesirable ergonomic and safety situations (Davy et al., 1992; Forza & Choo, 1996). Given the extended literature on the impact of 5S on worksites, its implementation was chosen as a solution to test for both health and safety concerns and the site's lack of spatial readability.

The objective of this stage was to transform the perception of the site into a production plant where 5S would be implemented as a routine in maintaining a safe and sound environment. Each step of the process would be followed and visually shared.

6.2.4 Develop further the solution

Although the PPC could be considered satisfactory (65%), some zones were still missing planned-for resources, limiting the pace of work. From the analysis of the reasons promises could not be kept, the bottleneck identified at this point was the site's physical disorganisation, even though the supply and logistics were correctly managed, that information was being correctly transmitted, and that only minor quality problems were being detected. The plan was to start with the first S of the 5S approach, which consisted of removing anything (rubbish, storage, material, tools, etc.) which was not needed on site, and giving visibility to the work to come (the aspiration zone) before introducing the next four Ss (set in order, sweep, standardise, sustain) and creating a 5S routine, such as the weekly coordination meeting.

A 30-minute training session was developed to train the foremen, and visuals were prepared which would be pinned up on the site and in the site bungalows. To avoid creating a bottleneck in the removal of waste, three bins were ordered, and the emptying of each was pre-ordered for the day of the action. All necessary tools and materials had been ordered and delivered (wheelbarrows, shovels, brooms, dust protection, painting drawer), and two helpers were specially appointed for the day to remove the rubbish.

6.2.5 Action taken

The foremen were first briefed for 30 minutes: the 5S method was explained, the objectives shared (identify any waste and remove as much as possible) and their role explained (they were the operational leaders of the action).

With every workman, site foreman and construction manager participating, the action was deconstructed into the following steps:

- The workmen were notified the morning of the action that they would have to meet at the bungalows.
- The work was stopped for 30 minutes.
- A stand-up briefing on the 5S approach was given on site to explain the approach (why, objectives, roles, and method).
- Each foreman and worker was challenged by the management of the site to determine the unnecessary materials and waste.
- Colour coding indicated what was to be evacuated.
- The workers removed the waste and unnecessary materials.
- Helpers cleaned and helped in the removal.
- A debrief was made at the end of the action, with the foremen.

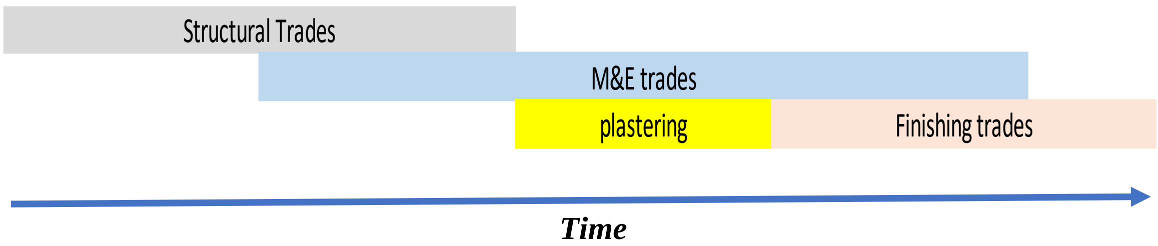
This action was repeated on three consecutive weeks, and semi-structured interviews with the foremen were conducted, the results of which are presented in the table in the following page.

Trade	Appraise the action	Comment	Suggestions
Structural works	2	"5S is time-consuming. We are already late in the concrete work on the 5th floor."	/
Mechanical	5	"It is a very good idea. We can work better after the structural work.". "The place is clean." "I hope 5S carries on."	"The mason should take a more active role"
Electrical	4	"I see 5S more applicable to our plant and warehouse".	/
Ventilation	3	"It comes too late and may be not carried on."	Start a routine and control the results
Plastering	2	"We are not impacted. We are used to working in dirty conditions."	/

Table 6.2.5-1 Feedback from the foremen on site following the application of 5S

The results of this semi-structured debrief were unsurprising. While the structural work and plastering foremen were not convinced of the approach, the mechanical and the electrical trade foremen were supportive of it.

The classic sequence of the work, upon which the master programme was built, explains this difference of perception. The following graph illustrates the classical sequence of the macro-trades:



While people in both structural and plastering trades are used to working in their area with limited overlap, people in the mechanical and the electrical trades must work in coordination with other trades. It was then clear that more time needed to be spent with the foremen from both the structural and plastering trades. The management of the contractors was invited on site, the *Why* was revisited with the foremen, and the developer insisted again on the importance of the method at this site as the start of a new model that could become the next standard for their future development. The support of the client gave weight to the initiative, and the managing directors of the trades understood the message, so both foremen became more collaborative.

Support (or non-financial sponsoring) of the hierarchy is considered a key element of the success of a lean approach (Pius et al., 2006; Ballard, 2007; Ward, 2015). The importance of direct involvement of senior management confirmed this finding from Bateman (2001). Spear (2004) also highlights this point. In discussing leadership training at Toyota, Spear describes in detail how senior managers personally support improvements, while Liker (2004) describes the Toyota principle of Genchi Genbutsu, which means *go see for yourself* . Direct involvement by senior management, by displaying commitment to the improvement team, helped to provide motivation. Decisions regarding improvements were then made much sooner, and this experience helped to maintain the momentum of the idea that there was only one way forward.

Once the site got rid of all the waste and unnecessary materials, the layout of the site was optimised. All the contractors were invited to share their storage requirements and ideal locations. Discussions and negotiations were conducted to find a trade-off layout that would suit every foreman's requirements. The result was then pinned on the wall to visually indicate the layout and general spatial organisation of the site. A global meeting then took place to inform all the workmen, foremen and contractors' managers of the rule that had been collectively constructed.

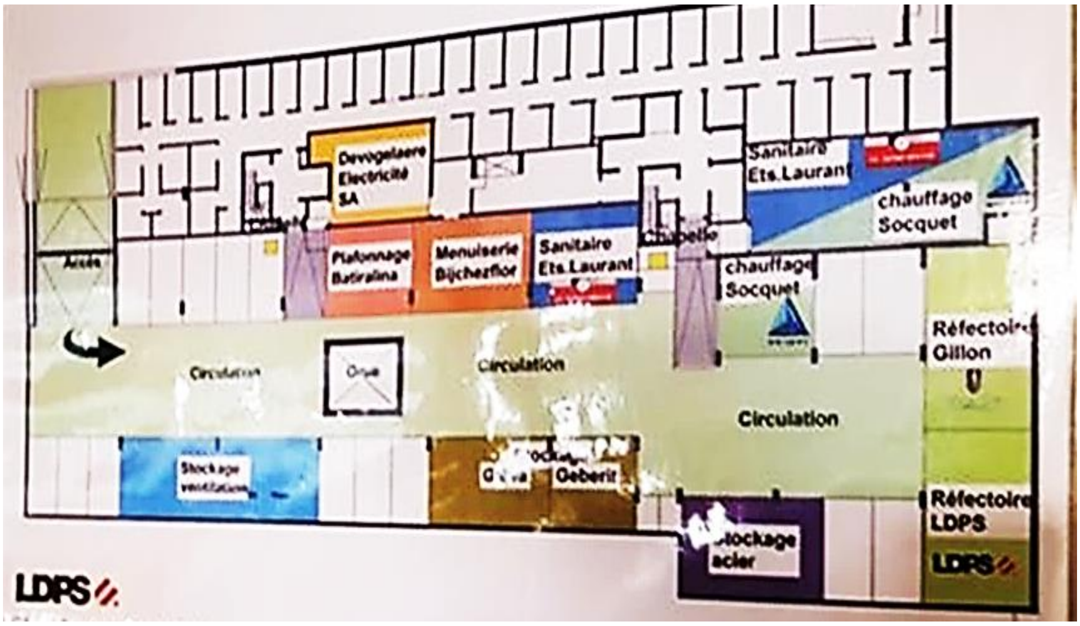


Table 6.2.5-2 Example of site visual management

6.2.6 Evaluation of research solution Stage 1.2: 5S

6.2.6.1 Impact on spatial organisation

The visual impact was immediate. The site was clean, and the paths, storage areas and transit areas were readable. The PPC continued to rise to reach 70%, which was the first target assigned. These actions consolidated and enlarged the group, providing coherence and respect between the trades. The first mutual aid and concern between foremen was noticed, which had been unlikely two months earlier, when each site foreman cared only for his section of work, regardless of the other trades.

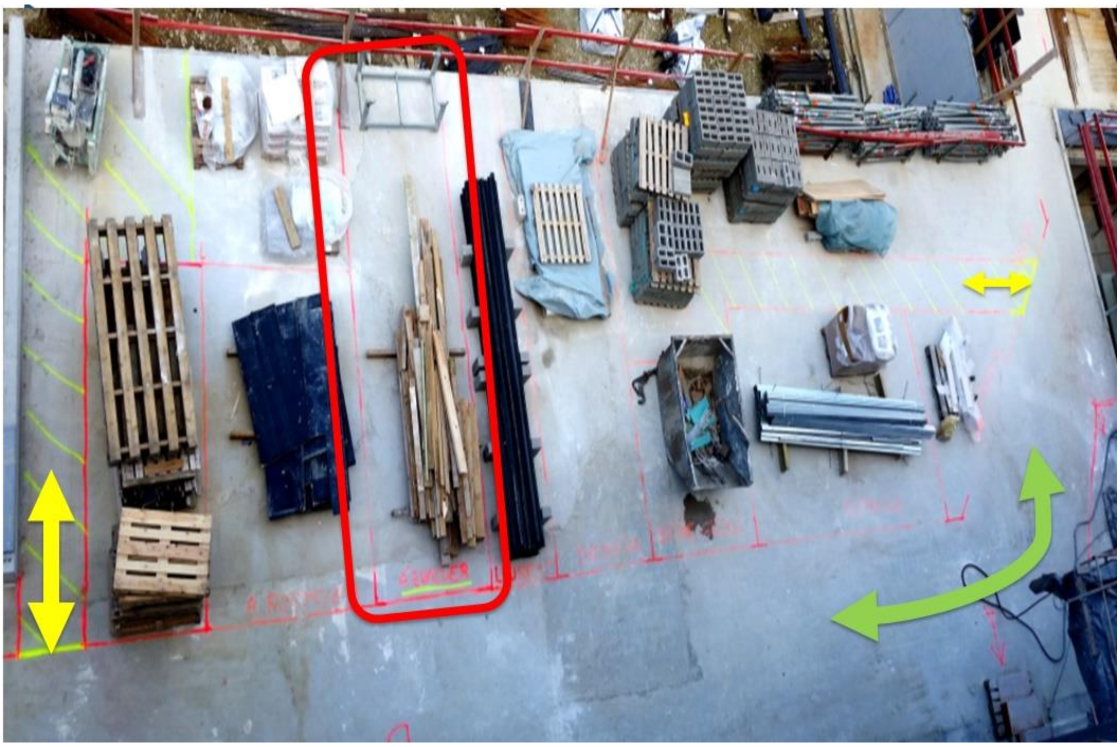


Table 6.2.6-1 Top view from the storage area after 5S: footway in storage area (yellow arrows), visually indicated storage area for each trade (i.e., red rectangle), general pathways (green arrows)

The site foremen were interviewed again, after another month, about their perceptions of the action (plus, delta, why, for what); the results were encouraging as they all showed interest in the approach and commitment to maintaining it.

Trade	Appraise the action (1–5)	Comment	Suggestions
Structure	4	"I must admit that 5S eases our daily work. We waste less time, and safety is better."	Work on the safety of the raisers in the erection phase
Mechanicals	5	"The site is great to work on. We are going well on schedule."	"The mason should take a more active role."
Electricals	5	"We can work even better with the mechanical trade foreman."	/
Ventilation	4	"We can come, work, leave and come back with very little disturbance for the schedule."	Generalise to the other sites
Plastering	2	"You can continue your 5S; it does not disturb my trade, working alongside others."	/

Table 6.2.6-2 Feedback from the foremen on site following the application of 5S

Both the position and perception of the plasterer trade foreman diverged from those of the other trade foremen. Despite three dedicated meetings, explanations and affirmation from the client, this contractor did not understand the method. The areas in which he worked were quite messy, his work was late, and 70% of the promises that were not kept on site were his promises. The client decided to replace this contractor with another, taking the precaution of warning the replacement about the ongoing on-site LPS and 5S integration. The results on site were then noticeable:

Table 6.2.6-3 Example of 5S on the slab

Table 6.2.6-4 Detail of visual management of 5S on the slab

Table 6.2.6-5 Detail of visual management of 5S on the slab

Table 6.2.6-6 Examples of visual management of 5S on the slab and inside

6.2.6.2 Impact on safety

Before the application of 5S, the report from the independent health and safety inspector on the site contained an average of 14.5 remarks, amongst which 3.2 were very urgent or critical. This inspector had not taken part in the 5S method. Over three months, the average fell to 3.5 remarks, and none were very urgent or critical. From this perspective, and considering this measure, we can conclude that 5S had an important impact on safety on-site.

Table 6.2.6-7 Detail safety improvement (full handrails all around)

6.2.6.3 Limitation of Stage 1.2

Despite the application of the WWP and of the 5S methods, PPC continued to fluctuate and needed to be stabilised to ensure work stability.

Systematic questioning of the site foremen on the reasons for the unfulfilled promises and a *five whys* analysis when possible or appropriate were conducted. Immediate answers hid the real difficulties faced by the foremen. A natural tendency to not reveal constraints and bad news was still deeply anchored in their culture.

6.3 Focus on make ready: development of research Stage 1.3

While Sections (6.1), *Beginning with LPS : development of research Stage 1.1*, and (6.2), *5Ss on site: development of research Stage 1.2*, introduced the approach developed in block 1 so far with the implementation of the WWP to be later complemented by the 5S approach, this section introduces the research developed in block 1 but with the addition of the make ready phase from the LLS in the scheduling system proposed and developed by the researcher.

6.3.1 Introduction

The two previous chapters have presented the results that can be achieved through the implementation of a WWP as part of the LPS and 5S approach and how both the researcher and the team were able to learn from the measures taken on site: the WWP from the LPS and 5S approach led to measurable improvements.

However, as in the previous situation, although the PPC reached between 50 - 70%, which can be considered reasonably high and levelled, it did not rise at a constant rate to reach the optimal 85% -90%, empirically considered a learning asymptote. The following graphs illustrate the PPC over the six-month period.

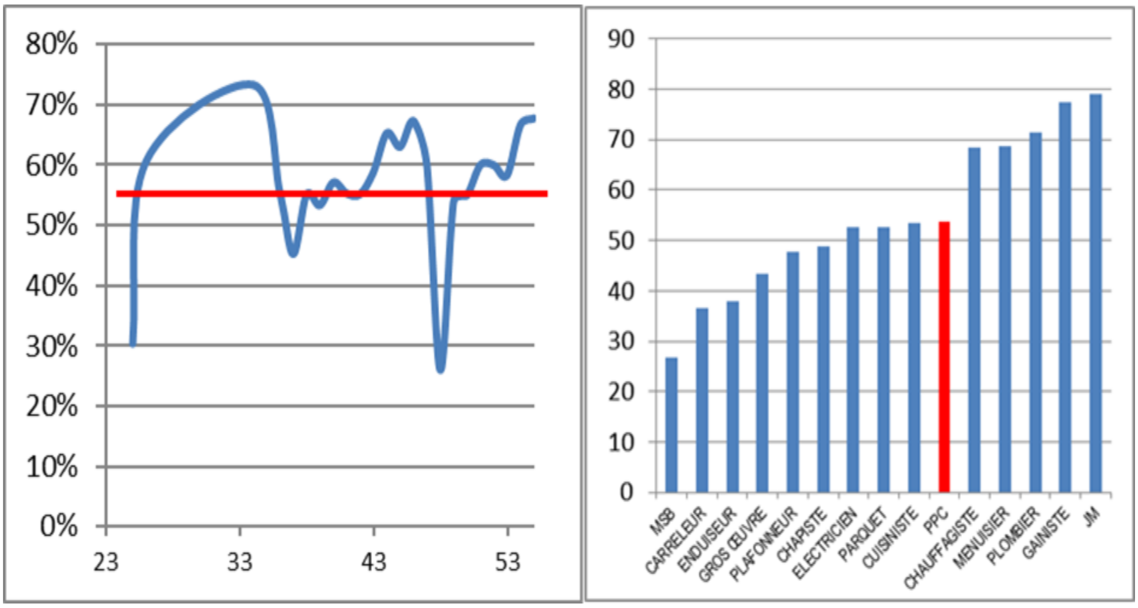


Table 6.3.1-1 PPC % log (left) and categorisation of reasons for not completing promises (right)

Two misfortunes in the organisation were notable, represented by the dips, and which, importantly, impacted the PPC level:

- *First drop:* The method had been initiated in April 2014 (week 14). The work on site was planned to continue over the summer holiday period, traditionally July in Belgium. The method, after only four months, was too fragile to resist the summer disorganisation: the foremen faced crucial difficulties in getting a clear vision of the available resources, both in terms of materials and workforce. The routine was also heavily impacted by the fact that all the foremen were absent at some point in July. For all these reasons, it has been decided to consider this drop in the PPC a misfortune.
- *Second drop:* The plasterer had not been supplied in week 46, so the electrician and the plumber (next in the sequence) could not work as planned, and the PPC immediately dropped below 30%. This correlation illustrates the interdependencies of the flow of works and the domino effect that can occur because of a misfortune in one link of the chain.

It is also notable that immediately after those «accidents» the PPC went up again to reach 70%. The routine of the system and engagement to improve can be illustrated by this measurement.

6.3.2 Diagnostic, clarification of the problem

However, the work remained behind schedule, despite the reasonable PPC. A root cause analysis was conducted with the foremen to understand why, and a large proportion of the work desynchronisation was found to have originated from a lack of activity preparation feeding it. The table and graph below illustrate the data recorded in block 1 concerning the reasons for not completing the promises made in the collaborative phase of the LPS. The reasons have been provided and categorised from the self-assessment of the site foremen. Sixty percent of the reasons referenced lack of human resources, the domino effect, or missing information.

Bloc 1 : reasons for not completing LPS promises

Manpower shortage	50	21%
Direct consequence of others' lack	40	17%
Making Do / improvisation	30	13%
Incomplete or missing information	20	8%
Interface with one or more other trade	20	8%
Late material / broken	20	8%
Wheather	20	8%
Overestimation of the works capability	15	6%
Rework	10	4%
Preworks not identified	10	4%
Change by the Client	2	1%

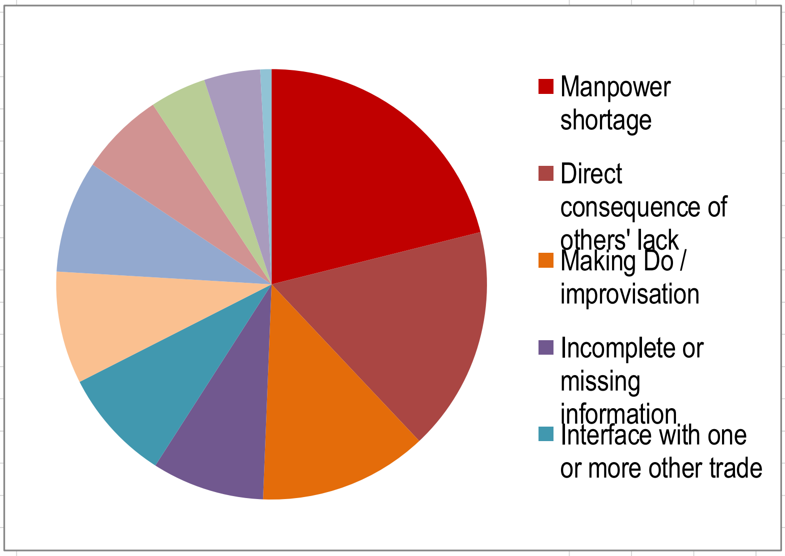


Table 6.3.2-1 Categorisation of reasons for not completing promises in block 1

The site foreman did not appoint the workforce and worked with the drawings that the site manager had given him. All the above reasons should now be treated at the management level, with better and more systematic preparation for the coming activities.

6.3.3 Develop solution

The make ready phase of the LPS offers the opportunity to systematically prepare the activity employing a look-ahead window. For Ballard et al. (2007), the key to make ready» is making sure that the activity is ready to start in all ways. This includes the availability of labour, equipment, materials and anything else required for the activity to start. For instance, if an activity is ready to begin, and scheduled to begin, but an important piece of equipment is absent, that activity would not be an assignable activity. The resources that would be taken up by this activity would be put to other uses until everything required for that activity was ready and waiting for the construction work to start.

The use of LPS and make ready are not easily separated; they are interdependent. In order for LPS scheduling to work efficiently, a make-ready process must be in place. For such a process to be implemented, an LPS system should be in place. Furthermore, these two factors are also closely related to the next subject, pull scheduling.

The development of a solution to the implementation of a make-ready process on site respected the key success factor of lean implementation from *Improving performance through measurement: The application of lean production and organisational learning principles* by Lantelme and Formoso:

- *Transparency:* The information was shared live, initially through an Excel spreadsheet being projected on the wall, for direct understanding of the information, later moving on to a Google spreadsheet folder that was constantly accessible and modifiable by the site managers.
- *Moments for reflection:* A routine weekly meeting was organised (either in person, on site, or over the phone) to decide upon the actions that were necessary to prepare the activities for the look-ahead window.
- *Systematic thinking:* Regular debriefing interviews and improvement meetings with the site managers were organised to detect how to make the system more efficient.
- *Reducing CT:* The make ready meetings lasted 30 minutes at most.
- *Simplification:* Access to the system was key to engage the site managers. The Excel programme developed automatically generated colour codes to indicate (a) the urgency of a task (from green to red), (b) how much preparation had been completed for each activity, and (c) what prerequisites had been checked. The system automatically updated the visuals to lead the site managers and aid

in the completion process.

- *Benchmarking:* Information on the number of tasks prepared and the anticipation times of other sites in Belgium and France gave an indication to the crew of their performance, and it challenged them.

SUIVI PREPARATION TRAVAUX														YSAYE
03/06/2014		15/07/2014			anticipation:	6	semaines							
Activité	Durée	Début	Fin		Contrat	Sécurité	budget	Plans éxé	Approuvé	M Œuvre	Materiel	Materiaux	Tvx prérequis	Surface prête?
GAINISTE	**70 jours**	03/06/2014	08/10/2014											
Gainage horizontal	8 jours	03/06/2014	13/06/2014											
Placement appareil plafonier	2 jours	06/06/2014	10/06/2014											
Carrotage Silicat	2 jours	02/07/2014	03/07/2014											
Gainage vertical trémie	3 jours	04/07/2014	05/08/2014											
Isolation gainage vertical	2 jours	06/08/2014	07/08/2014											
Placement appareils muraux	3 jours	16/09/2014	18/09/2014											
Placement ventouse	2 jours	19/09/2014	22/09/2014											
Placement ventouse faux plaf	3 jours	23/09/2014	25/09/2014											
Raccordement électrique	5 jours	30/09/2014	06/10/2014											
Mise en route	2 jours	07/10/2014	08/10/2014											
PLAFONNEUR	**35 jours**	18/06/2014	03/09/2014											
Plafonage	3 jours	18/06/2014	20/06/2014											
Pose cornières	2 jours	18/06/2014	19/06/2014											
Enduit prédalles	2 jours	23/06/2014	24/06/2014											
Pose des cadres de faux plafond	2 jours	13/08/2014	14/08/2014											
Pose plaques faux plafond	2 jours	02/09/2014	03/09/2014											
CUISINISTE	**48 jours**	24/06/2014	29/09/2014											
Prise de mesures	0 jour	24/06/2014	24/06/2014											
Livraison cuisine	1 jour	04/09/2014	04/09/2014											

Table 6.3.3-1 Example of make ready table - Template

Based on the extended literature on LPS and the make ready approach, 10 prerequisites were decided upon:

- *Contract:* Is the activity contractually defined?
- *Safety:* Has the contractor planned the activity in the safety booklet?
- *Budget:* Is the activity budgeted? Has the budget been agreed upon?
- *Shop drawings:* Have all the necessary shop drawings been issued (either by the engineer or by the contractor)?
- *Approved:* Have all the necessary shop drawings been validated by all the parties (engineers, contractors, clients, consultants, and so on)?

- *Manpower:* Are the workmen dedicated to their tasks on site or scheduled to show up at the due date? Have all the administrative duties been fulfilled at the local authorities to prevent any legal issues?
- *Tools:* Are all the tools on-site? Have the workers been trained in the use of the tools?
- *Materials:* Are all the materials necessary to make the activities on site? Are they stored where appropriate?
- *Pre-works:* Has the prerequisite work (by the contractor or by others) been done to a satisfactory level?
- *Surface ready:* Has the area where the work is due been made ready (i.e. accessible, clear, and clean)?

The programme was designed to be as visual as possible, based on the visual management fundamentals. The start dates were automatically coloured from green to red to indicate the level of urgency when checking the prerequisites, and the boxes left white indicated activities which lay outside of the look-ahead window. Hence, the site manager could focus on only the most urgent and less-prepared tasks if time was short and make sure, by scrolling down, that no activity had been missed. The programme contains boxes to be ticked by the site manager. When a box was ready, the site manager could insert a ”1” in it to indicate the prerequisite had been checked. The box was then coloured in green to ease readability and visual management.

6.3.4 Action taken

Dedicated training in LPS make ready was developed, and each site manager was coached in the first steps of the use of the programme. It was feared that the site managers could feel this monitoring and transparency as a threat of indigence, but the method was quite welcome in principle. In practice, the site managers, even though they understood the usefulness of the programme in the release of site preparation checks, faced massive difficulties in freeing time and feeding the system. The concepts of *shielding* and the *make-ready process* in LPS were introduced into the daily work plan system to keep the PPC high and increase work productivity to make up time on the schedule.

SUIVI PREPARATION TRAVAUX														YSAYE
03/06/2014		15/07/2014				anticipation:		6		semaines				
Activité	**Durée**	**Début**	**Fin**		Contrat	Sécurité	budget	Plans éxé	Approuvé	M Œuvre	Materiel	Materiaux	Tvx prérequis	Surface prête?
GAINISTE	**70 jours**	03/06/2014	08/10/2014		1	1	1	1	1	1	1	1	1	1
Gainage horizontal	8 jours	03/06/2014	13/06/2014		1	1	1	1	1	1	1	1	1	1
Placement appareil plafonier	2 jours	06/06/2014	10/06/2014		1	1	1	1	1	1	1	1	1	1
Carrotage Silicat	2 jours	02/07/2014	03/07/2014		1	1	1	1	1	1	1	1	1	1
Gainage vertical trémie	3 jours	04/07/2014	05/08/2014		1	1	1	1	1	1	1	1	1	1
Isolation gainage vertical	2 jours	06/08/2014	07/08/2014		1	1	1	1	1	1	1	1	1	
Placement appareils muraux	3 jours	16/09/2014	18/09/2014		1	1	1	1	1	1	1	1	1	
Placement ventouse	2 jours	19/09/2014	22/09/2014		1	1	1	1	1	1	1	1		
Placement ventouse faux plaf	3 jours	23/09/2014	25/09/2014		1	1	1	1	1	1				
Raccordement électrique	5 jours	30/09/2014	06/10/2014											
Mise en route	2 jours	07/10/2014	08/10/2014											
PLAFONNEUR	**35 jours**	18/06/2014	03/09/2014		1	1	1	1	1	1	1	1		
Plafonage	3 jours	18/06/2014	20/06/2014		1	1	1	1	1	1	1	1		
Pose cornières	2 jours	18/06/2014	19/06/2014		1	1	1	1	1	1	1	1		
Enduit prédalles	2 jours	23/06/2014	24/06/2014		1	1	1	1	1	1	1			
Pose des cadres de faux plafond	2 jours	13/08/2014	14/08/2014		1	1				1	1			
Pose plaques faux plafond	2 jours	02/09/2014	03/09/2014		1					1	1			
CUISINISTE	**48 jours**	24/06/2014	29/09/2014		1	1	1	1	1	1	1			
Prise de mesures	0 jour	24/06/2014	24/06/2014		1	1	1	1	1		1			
Livraison cuisine	1 jour	04/09/2014	04/09/2014		1						1			

Graph 6.3.4-1 Example of a filled make ready table

The data collected were photos of the site, layout plans, interviews with the foremen, PPC collection and the weekly percentage of completion of each.

6.3.5 Evaluation of the research solution Stage 1.3: make ready

The application of make ready allowed an increase in the level of rigour in the preparation of the tasks. While only 32% of the tasks were made ready one week before the beginning of the task, three months later this proportion rose to 78%, while the PPC stabilised at around 70%.

Although the data should be filled in by the contractor as a self-administered process for better performance, none of them took full advantage of it. On other sites involving bigger companies and more mature lean performance processes, this program is pulled by the contractors, some of whom have integrated it into their quality approach. On this site, the client site manager met and called the contractors to feed the system.

	Appt	Rmqs Rprov	
	P01	0	
	P02	2	
	P11	0	
	P12	0	
	P21	0	
	P22	0	
	P31	0	
	P32	1	
	P41	9	
	Q01	2	
	Q02	3	
	Q11	0	
	Q12	0	
	Q21	0	
	Q22	0	
	Q31	1	
	Q32	0	
	Q41	0	
	R01	0	
	R02	0	
	R11	0	
	R12	0	
	R21	0	
	R22	0	
	R31	0	
	R32	0	
Nombre total remarques		18	
Moyenne		**0,69**	**remarques par appartement**
Nombre d'appts sans remarque		20	
Moyenne		**77%**	**d'appartements sans remarque**

Table 6.3.5-1 Number of snag works per apartment

6.4 Section summary

This section summarises the approach developed in block 1.

The researcher initiated the research on block 1 (of 3) of the last phase (of 3) of a 10-year real estate development project. The client (the developer) had a dual problem concerning scheduling and quality (see (4.1) *Problem diagnostic and*). The research on block 1 focused on validating the applicability of existing lean-construction-based systems by the application of two phases of the LPS (WWP and make ready) and of the 5 S approach.

The results that were measured from this are:

- No major safety issue was reported
- Only six snagging works existed at completion (out of 35 apartments)
- 100% of the apartments were delivered earlier than planned (mean of -2.5 per month)
- Construction cost decreased from previous phases by 1.9% (considering 1.5% inflation)

Case Study on block 2: Development of the solution

While Chapter (6), *Case Study of block 1: inception of lean*. described the research made and the approach developed in block 1, this chapter follows the same path in block 2. It is organised into four sections:

- Section (7.1), *Raisers technical improvements: development of research Stage 2.1,* develops the research made on block 2 that capitalises on the findings and limitations raised in block1 and developed in Chapter (6) *Case Study of block 1: inception of lean*, where the stability of the production flow has been improved but new where the research made new improvements emerge as described earlier.
- Section (7.2), *Beyond PPC, need for a stability indicator. development of research Stage 2.2*, develops how a stability indicator was suggested to continue the improvement in flow stability and measure the output.

- Section (7.3), *Takt planning: Development of research Stage 2.3*, addresses how the takt approach has been adapted and implemented to narrow the stability output as measured in the previous section.
- Section (7.4), *Section summary*, concludes the chapter and introduces the following chapter concerning the research made in block 3 that involves the application of a kanban-based approach.

The research continued from 2015 to 2017 on block 2 (of the project that comprised of three). Block 2 comprised of 65 apartments which layout, room distribution, size and global M&E technics did not fundamentally differ from block 1.

Picture 6.3.5-1 on the next page shows the concrete works of Block 2, just behind the ground platform, being prepared in the front. It is to be noted that only one path (right side on the picture) allowed the loading of materials. This constraint was seized upon as an opportunity to introduce pull logistics in correlation with the pull planning already running to ease the production flow and avoid material congestion or production disruption.

Picture 6.3.5-1 View of block 2 building (back) and block 3 ground levelling in front

6.5 Raisers technical improvements: development of research Stage 2.1

6.5.1 Introduction

Block 1 experienced positive impacts following the implementation of LPS and 5S in the search for a stable production flow: a higher PPC than on classically project-managed operations, fewer snag works at completion and a higher production rate (block delivered earlier than planned), as well as the emergence of other flows: technical, safety, human. However, as a reminder and illustrated in the picture below, there were high risks of fall in the raisers in block 1. This was not to happen any more on this site as a correlational effect of lean.

Picture 6.5.1-1 Example of safety issue (technical raisers) in block 1 (reminder)

It was then decided that safety in the raisers was the main improvement to be made moving from block 1 to block 2. The consequences of the fall of a worker would, without doubt, have the most negative impact on the project. Plus, improving safety would necessarily introduce technical constraints that could be treated in the row. Improving safety in the raisers would need improvements in the works sequence, and vice versa as technical and safety issues are intrinsically related.

6.5.2 Diagnostic, clarification of the problem

Physical progress in the raisers represented both a safety issue and a bottleneck in the start of the work which delayed the whole workflow. Consequently, the workers decided to work in an unsafe “let’s make do” mode. From their self-assessment, it appears they had limited micro-supervision. The need for works coordination in the raisers (a nominal part of the whole site) had, in fact, not been identified, either by the foreman or by the site manager. Neither had the impact of this lack in the production flow nor the risk of fall and safety in general.

6.5.3 Definition of objectives for the solution

The researcher proposed to first address the works coordination issue, in relation to safety, with the objective of improving the flow stability on block 2. The LPS and 5S process introduced in block 1 would not change. As a consequence, it was expected that the PPC would rise and maintain a level of 80%, that the progress of the works in each apartment would be more stable from one week to the next and that the safety issues that had been identified in block 1 would not appear in block 2.

6.5.4 Develop solution

A series of three workshops was organised to address the problems of works coordination and safety. These workshops aimed at defining micro-planning to micro-synchronise the works in each raiser and provide concrete solutions to both problems in terms of what to do (coordination) and how to do it (safety). The assumption made here was that the effect of the experience of implementing LPS and the 5S in block 1, and continuing this in block 2, would also help stabilise the works at this stage.

6.5.5 Action taken

To be in accordance with the lean methods that had been introduced in block 1, the researcher decided to apply “kaizen blitz” mode workshops to resolve the problems identified. All the parties that could be impacted or would need to take action or make decisions to solve the issues were invited to these workshops to assure a collaborative redesign and planning of the works. The trade foremen and the project managers of all the technical companies (M&E: plumber, electrician, ductworks and structural works), the architect and the client were present.

Examples of the output of these workshops are presented in the figures below. It can be seen that the internal design of some raisers had to change to ease the operations within. Simplification of the design also helped the developer to promote smaller sized raisers that would increase the total surface sold.

The walls left open in the concrete structure to access the raisers were also defined on the raiser plans to provide a more ergonomic organisation and ease the workers' interventions. This decision would normally have been left to the structural works foreman, with no consultation with the technical trades who would work in. In fact, the latter would discover the choice of the former when the concrete was poured, and the formwork taken off, accepting this "information" as a constraint. Given that the raiser generally comprises four walls, the probability that the wall left open would fit the technical and organisational constraints of the M&E trades was 25%, favouring making do. In the following illustrations, the left side shows the technical drawing as the M&E engineer drew it. No indication of the sequence was mentioned, the whole organisation of the works on site left to the foreman, with no possibility of design improvement. The result of the workshop has been a rethink of the location of each element of the M&E to ease the fixing on site without altering the technicalities themselves. The sequence of the works has been determined for each raiser and indicated on each plan. From this, it has been made possible to leave a wall empty of concrete, hence making it non-structural, and to indicate it on the drawings (in green in the pictures below). This wall would be filled with blocks when the M&E works were completed and checked, in sequence and safely.

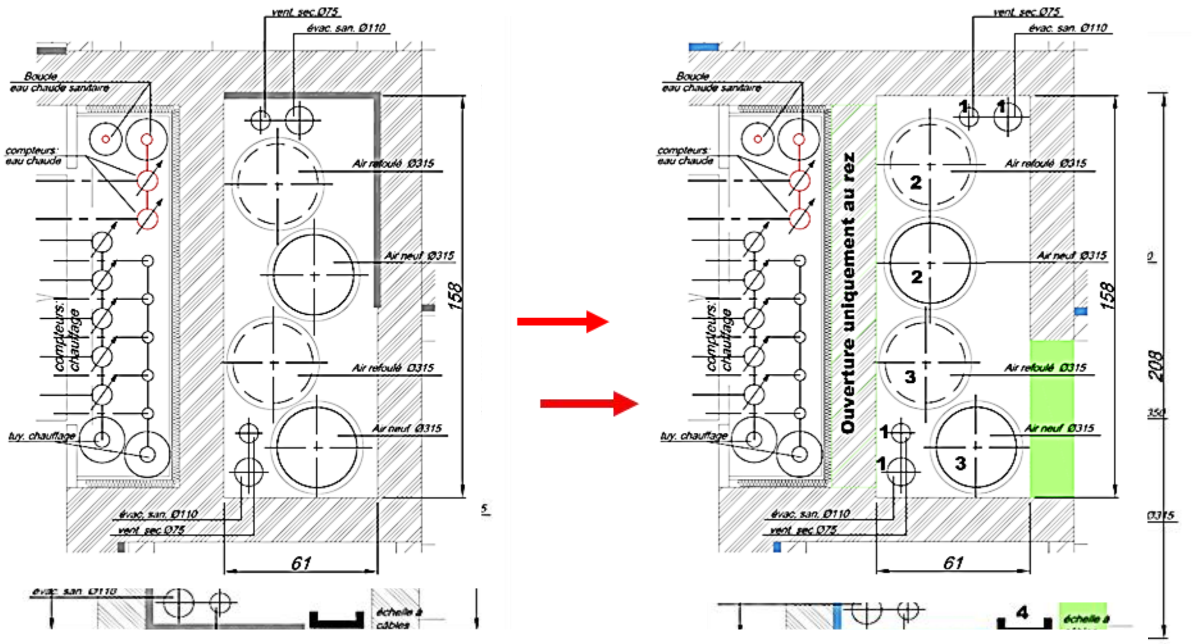


Table 6.5.5-1 Detail section of the M&E of raiser 12-13 of block 2

Table 6.5.5-3 Detail section of the M&E of raiser 6 of block 2

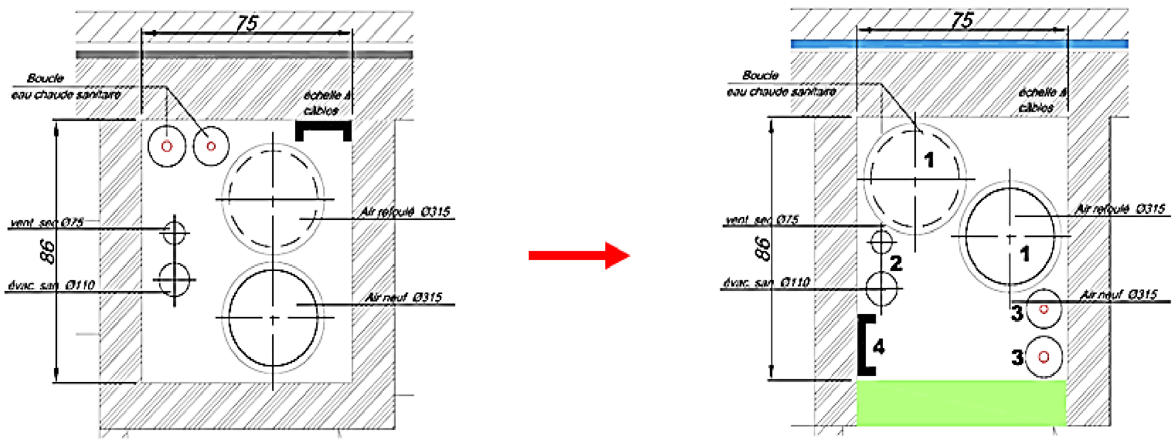


Table 6.5.5-3 Detail section of the M&E of raiser 10 of block 2

The data which were collected on a weekly on site included:

- PPC
- Works progress on each apartment
- Number of remarks from the Health & Safety Officer

6.5.6 Demonstration of the solution

The solution went beyond expectations in that it helped improve the two problems (technical coordination and safety) and allowed the creation of a temporary slab waterproofing that would create a better working environment for the floors beneath in the case of rain.

The solution consisted of laying:

- a temporary waterproofing layer (at the waterproofed level)
- an iron trellis that supported the weight of five men (450 kg)
- a first row of blocks
- and erecting the wall of the raisers according to the coordination plan defined in the kaizen

100% of the promises made concerning the raisers in the LPS WWP meeting were met, no comments were received from the Health & Safety Officer regarding the works in the raisers, and the all the workmen interviewed agreed that the solution greatly improved the working environment in the raisers. The lead time to complete the raisers at each level has been decreased by 70%. No quality issue has been detected. The raisers were no longer a bottleneck.

Figure 6.5.6-1 Steps 1 to secure the works in the raisers of block 2

Figure 6.5.6-3 Step 3 to secure the works in the raisers of block 2

6.5.7 Evaluation of research solution on Stage 2.1: Raisers technical improvements

The impact on both quality, safety and time saved has been measured as a direct effect of the solution developed collectively. This solution (see 7.1.6) allowed coordination of the works by dividing the building into horizontal slices of three floors. An iron trellis was laid on each floor in each raiser to assure safety. Waterproofing was first laid on the slab of the 3rd floor and then on the last slab, the roof.

In the previous phases (made following traditional project management) the installation of the windows started after the last floor had been completed. The picture below illustrates this non-overlapping sequence.

Figure 6.5.7-1-1 Illustration of the non-overlapping work sequence in the previous phases of the project (the windows were not installed before the end of the concrete works)

In block 2, providing an airy and waterproofed working environment allowed the sequences to be optimised and the waiting time to be limited, to the windows (glazes included) being ordered and delivered six months earlier. The dedicated windows (frames and glass) and some temporary waterproofing on the slab closed the building off from the wind, rain and cold and provided an appropriate environment for the workmen in autumn and winter:

- No icy air circulation nor water infiltration
- Possibility of heating the spaces under waterproofing
- Safe conditions for electrical installation; possibility of installing ad hoc site lighting

The picture below illustrates the side effect of the solution: the windows (glazes included) are fixed from the ground to the 2nd floor. Level 3 was kept as a concrete drying buffer level, while the concrete works were ongoing on the 4th floor.

Figure 6.5.7-2 Illustration of sequenced works in Block 2 (block 2)

6.6 Beyond PPC, need for a stability indicator. development of research Stage 2.2

Section (7.1), *Raisers technical improvements: development of research Stage 2.1*, presented the technical and design improvements made in the technical raisers moving to block 2 from block 1, where the organisation of the flow of works in these spaces was left to the daily self-coordination of the foremen. Now, the need to measure flow differently emerged to fine-tune the follow-up of the progress made in the search for stability.

This section presents the rise of the need for a stability indicator as it emerged on site.

6.6.1 Introduction

The lean first action made on block 2, presented in 7.2.1 , had tangible impacts on the works involving the raisers themselves and an assumption was made that LPS and 5S would become more effective from the experience gathered and that the PPC would continue to grow. It was assumed that the effects of this conjunction of positive factors would be measured on site in terms of flow stability. However, although the LPS was running, the PPC score had grown to a satisfactory level and the raisers issues were better than solved, with early air and waterproofing, the progress of the works measured weekly was still highly volatile or, to put it another way, highly unstable. The PPC itself would not be sufficient alone as a measure in the search for stability.

The researcher introduced a complementary measure for each apartment - % of physical progress completed versus % of theoretical physical progress - to help track and keep a log of the complementary actions that were introduced to the system already in place.

6.6.2 Diagnostic, clarification of the problem

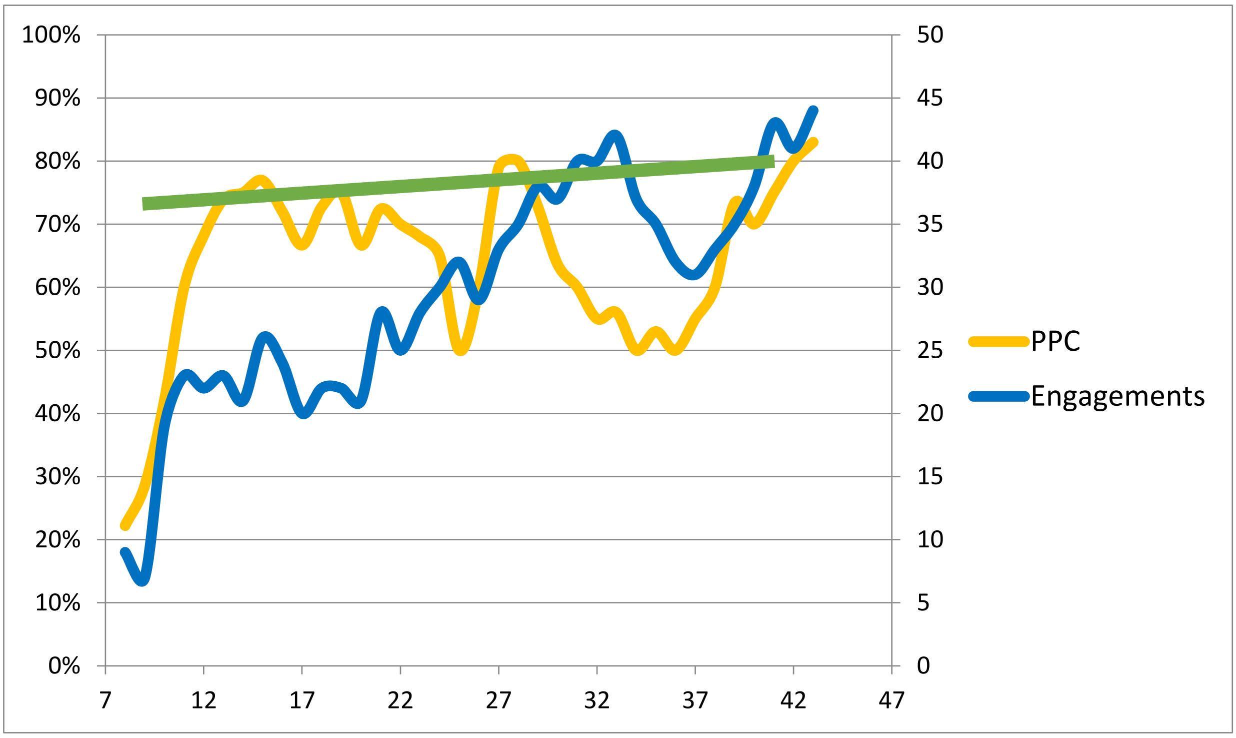


Figure 6.6.2- 6.6.2-1PPC follow- up in Block 2 (block 2)

The PPC was high (>50%) but the works completed from one week to the next was not stable (see Chapter 9). The contractors all agreed that completed promises did not father a stable workflow. In other words, if they all agreed on chaos between two project milestones, PPC would be high but the works on site could be chaotic. The researcher came to the following conclusion:

- a high PPC from week to week can reflect large disparities in the workflow

So, at this stage, the PPC alone was not sufficient to achieve the aimed flow stability: hence, the need to introduce a complementary measure.

6.6.3 Developed solution – weekly progress stability indicator

The essence of flow stability is the continuity and levelling of the physical progress made on site. To illustrate the latter, the researcher calculated the theoretical weekly progress for each apartment in a stable production flow and measured the weekly progress made on site. The two figures were then compared, as described in Chapter 9.

The indicator was calculated as *the mean standard deviation* of the variability of the workflow (developed in Chapter 9). The model was determined to calculate the planned progress for a given week and measure the percentage completed for each trade for each apartment over a period of six weeks under a high and stable PPC.

6.6.4 Evaluation research solution on Stage 2.2: beyond PPC, the need for a stability indicator

Tracking this indicator helped confirm the PPC score and gave a precise indication of the measure of the works' stability. Wide discrepancies between the theory and the actual physical progress despite a high and stable PPC were found, confirming the researcher should go beyond the PPC indicator and keep track of the stability indicator.

6.7 Takt planning: Development of research Stage 2.3

While Section (7.1) and (7.2) presented the progresses made on the technical raisers and in the generation of a stability indicator, this section presents the application of a takt-based approach to scheduling the works to ease the stability of the workflow on site.

6.7.1 Introduction

The actions undertaken during the research had shown the limitations of applying the LPS and using solely the PPC as a lean indicator. Subsection (7.2.3), *Developed solution – weekly progress stability indicator*, described the development of a new indicator to measure the progress of stability. Through this new indicator, and the retention of a high PPC, the progress measured was highly unstable from one week to the next. This paragraph describes how takt time was applied on site to ease the flow and provide rhythm, and to level the resources required.

6.7.2 Diagnostic, clarification of the problem

Interviewing the foremen during the WWP phase of the PPC on the measures of planned vs actual revealed that the contractors had experienced difficulties in planning their resources. The progress curve showed accelerations and decelerations in the pace of the work from one apartment to the next, from a week to the next. All the contractors were SMEs; that their resources were intrinsically limited. In contrast to larger companies or groups which can allocate more resources (internal or external) given their size and, hence, absorb some variability in the resources to allocate, an SME is generally limited in delivering external resources to a given site due to its internal resources. Hence, the variability of the works of block 2 initiated by the first contractor in the row in the works sequence fathered a chain of variability that amplified. Worse, some contractors had to leave to work on other sites. The problem arose because the site organisation did not allow the contractor to keep a constant and levelled team on site that would have made use of their resources at a stable pace.

6.7.3 Definition of objectives for the solution

With the aim of improving stability as a constant pace of work, the site organisation sought to level the organisation of the works of each contractor to reach the same pace and make it possible for a given contractor to keep a levelled number of resources. Providing a solution to this problem would bring tangible support to the SMEs' internal resource management. The aim of the solution was to provide a management system for the workflow that would "feed" each contractor's resources at an optimal level and keep them there. The consequence would mathematically be a higher score in the stability indicator as defined in (7.2.3) *Developed solution – weekly progress stability indicator*.

6.7.4 Develop solution

Production system design in construction is complex in essence given the large number of organisations involved in a limited time where the effect of the experience is limited. A construction site is mainly driven with the experience gained from the previous sites, with limited innovation. The output, which is unique, is created by a dynamic team of individuals in a project-based environment with significant time and budget constraints. As such, any theory that would help project teams in the organisation of their production by solving system problems should aim to be more prescriptive (Rooke et al. 2012).

The takt time method was developed in the manufacturing industry; it aims to structure production around the principles of continuous flow and production-levelling.

This approach to work structuring aligns with the two-part lean implementation strategy outlined by Ballard and Howell (1998). The word *takt* is German from the music world that means *beat*. Takt time is "*the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand rate)*" (Frandson et al. 2013). In the approach this thesis takes, given that the LPS alone was not sufficient to reach a stable workflow, takt time has been proposed to help create a more stable environment for the LPS. The hope in implementing takt time was that it would ease setting up and maintain a continuous workflow for trade activities wherever possible.

Yu et al. (2009) proposed a production flow synchronised to takt time in the home building industry. They argued that applying just lean production tools, like the supermarket-based pull flow, to achieve a reliable working process does not work in construction. Therefore, they proposed a FIFO lane-based flow system based on the LPS methodology. The mentioned system is based on the so-called *Heijunka Box*. The aim is to stabilise and reduce lead time by guaranteeing trade contractor's working load, using agreed capacity between a home builder and its trade partner regarding the number of jobs that a sub-trade will perform each week (Yu et al. 2009). As a result, Yu showed in the paper that the total construction duration could be reduced by about 41 percent, the waiting time could be reduced by about 11 percent, and the value-added ratio could be increased from 17 to 26 percent (Yu et al. 2009). However, the applicability of this system to an apartment development such as the one in this research was not fully justified. The researcher decided to turn to the existing state of the art and adapt it to the residential project where this research was grounded.

6.7.5 Justification for the use of Takt Planning as a complement to the Last Planner™ System

As recalled by Frandson (2013), developed by Liker and Meier (2006), in the context of the continuous improvement spiral of the TPS (figure 7.3-1) in the search for a control mechanism and stability in the production system, "*the Last Planner™ System supports the step of 'stabilising' and takt time planning provides the means of 'creating flow*".

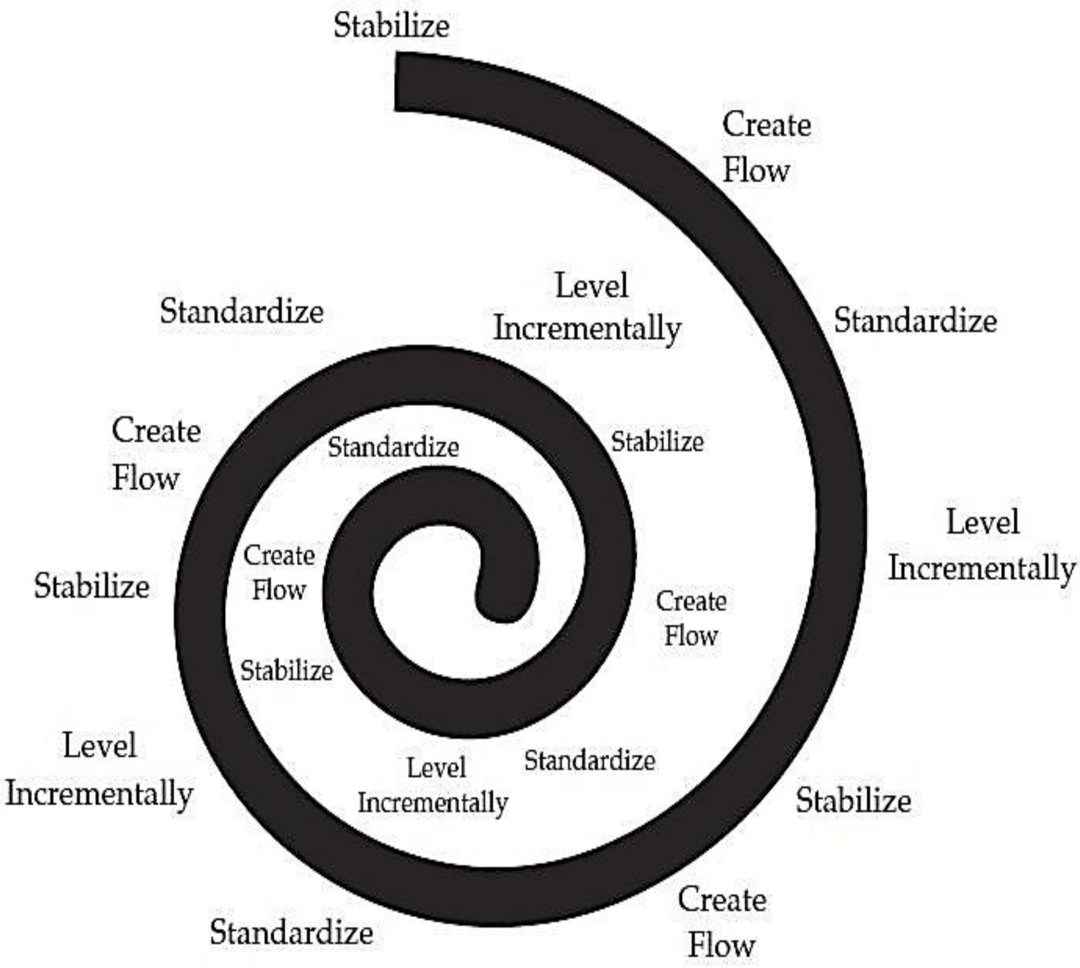


Figure 6.7.5-1 Continuous improvement spiral (Figure 3-4 in Liker and Meier (2006))

Ballard (1999) posed six questions that a production system should answer as a base for designing a work structuring approach:

1. “*In what chunks will work be assigned to specialists?*”
2. “*How will work chunks be sequenced?*”
3. “*How will work be released from one unit [one trade crew activity performing an activity] to the next?*”
4. “*Where will decoupling buffers be needed and how should they be sized?*”
5. “*When will the different chunks of work be done?*”
6. “*Will consecutive production units execute work in a continuous flow process or will their work be de-coupled?*” (Tsao et al. 2000)

As proposed by Frandson (2013), the application of takt time planning develops answers for these questions over an iterative six-step process:

- data gathering,
- zone definition,
- trade sequence generation,
- individual trade duration,
- workflow balancing, and schedule finalisation

The approach follows the same “rough to fine” strategy as the one proposed in the process design steps outlined in *Aiming for continuous flow*, a paper by Ballard and Tommelein in 1998. As mentioned by Frandson (2014),

> *“Takt time planning uses production science to establish continuous flow where possible and to manage buffers in the form of additional crew capacity. The process requires a long-term philosophy of developing the capability of all team members, as well as understanding the importance of production planning as early as possible. A successful production plan developed from takt-time planning is possible only through systems thinking and effectively managing the knowledge of the entire team. Last, the benefits and costs of all stakeholders identify the conditions of satisfaction and trade sequence.”*

In many ways, takt time planning can be seen as a next step complement to the LPS complement. The LPS provides the mechanism for controlling and facilitating the construction and execution of planning, and to adapt it to the evolution of the project in a collaborative and participative effort. Takt time planning strengthens the stability of the production flow by seeking more standardised work where continuous flow is not possible.

6.7.5.1 Creating a rhythm in the succession of batches of production works

Takt time aims to introduce a beat and workflow to the planning system to meet the rate of the customer's demand. On a site, the customer is the next foreman in the queue, from the sequence defined by the application of the LPS. In the complete life of a construction site, given the high volatility of the environment and changing conditions (weather, extra works, unforeseen issues, absences, technical issues, etc.), the customer demand rate is flexible, in essence. However, in a given phase, some stability in the demand can be found by the production team. Then, a takt-inspired system can be envisaged and can benefit the production system in play (Frandson 2014) by:

- "providing activities of the correct size and sequence to the Last Planner as well as a clear outlook on upcoming work"
- "reducing stress on the foreman (…) as long as s/he is on track for completing the small batch of work assigned in the takt time cycle then s/he is on track for the entire job."

Another benefit of the application of takt time is to create tension with respect to engagement. In the context of continuous improvement, as Howell (2002) recalls "*bad news early is good information*", and a takt-planned workflow helps (new) production problems to surface and to be solved to improve works stability.

By introducing simplified to standardised, clear batches of work, takt time provides an increased focus and standardisation of the look-ahead process. The takt process should be designed to be easy to follow, and maintained that way, to ease the appropriation process and maintain the pace through a succession of beats or, in the construction industry, a succession of batches of production working in rhythm.

While the LPS sets the basis of flow mechanism and proposes an alternative approach to traditional command/control, takt time planning inserts rhythm and standardisation to the design of the process of sequencing and levelling production.

6.7.5.2 Increasing a common understanding

Pasquire (2012) proposed considering "*common understanding*" as the 8th flow, complementing the seven flows proposed by Koskela in the construction industry. Creating a common understanding is essential to building engagement in a team that will work toward a common purpose. A clear view is pulled by a clear understanding, a common understanding pulls engagement and drives confusion away. On a construction site, each stakeholder should be pulled by a single, common goal, which is the achievement of the end-product as a whole. This should be the purpose that leads everything and provides a foundation for engagement. The discussions that are necessary to build takt planning inherently create conditions to create analysis, measurements, trade-offs and compromises among the production team (from detailers to foreman in the field). From this exercise, the team creates the opportunity to develop a common understanding of the overall production strategy. This strategy will then be split into manageable pieces of daily goals for workers to meet at even intervals. Defining the purpose and providing clarity of the sub-end-product, as standardised as possible, helps develop maturity in the common understanding of the system. This approach is the reverse of the traditional command/control management approaches.

While the LPS promotes the foremen's engagement, takt planning engages all the team, even at the workman's level, through the practical wisdom offered.

6.7.5.3 Increasing awareness of Make Ready relevance

As a consultant, the researcher has long faced large reluctance expressed by the site-management team to fill and feed the make ready follow-up table contained in the LPS. The openness that the make-ready phase requires is often perceived as intervening in the intrinsic organisation and expressing a lack of trust. This behaviour reflects the traditional mistrust that generally exists within the site management, even though information-sharing is crucial in any efficient production system. Planning according to takt time will automatically create the necessity to feed the make ready analysis and seek concrete solutions to the problems detected. The domino effect, which is illustrated in *The Parade of Trades* (Tommelein et al. 1999), becomes immediately visible and the trade that does not perform its task within the common takt time (including the buffer) will instantly prevent the others from accomplishing their tasks and, hence, introduce desynchronisation. The effect will grow as the works continue, most probably leading to a total blockage, a situation that is not uncommon in a traditional system where the main concern of each stakeholder is to plead ‘not guilty’ regarding the losses caused by the blockage.

The effect of takt planning is beneficial in increasing awareness of the relevance of make ready as a trust builder and as anticipation structuring.

While the LPS is a means of obtaining the data, the takt time planning would consider any variations to be *noise* if they do not affect the hand-off of work. In the LPS approach, make ready and commitment planning are a means of adapting to variations at the operational level and the PPC measures these variations when they affect the execution of the work. Takt planning goes further in that the whole chain of sequence is affected by a works’ desynchronisation, and the whole chain should be regarded and anticipated as a whole.

6.7.5.4 Reducing the scope of pull planning

Planning the works from inception to completion is rethought on the basis of the phase scheduling of the LPS . Takt planning goes further in narrowing the scope of manageable units into a sequence of work. The sequence is defined by areas so the scope of work that needs to be pull-planned is reduced to one off pieces of work (e.g., zone or apartment) that can be as small as an operating room or a bathroom. Each piece corresponds to the area where the minimum works can be seen as a piece of works. For convenience, the zone is defined by the mechanical and electrical distribution networks.

The “one-piece flow” definition can be narrowed in certain circumstances (when time is particularly constrained, when the works are over-complex, etc.). In this case, a whole project can be dichotomized into a succession of pieces (or rooms) that will be treated as a single piece. In this case, the design of the project must be compatible with such a spatial dichotomy or, in other words, the inherent nature of the works and of the shape of the site should be regular. This is generally the case in hotels or social apartment housing.

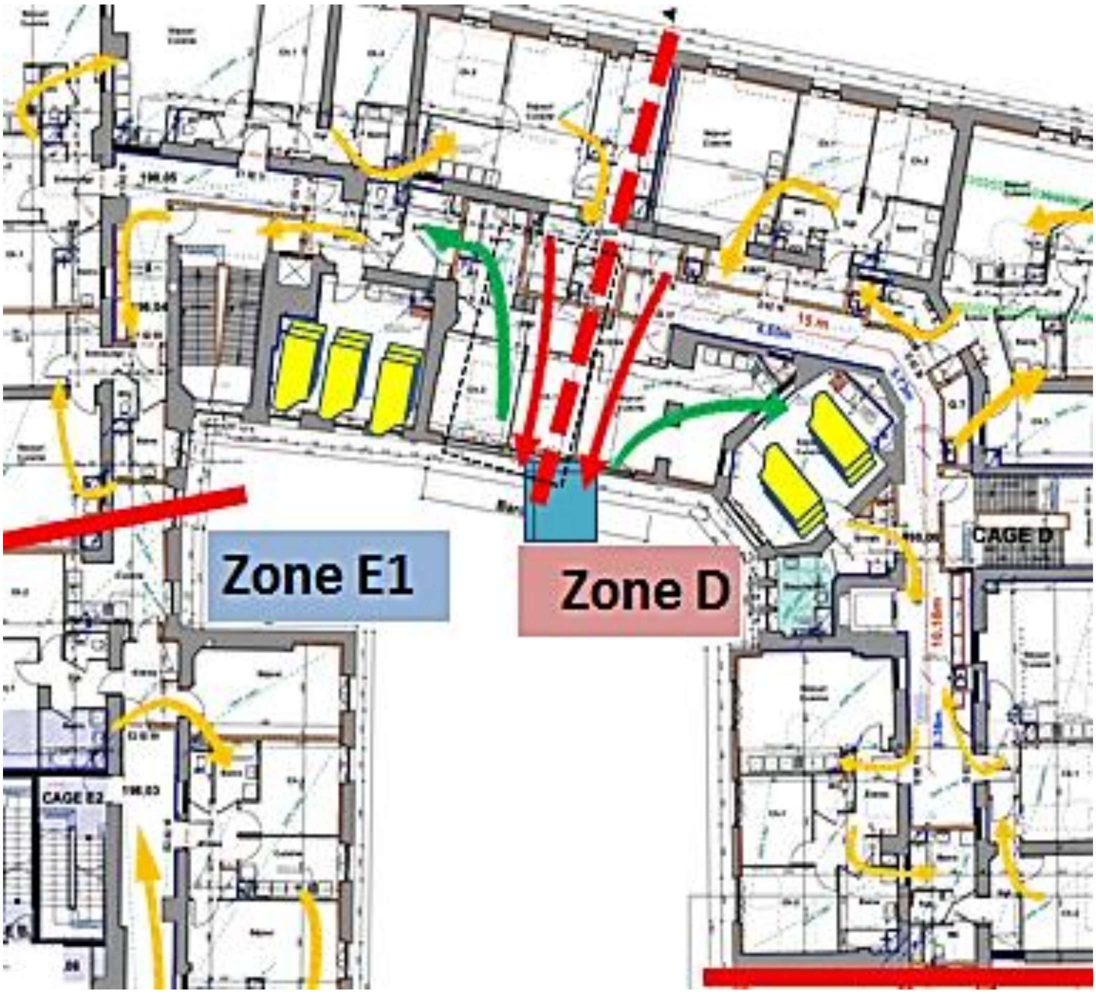


Figure 6.7.5-2Illustration of spatial takt for the rooms in social housing

6.7.5.5 Identifying 'schedule noise' vs true 'schedule variance':

Planning under a takt time strategy means scheduling "noises" and "variances" in the commitment plan. For Frandson et al (2014): "*Schedule noise is defined as the temporal movement of a task within a given takt-time sequence that does not affect the completion of work within the takt-time sequence. Schedule variance is defined as the temporal movement of a task within a given takt-time sequence that shifts into another takt-time sequence.*"

An illustration of this is the domino effect. A domino chain will continue if, and only if, each fall of a piece contains enough energy to destabilise the next in the queue and feed the next fall. If a piece falls without enough energy, it will gently lean against the next, which may move slightly but will remain in place. In takt planning, the energy consumed to lean is the buffer consumption that each task or system inherently contains. If a task moves within its buffer, the energy of the move will eat the buffer, but the strength will not be enough to disturb the next task. If a task moves beyond its buffer, the energy will exceed the buffer and the next task in the queue will be impacted. This situation is known as a soft conflict and it occurs if a task conflicts with another trade activity and requires communication to be solved. A hard conflict occurs when re-planning of the work is necessary because using the current schedule will result in a delay of work for the incoming trade.

The works levelling effect of takt is particularly visible from this perspective, and it is key to the works stability that is sought in this research. Espejo and Reyes (2011) developed this aspect from a management cybernetics perspective and recall that takt-time is a kind of "attenuator of complexity".

As Frandson (2014) recalls, takt-time planning shines a light on the PPC metrics in that PPC is viewed as a measure of the liability of the works hand-off at the correct moment instead of measuring the daily fluctuations in the schedule. Takt planning bring an extra dimension to the PPC, which is respect for the sequence at the defined pace.

While the LPS accounts for go-back work as well as for work-in-process, takt-time planning goes further and levels irregular works in the whole spatial sequence in the search for eliminating variances to create a stable workflow.

6.7.6 Action taken

6.7.6.1 From theory to action

Frandson (2013) proposed a method to introduce takt time in the organisation of the works on site which starts by (1) collecting data before (2) determining the zone and/or the appropriate intrinsic takt of the project. The next step (3) focusses on identifying the trade sequence before (4) the plan can be balanced and (5) the production schedule can be finalised. Of course, in a continuous improvement approach such as lean, the data collected across all the steps would help close the circle to propose improvements to the system. Figure 7.3-4 below illustrates Frandson's steps.

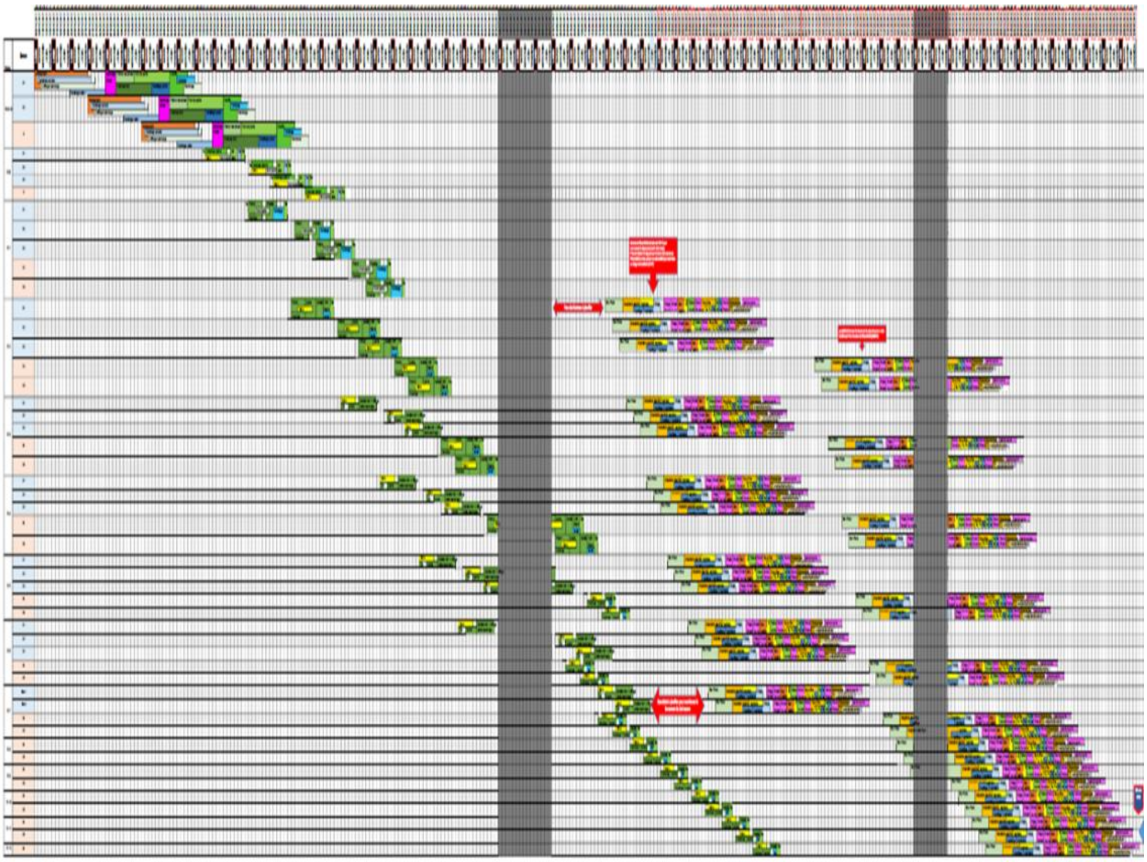
Figure 6.7.6-1Frandson's 5 steps (2013)

Determining a takt time that should allow each trade to complete its works in a single apartment (or batch of apartments) before working in the next meant finding the unit task that would give the pace to the whole in partnership with a reasonable team (limiting the constraint of the chain). To define the initial trade bottleneck, each contractor was asked to indicate the number of resources that would be reasonably provided (constraint 1). Note that the notion of reasonability has been introduced to avoid the contractors proposing over-optimistic capabilities. From this calculation, each contractor was then invited to indicate the typical area that could be delivered in a day by his team or the area that would need to be at the disposal of his trade (constraint 2), provided that the team would be provided with enough materials and information (constraint 3).

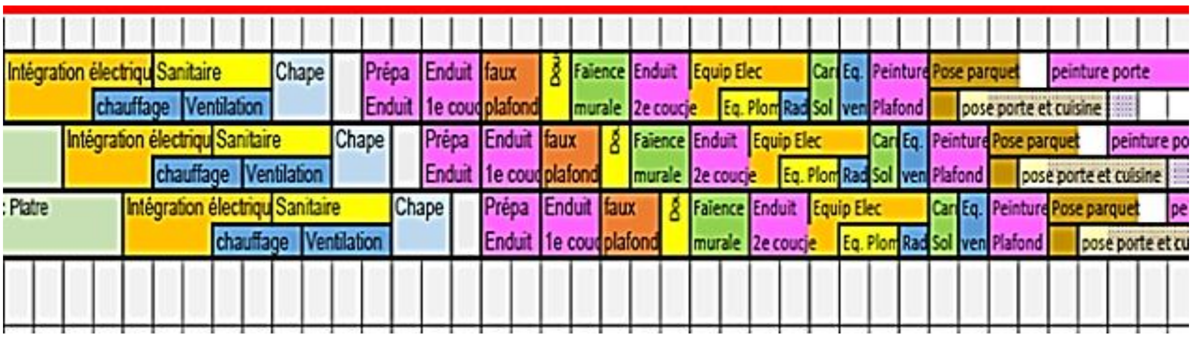
It was found that the initial bottleneck was the plasterer, who claimed he needed areas of work as large as a whole storey. The initial bottleneck, hence, came from constraint 2 and this has been challenged by the researcher, as illustrated below. It was explained to the plasterer that, if a project requires four tasks of six days per trade per floor, the project would be delivered in 24 days. Then, if each trade splits the resources between two teams (at a stable amount of resource), and if each team starts on a half floor, then the project could be completed in 15 days. Also, by separating the team into two sub-teams, the risk of being blocked decreased and this diluted the related impact on the delay and costs of demobilisation-remobilisation.

On this basis, the plasterer then volunteered to split his team into three sub-teams, constraints 1, 2 and 3 of all other trades were still lower than this latter, which was the bottleneck on the site to be tested. It was decided not to challenge the contractor again, nor force him to go beyond his self-trust zone, to avoid any systemic weakness that could be introduced by the researcher which could bias the results of the solution.

Following the work in the sequence of apartments and taking into account the allocated time, the following schedule was constructed:



Picture 6.7.6-1 Takt planning of block 2 (not meant to be readable)



Picture 6.7.6-2 Detail of takt planning block 2

6.7.6.2 Takt and buffer

The whole project was planned to follow the takt timing of what represented a week of work agreed among the teams. In other words, each trade would switch from one area to the next every Monday. This simple method would also correspond to the weekly organisation, that had been complexified in block 3 as described in Chapter 8. It was determined that, under this system, there would be no need to work on Saturdays, which are traditionally used as a way to artificially increase the number of days worked while keeping to the deadline.

In block 2, Saturdays would be used as a buffer when a task needed to be completed or prepared. This approach served as an introduction of the notion of the buffer to the team, a notion that was commonly underappreciated. Identifying Saturdays as such made the team fully aware that the system sought to measure the works (done and remaining) in detail. To calculate the buffer, the mean of the works not completed from one week to the next on block 1 was extracted from the PPC (see 9.1.1) and it was found that between 15% to 20% of the works (in duration) would not be completed in this fashion. From the data available collected each week from the WWP and PPC, it was not possible to extract a more precise level of incomplete works; the data collected did not measure the time the team spent completing the works separate from the time spent in rescheduling or making do because of desynchronisation.

Thus, the buffer introduced in block 2 and proposed to the teams was only partly based on the measure. The teams were reminded that the system would not demand that any contractor work on a Saturday (apart from the unlikely situation where 100% of the contractors would ask to, so that no buffer would be needed in the system at all). All the foremen considered a 20% buffer (a 1-day buffer out of 5 days worked) big enough, from their experience, to complete the works that they had not been able to complete within the week.

Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	TAKT TIME : 2,5 days		Buffer	TAKT TIME : 2,5 days		Buffer	

Table 6.7.6-1 Weekly site works organisation in block 3

A log of the Saturdays worked would then be kept identifying why the buffer was necessary and feed the continuous improvement approach.

6.7.7 Evaluation of research solution on Stage 2.3: takt planning

The PPC stabilised between 70% and 90%, which is considered a high score in the construction industry, the stability indicator improved, and the progress measured on site went more quickly than planned0 The key success factors learned were:

- ✓ Commit to following the rules
- ✓ Do not start work in a zone before it is ready
- ✓ Start work in a zone only when it is your turn
- ✓ Share issues as soon as possible, and during the weekly meeting at the latest
- ✓ Accept the possibility of rethinking the sequences (within or amongst) areas, redesigning the zones: reach trade-offs collaboratively
- ✓ Engage foremen in the search for the best system

Although the works pace improved from block 1 to block 2; the researcher noted that some trades were still working on site on Saturdays. One of the main reasons for this was collectively identified. Determination of the origin of the problem was assessed by the foreman (among a choice of five possible categories of reasons) in identifying the number of workmen on site and the reasons for being there on a Saturday.

The experience of the foremen as foremen on residential sites was as follows: mason: 34 years, joiner: 15 years, window installer: 12 years, plasterer: 18 years, plumber: 6 years, duct installer: 15 years, electrician: 8 years, heating installer: 15 years, floor installer 5 years, painter: 20 years. These levels of experience were considered sufficient to be relevant.

The following table shows the results according to the experience of the foremen on traditional sites based on the following reasons;

- reason 1 = completion of works that were not done within the week
- reason 2 = works being made good to lower the snag at completion
- reason 3 = site cleaning-up and 5S sweeping
- reason 4 = works in preparation for the following week
- reason 5 = other (technical inspections, site visits, material supply or evacuation)

Survey on "classical" sites. Reasons for working on Saturdays						
	% of the team	Reason 1 %	Reason 2 %	Reason 3 %	Reason 4 %	Reason 5 %
Mason	***70***	80	10	10	0	0
Joiner	***30***	90	5	5	0	0
Windows installer	***40***	70	20	10	0	0
Plasterer	***20***	100	0	0	0	0
Plumber	***50***	70	20	10	0	0
Duct installer	***30***	80	10	10	0	0
Electrician	***50***	70	30	0	0	0
Heating installer	***30***	70	20	10	0	0
Floor installer	***70***	90	5	5	0	0
Painter	***40***	80	10	10	0	0
Mean	***43%***	***80%***	***13%***	***7%***	***0%***	***0%***

Table 6.7.7-1 " Traditional" sites. Reasons for working on Saturdays

From the above table (7.3-1), the mean of the results can be seen to be:

- 80% completion of works that were not done within the week
- 13% works being made good to lower the snag at completion
- 7% site cleaning-up and 5S sweeping
- 0% works in preparation for the following week
- 0% other (technical inspections, site visits, material supply or evacuation)

The following reasons were considered to be non-value-adding activities as they were made necessary by a lack of anticipation or to cure intrinsic organisational issues:

- completion of works that were not done within the week: considered as a non-value-adding activity as it clearly showed no reliability that tasks would be completed. This activity is a patch that does not treat the inherent issue of being able to keep to the programme as planned
- works being made good to lower the snag at completion: considered as a non-value-adding activity as lean advocates the following approach - ‘do right first time’. This activity is another patch on a lack of quality process/engagement to do a good job in the shop floor at the first attempt.

The following reasons were considered to be value-adding activities as participating in them increased anticipation, safety, quality:

- ✓ Site cleaning-up and 5S sweeping: considered to be a value-adding activity as they provided the comfort of a safe and pleasant environment for the workmen to work in. The image of the site was also improved by these activities, thus improving quality (perceived and measured).
- ✓ Works in preparation for the following week: considered to be a value-adding activity as it involves participation in the anticipation that is necessary to validate, maintain and improve the system.
- ✓ Other (technical inspections, site visits, material supply or evacuation): considered to be value-adding activities as either participation improves the quality and/or the image of the site and/or long-term anticipation.

Survey on "classical" sites. Reasons for working on Saturdays						
	% of the team	Reason 1 %	Reason 2 %	Reason 3 %	Reason 4 %	Reason 5 %
Mason	***70***	80	10	10	0	0
Joiner	***30***	90	5	5	0	0
Windows installer	***40***	70	20	10	0	0
Plasterer	***20***	100	0	0	0	0
Plumber	***50***	70	20	10	0	0
[illegible]	[illegible]	[illegible]	10	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	30	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	20	10	0	0
[illegible]	[illegible]	[illegible]	5	5	0	0
Painter	***40***	80	10	10	0	0
Mean	***43%***	***80%***	***13%***	***7%***	***0%***	***0%***

Non-Value-Adding Activities

Value-Adding Activities

Table 6.7.7-2 "Traditional" sites. Reasons for working on Saturdays (Value Adding and Non Value Adding)

The table above shows that the vast majority of the time spent on site on Saturdays is traditionally allocated to completing the works that have not been finished during the week (80%). This brings only a limited amount of value to the production and fathers a waste of energy in the long run and questions the feasibility of keeping up with the pace across the project time.

The same question regarding working on Saturdays was put to the foremen in Block 2 after the takt planning had been initiated. Although the planning was maintained, between 25% of the time spent on site was used to complete the works that had not been completed within the allocated takt time.

Survey on bloc 2 "Chopin". Reasons for working on Saturdays						
	% of the team	Reason 1 %	Reason 2 %	Reason 3 %	Reason 4 %	Reason 5 %
Mason	***25***	30	30	20	5	15
Joiner	***15***	5	35	30	10	20
Windows installer	***10***	25	25	20	20	10
Plasterer	***10***	20	35	15	10	20
Plumber	***25***	30	25	20	20	5
Duct installer	***15***	20	30	30	20	0
Electrician	***25***	20	30	20	15	15
Heating installer	***15***	20	25	20	20	15
Floor installer	***40***	40	30	20	10	0
Painter	***20***	30	35	20	0	15
Mean	***20%***	***25%***	***30%***	***21%***	***13%***	***11%***

Table 6.7.7-3 Reasons for working on Saturdays (10-25% of the global team)

From the above table, the main reasons appear to be:

- 25 % completion of works that were not done within the week
- 30 % works being made good to lower the snag at completion
- 21 % site cleaning-up and 5S sweeping
- 13 % works in preparation for the following week
- 11 % other (technical inspections, site visits, material supply or evacuation)

From the above figures, it appears that the number of hours spent on Saturdays used to complete the works were limited in comparison to the more traditionally organised site. From the assessment of the foremen based on their experience on similar sites, the proportion of hours spent on a traditionally managed site needed to catch up with the weekly delay (or accumulated delay) would be around 6 hours on top of the 35 hours of the standard week (17%). In block 2, as measured through the WWP, this proportion was less than 6 % (under 25% of the team worked less than 25% on Saturdays to complete the works). Interestingly, on the assessment of the site foremen, the team spent 15% of their time on making good activities, an initiative started by the mason and rapidly followed by the other trades. From their own assessment, these making good activities were traditionally neglected and left for the snag works at the completion of the works. This tends to show an increase of concern concerning the improvement in quality in the works executed, though it was not possible to find the root reasons or true driver for this mindset switch, nor what the trigger was.

Therefore, empirically, it appears that the awareness of quality and engagement increased because the trades were working alone in their own areas. They were self-empowered to raise the level of quality and they themselves decided to avoid delay in finishing their works. This approach pulled the perception of a nice site that the foremen wanted to keep. From the self-assessment of the foremen, 15% of the Saturday hours spent on site were dedicated to removing the waste, sorting, cleaning, and initiating preparation for the following week. The works preparation for the following week accounted for another 15%, which included moving materials, technical preparation and adaptation of the storage. The remaining 10% were used for technical inspections, site visits, material supply or evacuation.

The implementation of takt planning, on top of LPS and 5S and technical improvements on the raisers, helped improve site efficiency (pace of works and stability increased) and reduce stress (from the foremen's own assessments). The pace on site increased and the takt was better respected. At this stage, it was then tempting to increase the pace again in this block, taking into consideration that tension could be put in the system. Tension would mean a decrease in the takt timing to lower the buffer and make more productive use of the Saturdays. The PPC was high but still showed some instability. This indicated that the system itself was not yet mature enough and it was decided to allow the team to build its own experience before carrying out further experimentation.

6.8 Section summary

While the research on block 1 described in Chapter (6), *Case Study of block 1: inception of lean*, focused on validating the applicability of existing lean construction-based systems (LPS and 5S), this chapter described how the focus was switched to improving flow stability by introducing technical optimisations and takt planning.

The research reported significant improvements in the search for workflow stability:

- ✓ Improving coordination and safety of the works in the technical raisers as developed in (7.1) Raisers technical improvements: development of research Stage 2.1
- ✓ Decreasing the lead time by air/waterproofing and anticipating the finishing of works as developed in (7.1) *Raisers technical improvements: development of research Stage 2.1*
- ✓ Introducing a new production flow stability indicator as developed in (7.2) Beyond PPC, need for a stability indicator. development of research Stage 2.2
- ✓ Successfully introducing takt time-based planning as developed in (7.3) Takt planning: Development of research Stage 2.3

Significant tangible results have been measured on this basis:

- ✓ No major safety issue reported
- ✓ No snagging work at completion (out of 64 apartments)
- ✓ 100% of the apartments delivered earlier than planned (-3.5 month)
- ✓ Construction cost decreased by 2.9% (excluding 1.5% inflation)

From the above, it can be seen that, although the cause & consequence effect is still difficult to prove or assess at this stage and that some correlational effect should be considered, there is no doubt that quality, safety and delay have been tangibly improved in block 2. The following chapter presents the continuity of the research on block3.

7 Case Study on block 3: further development of a pull flow system

This chapter will follow the same research path as the previous chapters, (6), *Case Study of block 1: inception of lean*, which described the research undertaken and the approach developed in block 1, and Chapter (7), *Case Study on block 2: Development of the solution*, which did the same for block 2 .

Chapter (8) presents the final research cycle that has been undertaken in block 3 in the development of a scheduling approach based on a visual kanban. The research in block 3 capitalises on that of the two previous blocks and the lessons learned, but pushes the boundaries further in respect of the promises of the WWP and in the discipline of completing them.

The same 6-step-approach as in block 1 and in block 2 has been followed and adapted in block 3. This chapter is organised around two sections:

- (8.1) Human factor bias: introduction of discipline and kanban, presents how a visual tool (kanban) can help discipline on site
- (8.2) Section summary summarises the chapter

In block 2, although the impacts on works coordination and anticipation were very positive because of the development of the research, the expected result was focused on more reliability in keeping the work sequence and, therefore, the creation of a more stable and predictable workflow. The research in block 2 developed the implementation of takt time with kanban to give a clear visual presentation of the work that could be done on the shop floor.

To maintain consistency with the measures used in the first two blocks, the PPC and 5S data continued to be measured, as well as the physical progress. A third measure was introduced, however: the linearity of the curve created by the progress measures, based on standard deviation. The aim of this indicator is to provide an accurate representation of the work continuity and stability.

The expected result is that the actions undertaken in the research facilitate the achievement of a high score and, hence, a more predictable workflow.

7.1 Human factor bias: introduction of discipline and kanban

7.1.1 Introduction

As shown in the previous chapters, the research conducted on the previous blocks (block 1 and block 2) showed tangible positive impacts in the search for a stable production flow. Deming (1952) and the continuous improvement approach teach us that a process can, in essence, always be improved. The opportunity for continuing the research on a third block was seized upon by the researcher. Block 3, comprised 45 apartments. Apart from some minor architectural modifications, this block was similar to the first two blocks. The size of the apartments, the technical features and materials used from the foundations to the roof were alike. The zero-snag work delivery success of block 2 had not only to be achieved in block 3 but to be improved.

Figure 7.1.1-1 End product of Block 3 (block 3)

7.1.2 Diagnostic, clarification of the problem

As discussed in the previous chapter, the flow stability improved in block 2 from block 1 but the analysis of the WWP meetings (LPS) showed that any disruptions where mainly caused by site congestion (too many workmen in a location at one time). Despite the experience gained in block 1 and in block 2, the site foremen did not fully stick to the agreed WWP and shared one week with another. The coordination system had to be made more robust to avoid last-minute making do, a long-term deeply anchored natural tendency that emerged at this point in the research.

7.1.3 Definition of objectives for the solution

To improve stability, the site organisation had to improve discipline in the commitment to respect promises made. Smallwood (2000), Ying (2010) and Haifeng (2012) pointed out that the main area of research regarding the application of discipline in the construction industry was developed and controlled by the construction managers (and other higher levels). They showed that the training of the foremen was mainly centred on technical skills, ignoring most of the organisational and associated skills and tools. Kamara (2008) insisted on the mechanism of information transfer on construction sites as a possible source of making do, leading to a lack of discipline. Todaro et al. (2016) further emphasised the importance of discipline in any proposed model (developed in BIM). However, there is very limited literature on the importance and development of discipline at the operational level. The objective of the solution to be developed in block 3 was to make the system more robust by strengthening the discipline at the foremen level.

7.1.4 Developing the solution

Discipline has to be simple and visual to be easily adopted and maintained on site. Brady (2014) proposed using visual management to improve transparency in planning and control in construction and developed a visual system to share site information and to ease following the sequences. However, Brady faced significant disruptions on site due to a lack of discipline. She suggested that a tool based on kanban would facilitate respect for the promises, but it would have to be kept as simple as possible. Indeed, a drawback of the system Brady proposed was that it required the action of construction managers and it was difficult for foremen to run it alone. Adeyemi (2015), in a cross-disciplinary systematic literature review on kanban, showed that it was possible to use it in most software development environments as a means of imposing discipline. At the time of the start of the research in block 3 (2016), the kanban approach and its importance in creating and maintaining a stable workflow had already been introduced (Arbulu et al., 2003) but there was still only very limited literature concerning its application to construction sites made by SMEs.

7.1.5 Action taken

To improve works stability or, in other words, to meet the daily plans for the actual activities delivered on site, the discipline in following the system through until the end needed to be strengthened on block 3. It was, then, decided to dedicate a site manager or team leader to the management to oversee the global approach. Time was dedicated to meeting with each team leader and site manager to review the rules and insist on the importance of the system and of these rules. Everyone was then asked to commit to following the rules of the site.

7.1.5.1 Focus on the rules and discipline

To ease the discipline, the researcher reworded and formalised the rules to be instantly understood and easy to follow:

- “Commit to following the rules.”. Discipline starts with a formal engagement.
- “Do not start the works in a zone before it is ready and indicated as being ‘done’ by the relevant person from the previous trade.” This rule relates to a kanban system tried on site, where each foreman indicated the possibility for the next in the queue to start his work by sticking a pad on a board.
- “Start the works in a zone only when it is your turn”. This relates to the sequence previously agreed upon.
- “Share issues as soon as possible”. Information had to be shared during the weekly

meetings at the latest and a log would be kept ensuring no information would be left behind, as a source of continuous improvement. The culture of information hiding was to be reversed to “no bad news is bad news” and “bad news early is good information”.

- “No post-action excuse”. Rethink the sequences and/or redesigning the zones as necessary, seek trade-off on site collaboratively.
- “Be empowered in the search for the best system”. Continuous improvement was not to stay at the managers’ level; the foremen had to fully understand they were at the centre of the approach. The system would promote the detection and sharing of issues and the solutions for improvement offered by the foremen.

7.1.5.2 Making the rules as visual as possible

The sequence of the works for each trade was confirmed using an LPS collaborative method. Each action of a trade corresponded to a colour meaning that the sequence of the works was mainly visual and easily followed. Even if the words of the sequences were written in French, as the construction site was located in French-speaking Belgium, non-French speaking staff were able to follow the sequence :

Pink → Blue → Green → Yellow → Red

Layout and chapter drawings were displayed on the wall of the site meeting room. At the end of a given task, each trade would glue the corresponding-coloured sticky vignette to indicate the works of the action had been done. This would act as a sort of kanban to the next trade in the queue who was being shown the “green light” to start their works. In order to simplify the tool and ease its adoption on site, it was decided not to introduce any cards (the original meaning of kanban was to use a signalling card). It was considered that the signal, that was the essence of kanban, would be the action of gluing a vignette. When it was not possible to strictly follow the sequence (because of an issue concerning the availability of materials, for example), the system allowed for a successor to start their works. In such a case, the zone was then visually identified and the risk of desynchronisation of the rest of the areas was limited.

The picture below illustrates the result of this approach. While, in the duplex apartment A12, all five tasks had been declared completed, in apartment B12 the red task was missing and in C31, it had been decided to complete the green task before the pink and the blue were completed. This disruption in the sequence of the flow was not uncommon and showed that the prerequisites of moving from one task to another were flexible.

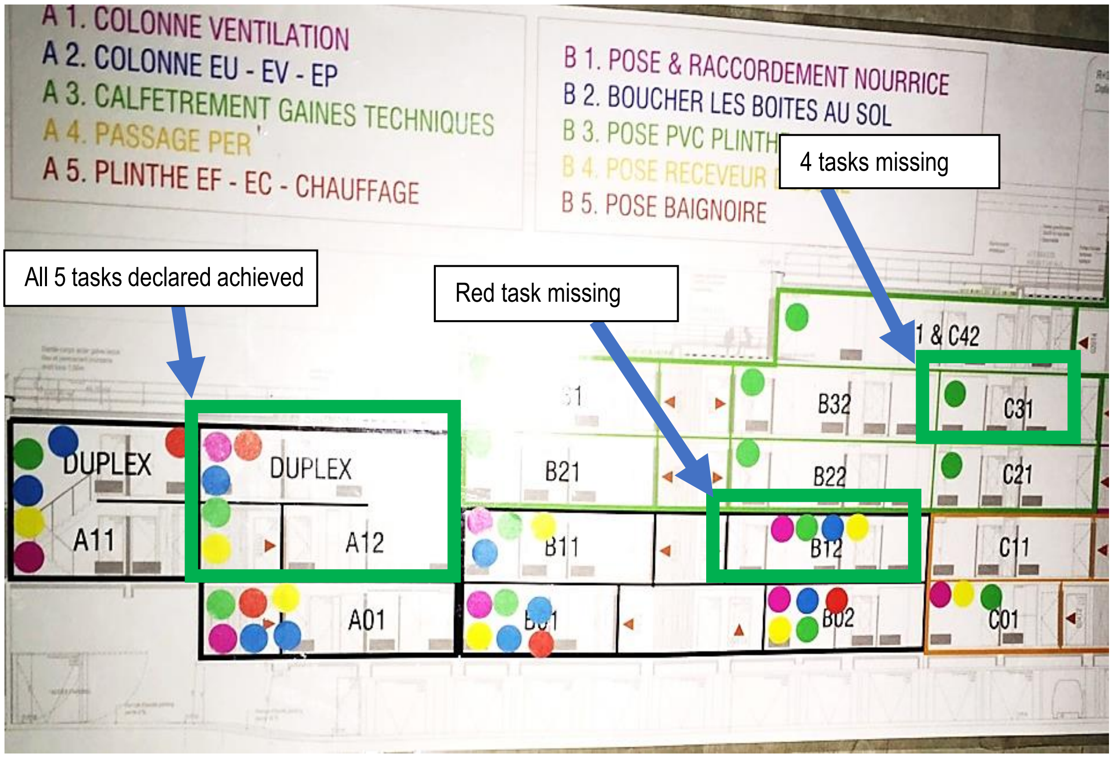


Figure 7.1.5-1 Example of visual management of Kanban

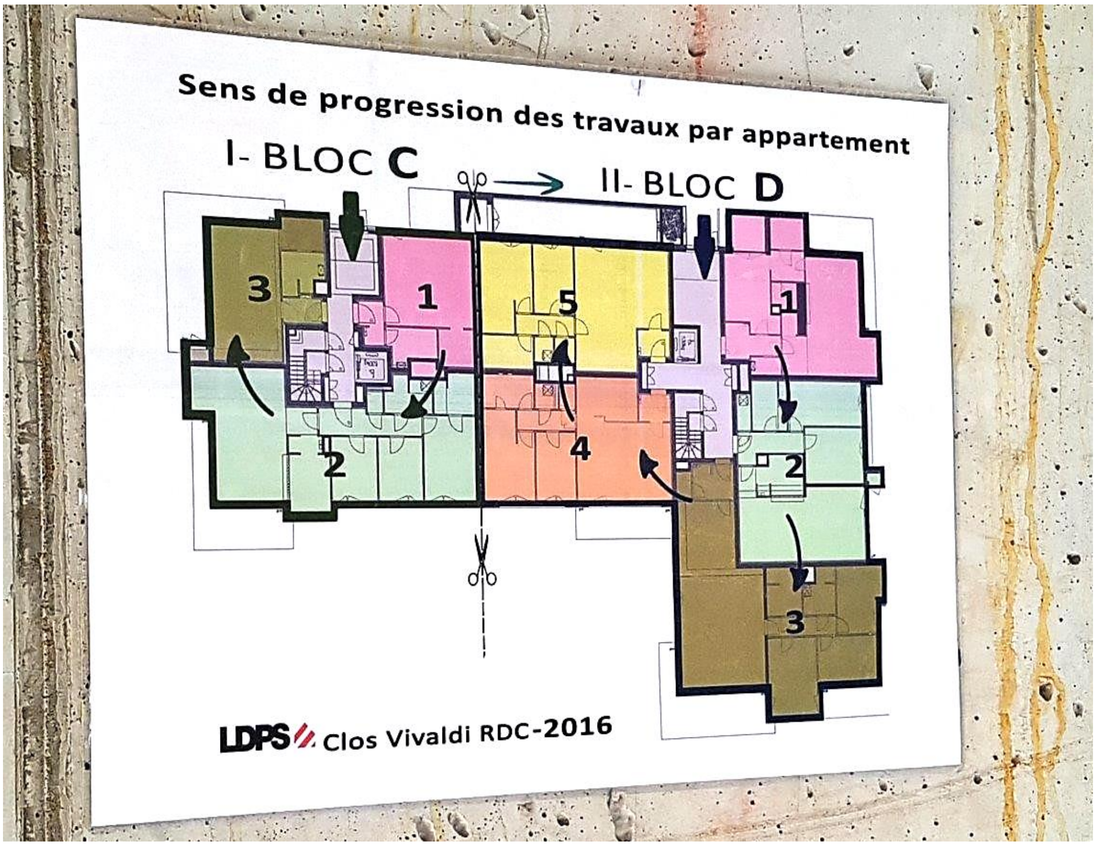


Figure 7.1.5-2 Illustration of visual management and apartment sequence in block 3 (Block 3)

As illustrated in the image below, a sequence strategy was also used in the façade work: the windows and glass were installed at the ground level while the glass was ready on the first floor, the frames were fixed at the second floor and the concrete works was ongoing on the 4th floor. The 3rd floor was left as a drying buffer.

Figure 7.1.5-3 Example of sequenced works in block 3: takt and buffer

Block 2 proved that a 1-week-takt was large enough to allow the trades to organise and follow their works in a 1-week timeframe. From this experience gained in block2, it was decided to try and decrease the time required to half a week. The ambition was to narrow the system to detect issues sooner and increase anticipation and problem-solving cycles.

It was first envisaged to split the week into two even periods: from Monday morning to Wednesday noon, leaving Wednesday afternoon as a buffer, and plan again the works from Thursday morning to Saturday noon, leaving Saturday afternoon as a buffer. This is described in table 8.1-1.

Week	Monday	Tuesday	Wednesday	Thurday	Friday	Saturday	Sunday
	TAKT TIME : 2,5 days		Buffer	TAKT TIME : 2,5 days		Buffer	

Table 7.1.5-1 First proposition of weekly site organisation in block 3

Despite being simple and attractive in theory and on paper, the reality of a construction site rapidly negated this solution, the main reasons being:
This scheme did not take into account the reality of how a week is organised; that is, Mondays and Fridays are singular days. The number of hours spent on site on these two days is traditionally fewer than on the other days, leaving the workmen time for the weekend to work on personal sites. This organisation implies that Saturday mornings are considered a weekday, which is not legal in Belgium.

It was then necessary to narrow the search for optimisation to the day to find an acceptable solution that would meet those two organisational constraints. The traditional number of hours worked on site was then collected from the foremen. This number showed some disparities from day to day. As shown on table 8.1-2 above, while Tuesdays to Thursdays were worked in full (8 hours a day), Mondays and Fridays were lighter (7 and 6 hours); the whole personal organisation of the workmen on these two days was involved activities such as taking children to school, going shopping, fulfilling medical appointments. Saturdays were extra hours and were considered to be a buffer. Most of the workmen did not particularly stick to the idea of making extra hours on Saturdays as they valued their personal life, or personal sites.

	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday	
hrs worked on site	*am*	*pm*	*am*	*pm*	*am*	*pm*	*am*	*pm*	*am*	*pm*	*am*	*pm*
	4	*3*	*5*	*3*	*5*	*3*	*5*	*3*	*4*	*2*	*4*	*2*
	7		**8**		**8**		**8**		**6**			

Table 7.1.5-2 Daily hours spent on site in a week in the traditional system

A lean approach, which is inherently seeking workmen's comfort could not propose a system that would be perceived as degrading their personal life.

7.1.5.3 Evolution between solutions in block 2 and in block 3

The ambition of the system was to:

- Level the hours spent daily on site as much as possible
- Retain the personal organisation of the workmen (light Friday afternoons)
- Work the legal weekly hours (37 per week)
- Create a regular takt time twice a week
- Keep buffers at a minimum of 20%
- Avoid working on Saturday

Considering the above, to achieve a sound weekly optimisation while keeping the constraints, it was proposed to slightly rearrange the time spent on site and plan the works from Monday morning to Tuesday afternoon. Wednesday morning was left as a buffer. The works were planned again from Wednesday morning to Friday noon. Friday afternoon was left as a buffer.
This proposition also levelled the number of hours spent on site from Monday to Thursday while leaving the possibility of working a reduced number of hours on Friday afternoon. This solution did not include working on Saturdays or Sundays.

	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday	
hrs worked on site	*am*	*pm*	*am*	*pm*	*am*	*pm*	*am*	*pm*	*am*	*pm*	*am*	*pm*
	5	***3***	***5***	***3***	***5***	***3***	***5***	***3***	***5***			
	TAKT TIME : 16 hours				Buffer	**TAKT TIME : 16 hours**				Buffer		

Table 7.1.5-3 Daily hours spent on site in a week in block 3

Hence:

- The hours spent daily on site was levelled from Monday to Thursday.
- The personal organisation of the workmen (having a light Friday afternoon) was retained.
- The legal weekly hours (37 per week) was retained.
- A regular takt time twice a week was created (2 x 16 hours).
- The buffer rose from 20% to 25%.
- No work was planned for Saturdays.

This solution implied that the number of works planned in the traditional weekly organisation in block 2 of 37 hours would be realised in 32 hours in this weekly organisation, which represented an ambitious 15% decrease of the hourly rates. The whole team supported this proposition, and the new organisation was set up.

The table below presents the reasons for working on Saturdays from the assessment of the contractors. The works started at 8.00am and most workmen had left by noon (a log was not kept for each company. The reasons for coming were the first concern as the origin of the issue to be treated). A limited part of the team showed up, if required; the majority of the team stayed at home during Saturdays.

In the table below, reason 1 stands for “completion of works that were not done within the week”, reason 2 for “making good works to lower the snag at completion”, reason 3 for “site cleaning-up and 5S sweeping”, reason 4 for “works in preparation for the following week”, reason 5 for “other (technical inspections, site visits, material supply or evacuation)”.

The measures were taken from the WWP confirmed by the site foremen and the information was gathered over a three-month period.

Survey on bloc 3	Reasons for working on Saturdays					
	% of the team	Reason 1 %	Reason 2 %	Reason 3 %	Reason 4 %	Reason 5 %
Mason	***20***	10	20	30	25	15
Joiner	***5***	0	0	0	80	20
Windows installer	***0***	10	20	30	25	15
Plasterer	***0***	5	10	40	30	15
Plumber	***10***	20	20	40	15	5
Duct installer	***5***	10	20	30	30	10
Electrician	***15***	15	30	30	10	15
Heating installer	***5***	10	20	40	20	10
Floor installer	***15***	15	30	30	15	10
Painter	***20***	5	10	50	20	15
Mean	***10%***	***10%***	***18%***	***32%***	***27%***	***10%***

Table 7.1.5-4 Survey on block 3 - reasons for working on Saturdays

From the table above, the means of the reasons for working on Saturday were:

- 32% site cleaning-up and 5S sweeping
- 27% works preparation for the following week
- 18% works being made good to lower the snag at completion
- 10% completion of works that were not done within the week
- 10% other (technical inspections, site visits, material supply or evacuation)

In block 2, 15% of the Saturday hours spent on site were dedicated to removing the waste, sorting, cleaning, and initiating the preparation for the following week. The works preparation for the following week accounted for another 15%, which included moving materials, technical preparation and adaptations of storage. The remaining 10% were used for technical inspections, site visits, material supply or evacuation.

In block 3, nearly 70% of the activities carried out on Friday afternoon (the time buffer) were considered value adding.

7.1.6 Evaluation of research solution on Stage 3: kanban

Figure 7.1.6-1 Illustration of sequenced works and 5S layout in Block 3 (block 3)

A very small number of workmen (10% of the whole staff) were working on Saturdays, the time spent in buffer time (now Friday afternoon) dropped from 20% in block 2 to 10% in block 3. The reasons for staying on site also evolved; while in block 2 only 40% of this time was devoted to site cleaning-up, 5S sweeping, works preparation for the following week and other reasons (technical inspections, site visits, material supply or evacuation), this proportion rose to nearly 70% in block 3. This indicates that the team were able to put more effort into anticipation and improvement of the system by the time generated by eliminating non-value-adding activities.

7.2 Section summary

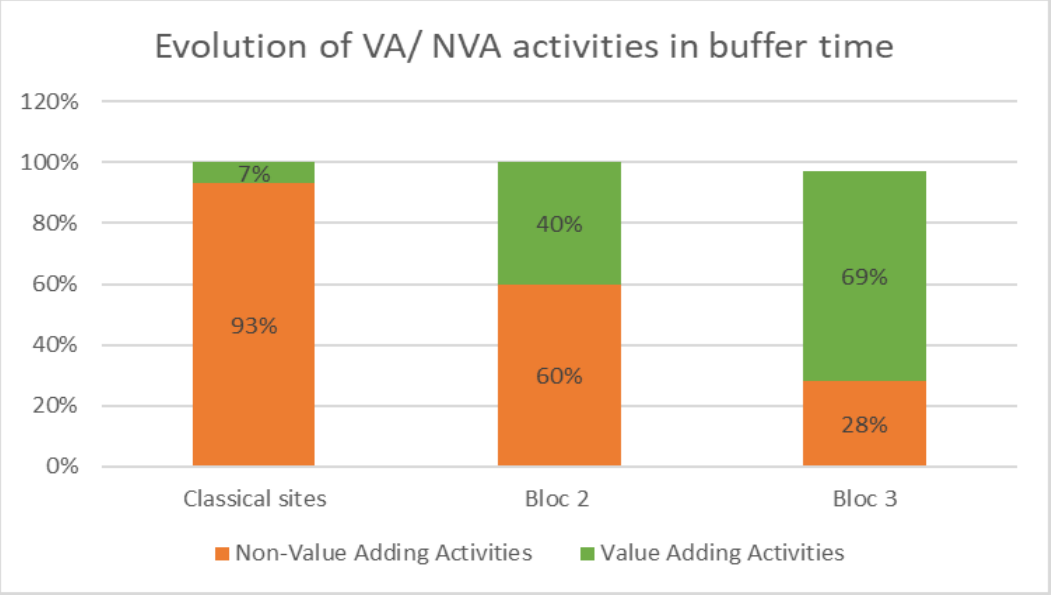
7.2.1 Synthesis

While the research on block 1 focused on validating the applicability of existing lean-construction-based systems (LPS and 5S), and block 2 focused on improving flow stability by widening the scope and introducing technical optimisations and takt planning, the research on block 3 introduced kanban as a discipline enforcer to:

- Improve flow stability
- Provide a visual indicator based on the kanban system
- Improve discipline on site (decrease making do)

The results that have been measured regarding this are:

- No major safety issues were reported
- No snagging work at completion (out of 45 apartments)
- 100% of the apartments were delivered earlier than planned (mean of -6 month)
- Construction costs decreased from block 2 by 8.5% (including 1.5% inflation)



Graph 7.2.1-1 Evolution of the proportion of value and non-value-adding activities in buffer time

The proportion of workmen on site in buffer time dropped from 43% on traditional sites (Saturdays) to 20% in block 2 (Saturdays) to 10% in block 3 (Friday afternoon).

	Proportion of the team	**Reason 1**	**Reason 2**	**Reason 3**	**Reason 4**	**Reason 5**
Classical sites	43%	80%	13%	7%	0%	0%
Bloc 2	20%	25%	35%	15%	15%	10%
Bloc 3	10%	10%	18%	32%	27%	10%

Figure 7.2.1-1 Proportion of workmen and reasons for working on Friday afternoon on block 3

While in a traditional approach, 93% of this time was spent on either making good the works done in the week or seeking to lower the snag at completion (finishing) and site cleaning-up/5S sweeping, in block 2 this proportion dropped to 60%, and then to 20% in block 3.

8 Collecting and analysing data on workflow stability

This chapter presents how the data were collected and the indicators developed. It is organised chronologically and presents the approach developed in the context of this research from block 1 to bloc 3.

- Section (9.1),
- *"Only what can be measured can be* improved", presents how the measures of the weekly progresses were made on block 1 following a traditional project management approach. (9.2), *Measures from Block 1-A: application of Last Planner™ System (w26 to w31)*, then develops the same but after the LPS has been initiated. Section (9.3), *Measures from Block 1-B: comparison with traditional scheduling (w26 to w31)*, presents a comparison of the measures t collected only from block 1-A following LPS with the ones collected using a more traditional approach of planning.

- Section 9.4, *Measures from block 2: application of takt planning. Focus on week 44 to 49* develops the results after takt planning has been added in block 2 and Section (9.5), *Measures from block 3. Application of kanban*, concludes the research with the application of kanban as a complement to LPS and takt time initiated in the previous blocks and sections.

- (9.6), Conclusions from the research on blocks 1 (A &B), 2 and 3, presents the conclusions of the data collected in the three blocks before Chapter (10), Tangible impacts of the research, introduces the visible effects that the approach developed on site has produced and that, despite the cause-consequence effect, it is still difficult to prove, at this stage, that some correlational effect should be considered.

- Section (9.7), Section summary, concludes this chapter.

8.1 "Only what can be measured can be improved"

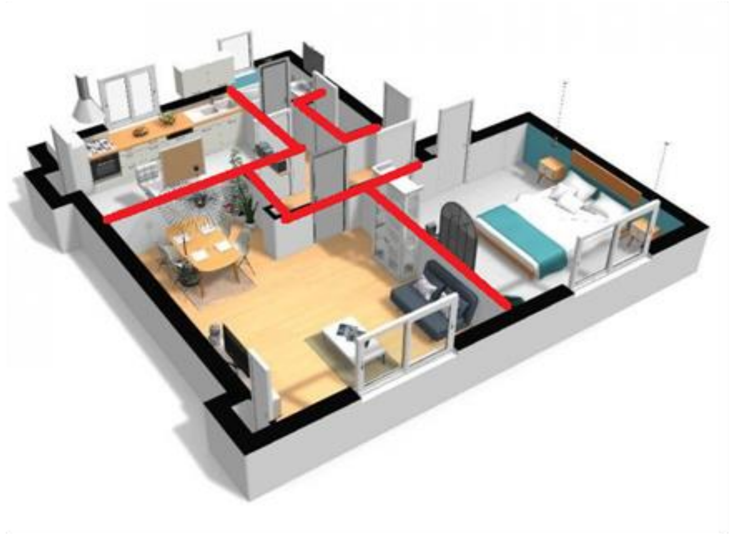
8.1.1 Measuring the number of works achieved in the week

Although the PPC (the indicator of WWP reliability) is regarded as an important measure in lean construction, if not the main one, Subsection (7.3.5), *Justification for the use of Takt Planning as a complement to the Last Planner*™ System, develops how the LPS can be complemented by other flow management system approaches.

It was then necessary to propose the measurement of indicators under whatever management systems were workable from site to site. Physical weekly progress in each zone (or here, each apartment) met the latter criterion. Measuring the progress of each apartment has been achieved by calculating the average mean (mathematical average) of the progress in the percentage of the physical progress of each trade.

In the example below, the apartment contains:

Four windows (units)



x linear metres of partition wall

y square metres of parquet flooring

Figure 8.1.1-1 Example of quantity calculations

The measure of the weekly progress each trade made on site was calculated using the following formula:

$$\%\ \text{works progress} = \sum \frac{\text{cumulative quantity fixed on site}}{\text{total quantity}}\ \text{x}\ 100$$

For the sake of simplification, no difference was made between elements of the same nature (each window installed counted for 1 unit, each linear metre of partition wall fixed counted for 1 unit, each square metre counted for 1 unit). Given the similar nature of all the apartments in a given block, it was decided to consider the differences in the unit time that intrinsically existed between the different construction elements of a given trade as not relevant to the present study. This assumption was made given that all the apartments of a given block contained the same type of finishing and that the comparison of the progress would not be made between blocks but rather between apartments (the progress of each apartment would be added to a global weekly progress report).

The differences in progress were then compiled to determine the weekly progress made on each apartment. The weekly data collection can hence be summarised as follows:

- Step 1: collection of the progress made on site for each trade
- Step 2: determination of the % of progress per trade per apartment
- Step 3: determination of the total % of the progress of the apartment as the mean of the above (it was considered that in a chain of works, each task had the same weight; hence, no financial considerations were taken into account at this point)

The data collected are presented in the following Table 9.1-1 (from week 26 to week 31 in lines), apartment by apartment (A01 to A52 in columns).

	Week					
	26	27	28	29	30	31
Apt	Actual	Actual	Actual	Actual	Actual	Actual
B01	85	95	95	100	100	100
B02	88	93	93	98	100	100
B11/B12	85	88	90	95	95	95
B13	88	95	100	100	100	100
B21	61	68	76	76	81	98
B22	66	75	81	86	86	95
B23	76	78	83	88	90	95
B31	56	71	74	81	90	92
B32	51	66	69	71	79	83
B33	40	45	65	79	92	94
B41	55	71	79	83	83	88
B42	50	66	74	79	79	83
B43	45	60	71	76	76	79
B51	42	55	52	69	76	76

Table 8.1.1-1 % of weekly works progress on Block 1 (block 1) under traditional project management

As illustrated above, this first row of measures shows that apartment B01 was 85% complete in week 26, then some works were carried out in week 27 to reach 95% completion, no progress was made in week 28 and the work in the apartment were then completed in week 29.

8.1.2 Measuring the regularity of works

The progress made from one week to the next was extracted from these data, as well as the mean of the progress per week. The mean of the weekly progress (in %) provided an indication of how the team was performing. The higher the mean, the more works were being accomplished. However, this data alone did not provide an indication of the volatility of the works. The standard deviation, or in other words how far each figure stood out from the mean on average, provided a better indication of the regularity of the works.

The standard deviation of the progress was calculated week by week:

Apt	Week 26	27		28		29		30		31	
	Actual	Actual	Δ	Actual	Δ	Actual	Δ	Actual	Δ	Actual	Δ
B01	85	95	*10*	95	0	100	5	100	-	100	-
B02	88	93	*5*	93	0	98	5	100	-	100	-
B11/B12	85	88	*3*	90	2	95	5	95	0	95	*0*
B13	88	95	*7*	100	5	100	-	100	-	100	-
B21	61	68	*7*	76	8	76	0	81	5	98	*17*
B22	66	75	*9*	81	6	86	5	86	0	95	*10*
B23	76	78	*2*	83	5	88	5	90	2	95	*5*
B31	56	71	*15*	74	3	81	7	90	10	92	*2*
B32	51	66	*15*	69	3	71	2	79	8	83	*4*
B33	40	45	*5*	65	20	79	14	92	13	94	*2*
B41	55	71	*16*	79	8	83	5	83	0	88	*5*
B42	50	66	*16*	74	8	79	5	79	0	83	*5*
B43	45	60	*15*	71	11	76	5	76	0	79	*3*
B51	42	55	*13*	52	-3	69	17	76	7	76	*0*
		Mean	**9,8**		**5,5**		**6,0**		**4,1**		**4,7**
Standard Deviation:			**4,9**		**5,6**		**4,4**		**4,7**		**4,9**

Table 8.1.2-1 Variation of weekly works progress (%) on block 1 under traditional project management

The table above (Table 8.2-2) shows that the weekly progress from week 26 to week 31 was situated between 4.1% to 9.8%, with a mean of 6%; and a standard deviation from 4.4 to 5.6, with a mean of 4.9. These measures show the initial state of the measures. As there is no broader or previous reference point commonly accepted, it is not possible to argue or assess these data; the researcher uses them as a reference point in the search for improvement across the 3-block research development.

8.1.3 Measuring stability of the works

The limits of the implementation of the LPS and complementary methods emerged in that it was not possible to measure the stability of the works, which were defined here by a regular quantity of works made each week that met completion as planned.

In a manufacturing plant, the production flows all through the production line by moving from tool to tool in a very precise and predefined sequence and pace, for a very precise and defined time. In a manufacturing plant, the production is dynamic (moves) while the production tools are static (stay in the same location). The figure below illustrates the production flow in a manufacturing plant.

Plant (tools)

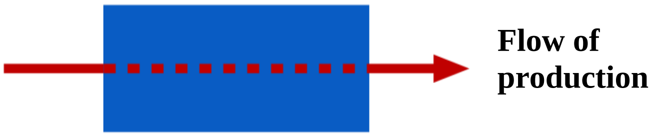


Figure 8.1.3-1 Illustration of production flow in the manufacturing industry

On a construction site, the production itself does not flow (the wall, the tiles, the windows, etc. stay where they are built). However, the whole production tool flows (workmen, materials and equipment), moving from one area (block, floor, area, room) to another. Apart from some specific construction sites such as road works, rail works and tunnels. for examples which can be considered linear pieces, the path followed by the tools on a construction site is not usually linear, as is illustrated below.

Construction site (production)

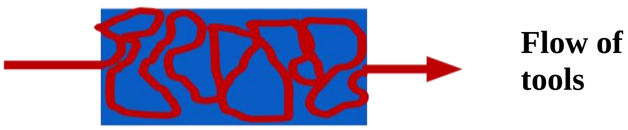


Figure 8.1.3-2 Illustration of production flow in the construction industry

Associated with micro-zoning, which aims to divide the project into manageable areas and find relevant sequences amongst and within them, the resources (i.e. human resources, materials and tools) loaded on site independently from the (actual) needs of the site are contrasted against the resources delivered on site, on (anticipated) demand. While manufacturing plants generally involve a static production tool that produces a dynamic product, construction sites generally involve a dynamic production tool that produces a static product. The respect for the sequences agreed upon in the LPS phase is essential for sound synchronisation of the work on site. A strong tendency prevails among site foremen not to respect sequences and to improvise new sequences once the original ones have not been kept. The consequences of overtaking the next trade in the sequence (not waiting until all the preliminary works are completed for a given task) can be many: The next trade work can prove to be more difficult (due to de-synchronisation, under-preparation), for example, or work occurs without all the reliable information required .

Extracted from the tasks identified in the phase scheduling workshop (i.e., the LPS), the entire work sequence was entered in a spreadsheet that indicated the state of the work in each apartment. A 1 was entered to indicate that the works were completed. In the next continuous improvement circle (Step 2), each site foreman was to enter their input into the IT system (or glue a sticker on the printed table) to indicate that their work for a particular apartment was completed (and had been checked), ready for the next trade in the queue. With this table, each site foreman had a global vision of the state of the work and precise knowledge of what apartment was ready for the next trade. This table was also used to feed the discussion at the WWP level.

YSAYE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
B11/B12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1
B13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
A21	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
A22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
A23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
A24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
B21	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	0	0	1
B22	1	0	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1
B23	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
A31	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
A32	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
A33	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0		
A34	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0			
B31	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1			
B32	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	0			
B33	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1				
A41	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
A42	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					
A43	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1							
A44	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1									
B41	1	1	1	1	1	1	1	1	1	1	1	1													
B42	1	1	0	0	1	1	1	1	1	1	1	1													
B43	1	1	0	0	1	1	1	1	1	1	1														
A51	1	1	1		1	1	1	1	1																
A52	1	1	1	0	1	1	1	1	0																

Table 8.1.3-1 Table used to follow the state of done works done.

A log of the progress of the works was kept over a six-week period to illustrate the search for a continuous and constant workflow. Each week, the global progress made was measured in each apartment and shown in a graph. Given that only one trade was meant to work in any given apartment at any one time, the graph represented the work progress of the trades in each apartment.

The goal of this log was to identify how the sequencing of the apartments was maintained and how linear the progress was in the broader concept of stability, as explained earlier. From this concept, the researcher developed a general formula that would help forecast the theoretical overall progress or individual progress (at the apartment level) of any given week from the general program.

Identification of the main schedule constraints

From the general works program in block 3 (35 apartments) the following was extracted:

- 42 macro tasks of half a week each were identified, so the works in each apartment were to be completed in 42 x 2.5 = 105 working days (or 21 weeks).
- Each apartment was to be started half a week after its predecessor (a 2.5-day lag). The total theoretical lead time was 105 days to complete the sequence of the works in the first apartment and then 2.5d × 34 apt = 85 days to complete to rest of the block.
- From the above, a total of 105 days + 85 days = 190 working days was planned for completion of the works in the 35 apartments.

Determination of the progress difference (%) between <u>two consecutive apartments</u>

This paragraph seeks to calculate the difference in progress between two consecutive apartments in a given week. The theoretical difference of progress (as a percentage) for a given week between two consecutive apartments can be calculated as follows: 100% / (number of tasks of the chain of works) / (number of apartments started in a week) = 1 / 42 × 2 = **1 / 84%.**

Determination of the <u>weekly progress</u> (%) for any given apartments

This paragraph seeks to calculate the progress made in each apartment from one week to the next. If each of the 42 tasks of the work chain was started each week, the weekly progress would be 1/42. But in block 3, each task was started according to a half week lag; that is to say that two tasks were started in a week. The theoretical weekly progress can be calculated as follows: 100% / (number of tasks of the chain of works) x (number of tasks started in a week in an apartment) = 1 / 42 x 2 = **1 / 21%.**

Determination of the formula from block 3

If P(1,1) represents the progress of Apartment 1 in Week one, P(1,2) the progress of Apartment 1 in Week 2, P(2,1) the progresses of Apartment 2 in Week 1 and P(2,2) the progresses of Apartment 2 in Week 2, and so on, then the differences in the progress in percentages can be calculated as follows:

$$p(i, i+1)\% = P(i,i) + \frac{1}{21}\%$$
$$p(i+1, i)\% = P(i,i) - \frac{1}{84}\%$$
$$p(i+1, i+1)\% = P(i,i) + \frac{1}{21}\% - \frac{1}{84}\%$$

Generalisation of the formula

And if *Ew* is the number of tasks to be achieved in the sequence of the works, then the progress from one week to the next can be defined as follows:

$$p(i+1, i+1)\% = P(i,i) + \frac{2}{Ew}\% - \frac{1}{(2\ x\ Ew)}\%$$

To complete this equation, if *TT* is the time to complete the works of a given task in an apartment and *L* the lag between two apartments, then:

$$\boldsymbol{p(A+1, W+1)\% = p(Ai, Wi)\% + \left(\frac{P}{Ew\ x\ TT}\right)\% - \left(\frac{L}{Ewx\ P}\right)\%}$$

where:

- L is the lag between two volume starts (to be expressed in relation to *TT* (i.e. *L* = 3*TT*), and
- *P* is the period between two instances of progress.

Applied to block 3, the theoretical data are shown in the following table:

	26	27	28	29	30	31
A01	88	93	98	100	100	100
A02	87	92	96	100	100	100
A03	86	90	95	100	100	100
A04	84	89	94	99	100	100
A11	83	88	93	98	100	100
A12	82	87	92	96	100	100
A13	81	86	90	95	100	100
A14	80	84	89	94	99	100
A21	78	83	88	93	98	100
A22	77	82	87	92	96	100
A23	76	81	86	90	95	100
A24	75	80	84	89	94	99
A31	74	78	83	88	93	98
A32	73	77	82	87	92	96
A33	71	76	81	86	90	95
A34	70	75	80	84	89	94
A41	69	74	78	83	88	93
A42	68	73	77	82	87	92
A43	67	71	76	81	86	90
A44	65	70	75	80	84	89
A51	64	69	74	78	83	88
A52	63	68	73	77	82	87

Table 8.1.3-2 Determination of the theoretical progress (%) for each apartment of block 1 from week 26 to week 31

The graph of the previous page shows the apartments (in sequence/order of work) in X and the cumulative global progress in Y for each apartment as calculated above or measured on site, as explained.

Each layer corresponds, for each apartment, to the addition of the works made each week. The greater the progress for a given week, the thicker the layer for a given apartment. Conversely, if no works were carried out in a given apartment, no line will appear and the disruption in the flow of progresses made on site will be represented as a cut layer.

If the same amount of works are carried out from one week to the next in each apartment as planned, each layer should be of equal thickness, representing the weekly rate of works. The slope of the graph represents the rate of the apartment given directly linked to the number of worked apartments each week. In the illustration of block 3 below, from the master planning:

- the works started at week 7
- the sequence of the apartments is as follows (in order of first to be started to last to be completed): A01, A02, A03, A04, A11, A12, A13, A14, A21, A22, A23, A24, A31, A32, A33, A34, A41, A42, A43, A44, A51, A52.

Consequently, as illustrated in the graph:

- The blue shadow shows the theoretical cumulative progress (CP) made in week 26
- The coloured layers shown on the graph show the theoretical works to be made each week: red for the works made in week 27, green in week 28, purple in 29, etc.
- (1) Apartment A03 should be completed in 7 (initial start of the works) + 21 weeks of works sequence = week 28
- (2) Apartment A14 should be 80% completed in week 26, and fully in week 31
- (3) Apartment A34 should be 70% completed in week 26, and 80% in week 28

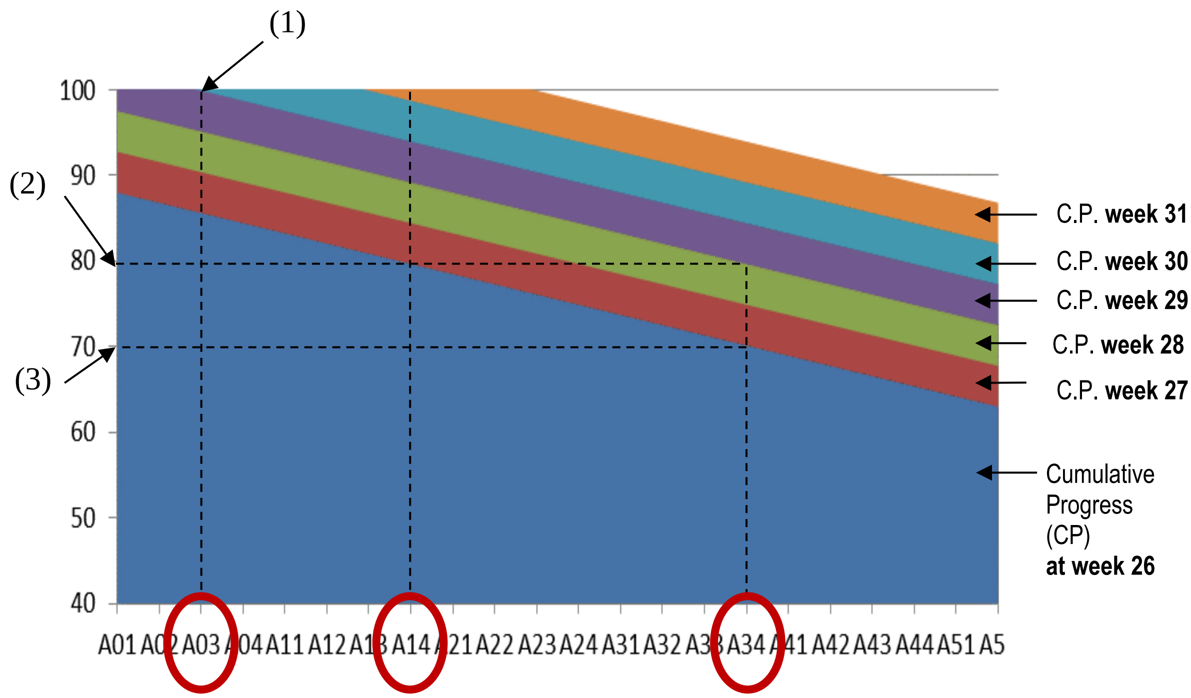


Figure 8.1.3-3 Illustration of the quantity of works to be made weekly (each layer), from week 26 to week 31 in block 1

In this synthesis, the constant thickness and straightness of the layers illustrates the linearity of the equation proposed, representing the stability of the workflow.

8.2 Measures from Block 1-A: application of Last Planner™ System (w26 to w31)

This section presents the data collected in part A of block 1 where works were made under an LPS approach. This initial observation, as developed later, is considered the reference for the subsequent data collection. Following the method developed in the above section (9.1), the cumulative progress of each apartment was measured weekly over a six-week period (from week 26 to week 31). To avoid obvious bias in the measures collected, this measure was started after the LPS had been implemented, i.e., when all the contractors had been appointed and had started their works on-site. The data were collected by measuring the progress of each trade partner (contractor) in each apartment.

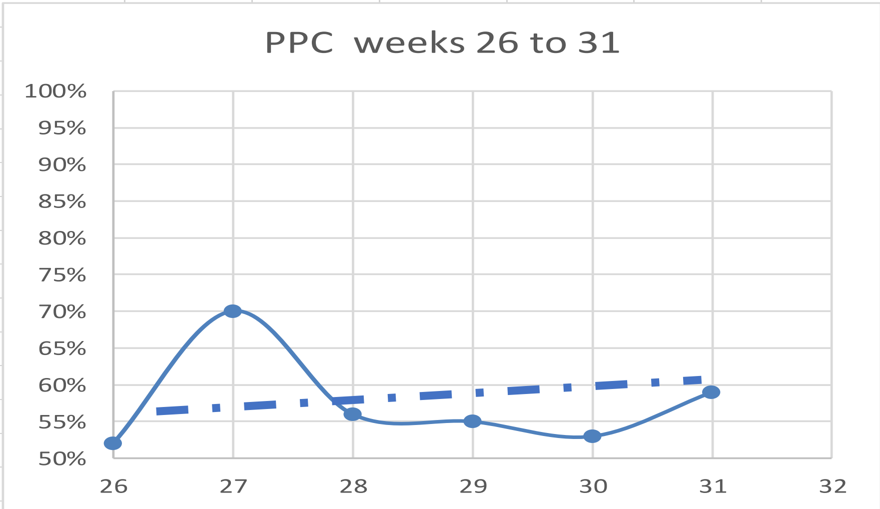
The overall progress of each apartment was then calculated as the sum of the physical progresses of each trade expressed as percentage.

8.2.1 Measures from the Weekly Work Plan

The WWP was made following the recommendation of the LPS. Only the tasks that started and ended the planned day were noted as completed promises. In this case, and only in this case, the figure “1” was inserted for the line of work. Conversely, if the task started or ended earlier or later or was not started or completed, the researcher noted the figure “1” to indicate that the promise was completed. The works were collaboratively noted as completed or not completed by both the contractor in charge and the company next in sequence and by the client. A task, when noted “1”, or completed, met all the criteria to avoid snagging works that would result in a misperception of the completion of the task. This task was considered “done, done” to indicate that it was 100% completed. This approach helped to create trust in the words and in the works of each of the contractors. The measures were carried out over 6 weeks (week 12 to 17), on the 33 significant apartments from Block 3 (the penthouses having been excluded from the research as they were not similar nor comparable with the other apartments). The contractors were the same as in block 2. This section presents the results of the WWP and compares these results with blocks 1 and 2 :

Block 1A : PPC weeks 26 to 31

Week :	26	27	28	29	30	31
PPC :	52%	70%	56%	55%	53%	59%



Graph 8.2.1-1 PPC in block 1-A from week 26 to week 31

The average of the PPCs during the period was 58%. Again, given the limited data available on comparable sites, it is difficult to state whether this score was high or low; the researcher took this measure as a starting point. The very first measures were set apart to avoid bias in the results by using data from the inception of the LPS and, hence, taking the discovery phase as a learning phase that did reflect the LSP and the ability of the group to apply the approach.

The tendency was that this score continued to move up, which was later confirmed in the works of block 1A, where the PPC had levelled at around 60 - 70%.

	26	27	28	29	30	31
A01	88	98	100	100	100	100
A02	93	100	100	100	100	100
A03	90	95	98	100	100	100
A04	88	98	98	98	98	100
A11	85	93	98	98	98	100
A12	78	85	95	100	100	100
A13	90	93	95	95	95	100
A14	80	88	95	95	98	100
A21	78	78	88	95	98	100
A22	73	73	88	100	100	100
A23	80	80	90	98	98	100
A24	78	78	88	93	95	100
A31	66	76	93	93	98	98
A32	66	78	88	95	100	100
A33	61	76	86	88	95	95
A34	61	78	86	88	100	100
A41	59	68	75	90	100	100
A42	56	66	81	86	95	100
A43	56	66	79	85	93	94
A44	59	66	79	83	93	98
A51	49	53	62	74	80	92
A52	45	55	62	71	79	93

Table 8.2.1-1 1Measurements of works progress (%) in Part A in Block 1.

8.2.2 Measure of the weekly quantity of works achieved in block 1 A

The above table presents the data collected in part A of Block 1 (scheduled under the LPS) reporting the progress of the works and which was measured between weeks 26 to 31, as represented in the following graph:

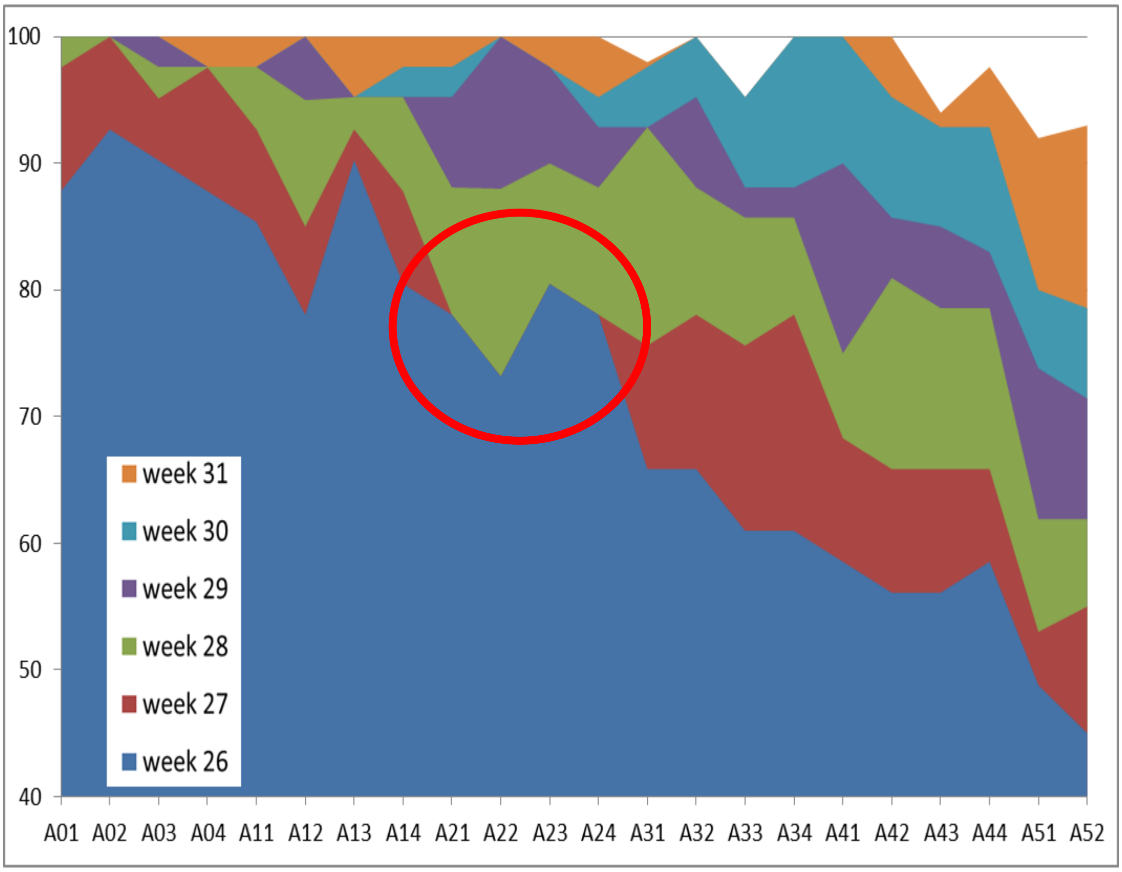


Table 8.2.2-1 Measurements of works progress (%) in Part A Building (Block 1).

The variations in the thickness of the layers in the graph below show peaks and valleys that represent weeks of high activity and low activity, respectively. This illustrates the volatility of the work made on site from one week to the next.

In some weeks, no works were done at all, which is visually noticeable where the red layer discontinues (see the red circle above: apartments 13 and 14 in week 29, for example).

The foremen were asked to give reasons for not completing the promises made in the WWP . The results are as follow.

Bloc 1 A : reasons for not completing LPS promises (weeks 26 to 31)

Manpower shortage	50	21%
Direct consequence of others' lack	40	17%
Making Do / improvisation	30	13%
Incomplete or missing information	20	8%
Interface with one or more other trade	20	8%
Late material / broken	20	8%
Wheather	20	8%
Overestimation of the works capability	15	6%
Rework	10	4%
Preworks not identified	10	4%
Change by the Client	2	1%

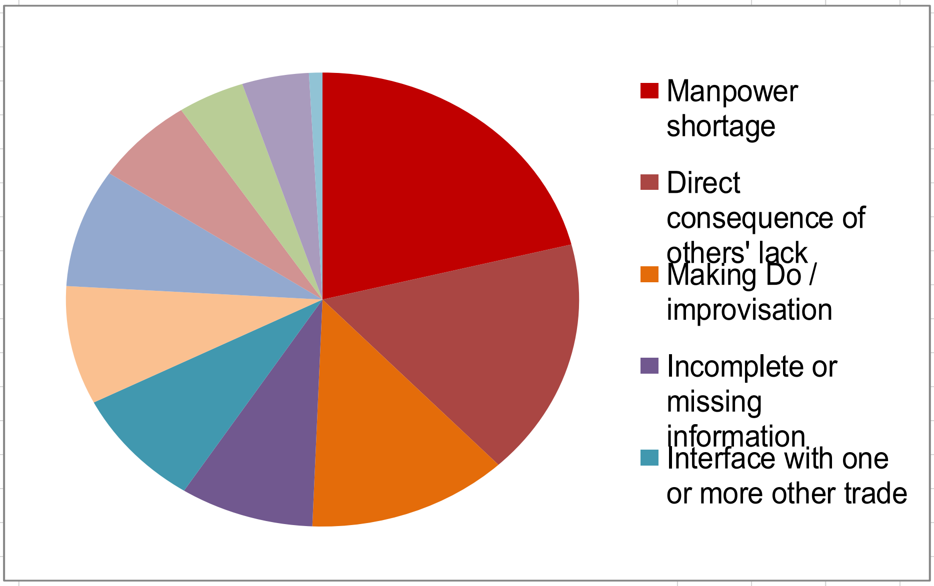


Table 8.2.2-2 Reasons for not completing LPS promises (weeks 26 to 31)

Given the very limited data available in the literature on similar sites, it is difficult to assess at this point whether the figures are high or low for each segment. The researcher considers the above data as baseline for comparisons for the next research circles on the other blocks to ensure a like for like comparison of data.

From the data collected so far, the weekly differences of progress gave a relative indication of the level of progress made each week on each apartment. The calculation of the standard deviation of the progress for each week gave a reliable indication of how the quantity of works varied from one week to another; this can be considered to be a variability index or volatility index.

8.2.3 Measure of the weekly regularity of the works in block 1 A

For each apartment, the differences (Δ) between the progress measured between two consecutive weeks were calculated. Δ represents the actual progress made on each apartment in each week. The mean of the Δ indicates the average global performance of the system in comparison to the target. The closer the mean to the target, the more reliable the target. However, it does not give any indication of the volatility of the flow of progress from one week to the next. This indication is important in assessing the stability of a system.

The standard deviation of the differences of Δ from week to week provided another step in assessing the level of work volatility. The greater the standard deviation of the Δ difference between two consecutive weeks, the higher the volatility. The smaller the standard deviation of the Δ difference between two consecutive weeks, the lower the volatility and the closer the work is to forecasts. The values of a completed apartment have been taken out from the calculation of the global mean to avoid bias in the results of the calculations (the yellow boxes in the tables of the following pages).

Initial Measures YSAYE - VARIATION OF WEEKLY PROGRESSES

	26	27		28		29		30		31	
	Actual	Actual	Δ	Actual	Δ	Actual	Δ	Actual	Δ	Actual	Δ
A01	88	98	*10*	100	*2*	100	-	100	-	100	-
A02	93	100	*7*	100	*0*	100	-	100	-	100	-
A03	90	95	*5*	98	*2*	100	*2*	100	-	100	-
A04	88	98	*10*	98	*0*	98	*0*	98	*0*	100	-
A11	85	93	*7*	98	*5*	98	*0*	98	*0*	100	-
A12	78	85	*7*	95	*10*	100	-	100	-	100	-
A13	90	93	*2*	95	*3*	95	*0*	95	*0*	100	*5*
A14	80	88	*7*	95	*7*	95	*0*	98	*2*	100	*2*
A21	78	78	*0*	88	*10*	95	*7*	98	*2*	100	*2*
A22	73	73	*0*	88	*15*	100	*12*	100	-	100	-
A23	80	80	*0*	90	*10*	98	*8*	98	*0*	100	*2*
A24	78	78	*0*	88	*10*	93	*5*	95	*2*	100	*5*
A31	66	76	*10*	93	*17*	93	*0*	98	*5*	98	*0*
A32	66	78	*12*	88	*10*	95	*7*	100	*5*	100	-
A33	61	76	*15*	86	*10*	88	*2*	95	*7*	95	*0*
A34	61	78	*17*	86	*8*	88	*2*	100	*12*	100	-
A41	59	68	*10*	75	*7*	90	*15*	100	*10*	100	-
A42	56	66	*10*	81	*15*	86	*5*	95	*10*	100	*5*
A43	56	66	*10*	79	*13*	85	*6*	93	*8*	94	*1*
A44	59	66	*7*	79	*13*	83	*4*	93	*10*	98	*5*
A51	49	53	*4*	62	*9*	74	*12*	80	*6*	92	*12*
A52	45	55	*10*	62	*7*	71	*10*	79	*7*	93	*14*
Standard Deviation:			**4,73**		**4,78**		**4,60**		**4,00**		**4,44**

Table 8.2.3-1 Measurements of the weekly work (%) variations in Part A (Block 1).

As the standard deviation indicates the distribution of the progress, the greater the standard deviation, the higher the volatility of the work. The mean of the standard deviations of the progress over the six-week period observed in block 1 part A above is 4.51, fluctuating between 4.00 in week 30 to 4.78 in week 28.

8.2.4 Measure of the weekly stability of the works in block 1 A

As the previous measure only indicates the volatility of the work, it is important, at this stage, to calculate the differences in the progress, planned (or theoretical) and actual. The table below presents this calculation for each apartment and presents both the mean and standard deviation.

YSAYE (A) - DIFFERENCE OF WEEKLY PROGRESSES (THEORY AND ACTUAL)																		
	26			27			28			29			30			31		
	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ
A01	88	88	*0*	92,76	98	*5*	98	100	*2*	100	100	*0*	100	100	-	100	100	-
A02	86,81	93	*6*	91,57	100	*8*	96	100	*4*	100	100	*0*	100	100	-	100	100	-
A03	86	90	*5*	90	95	*5*	95	98	*2*	100	100	*0*	100	100	-	100	100	-
A04	84	88	*3*	89	98	*8*	94	98	*4*	99	98	*-1*	100	98	*-2*	100	100	*0*
A11	83	85	*2*	88	93	*5*	93	98	*5*	98	98	*0*	100	98	*-2*	100	100	*0*
A12	82	78	*-4*	87	85	*-2*	92	95	*3*	96	100	*4*	100	100	-	100	100	-
A13	81	90	*9*	86	93	*7*	90	95	*5*	95	95	*0*	100	95	*-5*	100	100	*0*
A14	80	80	*1*	84	88	*3*	89	95	*6*	94	95	*1*	99	98	*-1*	100	100	*0*
A21	78	78	*0*	83	78	*-5*	88	88	*0*	93	95	*2*	98	98	*0*	100	100	*0*
A22	77	73	*-4*	82	73	*-9*	87	88	*1*	92	100	*8*	96	100	*4*	100	100	*0*
A23	76	80	*4*	81	80	*0*	86	90	*4*	90	98	*7*	95	98	*2*	100	100	*0*
A24	75	78	*3*	80	78	*-2*	84	88	*4*	89	93	*4*	94	95	*1*	99	100	*1*
A31	74	66	*-8*	78	76	*-3*	83	93	*10*	88	93	*5*	93	98	*5*	98	98	*0*
A32	73	66	*-7*	77	78	*1*	82	88	*6*	87	95	*8*	92	100	*8*	96	100	*4*
A33	71	61	*-10*	76	76	*0*	81	86	*5*	86	88	*2*	90	95	*5*	95	95	*0*
A34	70	61	*-9*	75	78	*3*	80	86	*6*	84	88	*4*	89	100	*11*	94	100	*6*
A41	69	59	*-10*	74	68	*-5*	78	75	*-3*	83	90	*7*	88	100	*12*	93	100	*7*
A42	68	56	*-12*	73	66	*-7*	77	81	*4*	82	86	*4*	87	95	*8*	92	100	*8*
A43	67	56	*-10*	71	66	*-5*	76	79	*2*	81	85	*4*	86	93	*7*	90	94	*4*
A44	65	59	*-7*	70	66	*-4*	75	79	*4*	80	83	*3*	84	93	*8*	89	98	*8*
A51	64	49	*-15*	69	53	*-16*	74	62	*-12*	78	74	*-5*	83	80	*-3*	88	92	*4*
A52	63	45	*-18*	68	55	*-13*	73	62	*-11*	77	71	*-6*	82	79	*-3*	87	93	*6*
	Mean:		***-3,72***			***-1,20***			***2,33***			***2,40***			***3,07***			***2,75***
Standard Deviation:			7,49			6,58			5,05			3,72			5,33			3,23

Table 8.2.4-1 Mean and standard deviation of weekly progress (%) in Part A (Block 1).

The difference in the theoretical and actual progress provided objective data that directly reflected the regularity (or volatility) of the works. A positive Δ indicates that the works made on site were ahead of schedule (time is gained and completion should be rescheduled as sooner). A negative Δ indicates the site is behind schedule (time is lost and completion should be rescheduled as later). From table 9-2.2, it can be calculated that the average of the Δ is 0.94 %. This indicates that, on average, in the six weeks observed, the site gained 0.94% over the theoretical ideally levelled schedule. The mean of standard deviation from these data provided a robust indication of the stability of the works.

Although the average of the means was 0.94% (i.e., 0.94% of the progress was gained from the schedule) the global standard deviation of the Δ was 6.0, and most of the weekly progress lay between −5.1% and +6.9% from the target. This scale indicates both the level of volatility and how the weekly targets were reached.

This initial measure has been taken as data of the initial state. At this point in this research, there are insufficient references to data on the level of regularity of the works made in residential construction sites by SMEs. Comparisons or reference to other systems (more mature companies or larger sites) would not be relevant as performance largely depends on the system, as noted earlier.

Hence, the researcher proposes to take the −5.1% and +6.9% scale from the target as a starting point for the measures within the iteration research circles. Comparisons of this measure from research circle to research circle helped record a log of the evolution of the system performance in the search for production flow stability and propose actions for the next research circle, accordingly. The same exercise was undertaken for block B, where the project management and works scheduling were made as usual: the plan was made by the project manager who led the subcontractors to follow a classic CPM. The results are presented in the next chapter.

8.3 Measures from Block 1-B: comparison with traditional scheduling (w26 to w31)

8.3.1 Data collection: weekly quantity of works achieved in block 1 B

This subsection presents the works made in block 1 part B, which were undertaken using a traditional approach (push planning and CPM). Part B of block 1 was taken as a reference data source for traditional scheduling performance output that would later be compared to the lean approach as the research circles developed. The progress of the works were measured over a 6-week period, from week 26 to week 31, following the method described in the previous paragraph. The following table presents the data collected. The same measurements, using the same method were undertaken for part A of Block A. Both blocks had similar apartments (shape, size and complexity).

Apt	Week					
	26	27	28	29	30	31
B01	85%	95%	95%	100%	100%	100%
BO2	88%	93%	93%	98%	100%	100%
Bll/12	85%	88%	90%	95%	95%	95%
B13	88%	95%	100%	100%	100%	100%
B 21	61%	68%	76%	76%	81%	98%
B22	66%	75%	81%	86%	86%	95%
B23	76%	78%	83%	88%	90%	95%
B31	56%	71%	74%	81%	90%	92%
B32	51%	66%	69%	71%	79%	83%
B33	40%	45%	65%	79%	92%	94%
B41	55%	71%	79%	83%	83%	88%
B42	50%	66%	74%	79%	79%	83%
B43	45%	60%	71%	76%	76%	79%
B51	42%	55%	52%	69%	76%	76%
Mean	**63%**	**73%**	**79%**	**84%**	**88%**	**91%**

Table 8.3.1-1 Measurements of work progress (%) in Part B (Block 1).

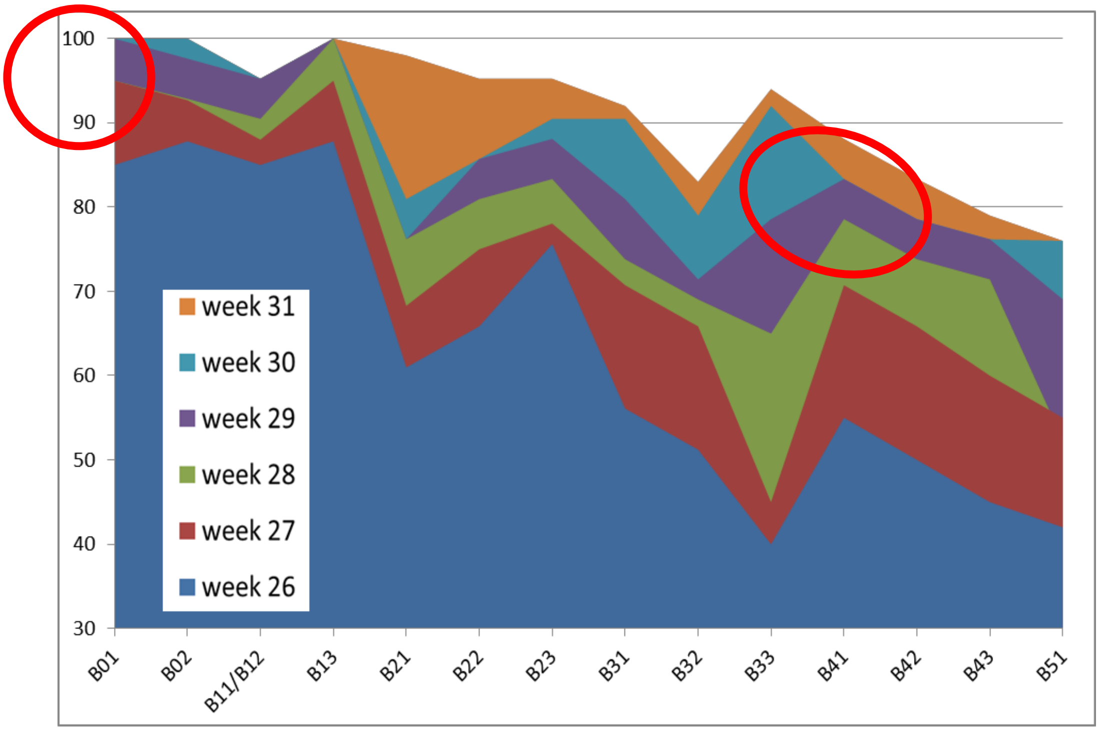


Figure 8.3.1-1 Measurements of work progress (%) in Part B Building (Block 1).

Note: As shown in part A of Block 1, no work was done in some apartments in some weeks (see red circles on the two graphs above).

8.3.2 Investigating the global stability of the works in block 1 B

Given that the measurement of the progress itself is not sufficient to assess the stability of the works as developed earlier, the table below presents the calculation of the standard deviation from the data of the progress collected weekly in part B of block 1.

	26	27		28		29		30		31	
	Actual	Actual	Δ	Actual	Δ	Actual	Δ	Actual	Δ	Actual	Δ
B01	85	95	*10*	95	0	100	5	100	-	100	-
B02	88	93	*5*	93	0	98	5	100	-	100	-
B11/B12	85	88	*3*	90	2	95	5	95	0	95	*0*
B13	88	95	*7*	100	5	100	-	100	-	100	-
B21	61	68	*7*	76	8	76	0	81	5	98	*17*
B22	66	75	*9*	81	6	86	5	86	0	95	*10*
B23	76	78	*2*	83	5	88	5	90	2	95	*5*
B31	56	71	*15*	74	3	81	7	90	10	92	*2*
B32	51	66	*15*	69	3	71	2	79	8	83	*4*
B33	40	45	*5*	65	20	79	14	92	13	94	*2*
B41	55	71	*16*	79	8	83	5	83	0	88	*5*
B42	50	66	*16*	74	8	79	5	79	0	83	*5*
B43	45	60	*15*	71	11	76	5	76	0	79	*3*
B51	42	55	*13*	52	-3	69	17	76	7	76	*0*
Standard Deviation:			**4,94**		**5,60**		**4,41**		**4,73**		**4,91**

Table 8.3.2-1 Measurements of the weekly works (%) variations in Part B of Block 1 Building (Block 1)

As the standard deviation indicates regarding the distribution of the progress from one week to another, the greater the standard deviation, the greater the volatility of the work. The mean of the standard deviations of the progress over the six-week period observed for block 1part B is 4.94. It oscillates between 4.41 in week 29 and 5.6 in week 26. In comparison, the standard deviation of part A of block 1 was 4.5. The difference in the standard deviation between the two parts of block 1 cannot be considered significant. This makes it unclear whether the LPS that had been introduced in block 1 phase A helped to lower work volatility in comparison to block 1 phase B, which was run following a traditional approach.

From the above, it is not possible to conclude that the LPS itself had any significant impact in the search for improved flow stability. The researcher decided to go further in the exploitation of the data collected and increase the level of understanding of the levels of progress made and measured weekly.

8.3.3 Measures of the weekly stability of the works in block 1 B

While the works have proven to be unstable both in the traditional scheduling system and in LPS scheduling, the weekly target of 4.8% progress (see 9.1.3) is less often attained following the traditional approach than following the LPS approach.

- From the progress of the 112 week/apartment measure in block 1 part B following the traditional scheduling approach, 20 apartments showed progress above the 4.8% target, which is 18% on average (see 9.1.3)
- From the progress of the 77 week/apartment measure in block 1 part A, following the LPS scheduling approach, 40 showed progresses above the 4.8% target, which is 52% on average.

The measure of the mean and standard deviation of the theoretical and actual work is presented below.

	26			27			28			29			30			31		
	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ
B01	85	95	*10*	90	95	*5*	95	95	*0*	99	100	*1*	100	100	*0*	100	100	-
B02	84	93	*9*	89	93	*4*	93	93	*0*	98	98	*0*	100	100	*0*	100	100	-
B11/B12	83	88	*5*	87	88	*1*	92	90	*-2*	97	95	*-2*	100	95	*-5*	100	95	*-5*
B13	81	95	*14*	86	95	*9*	91	100	*9*	96	100	*4*	100	100	*0*	100	100	-
B21	80	68	*-12*	85	68	*-17*	90	76	*-14*	95	76	*-18*	99	81	*-18*	100	98	*-2*
B22	79	75	*-4*	84	75	*-9*	89	81	*-8*	93	86	*-8*	98	86	*-12*	100	95	*-5*
B23	78	78	*0*	83	78	*-5*	87	83	*-4*	92	88	*-4*	97	90	*-6*	100	95	*-5*
B31	77	71	*-6*	81	71	*-11*	86	74	*-12*	91	81	*-10*	96	90	*-5*	100	92	*-8*
B32	75	66	*-10*	80	66	*-14*	85	69	*-16*	90	71	*-18*	95	79	*-16*	99	83	*-16*
B33	74	45	*-29*	79	45	*-34*	84	65	*-19*	89	79	*-10*	93	92	*-1*	98	94	*-4*
B41	73	71	*-2*	78	71	*-7*	83	79	*-4*	87	83	*-4*	92	83	*-9*	97	88	*-9*
B42	72	66	*-6*	77	66	*-11*	81	74	*-8*	86	79	*-8*	91	79	*-12*	96	83	*-12*
B43	71	60	*-11*	75	60	*-15*	80	71	*-9*	85	76	*-9*	90	76	*-14*	95	79	*-16*
B51	70	55	*-15*	74	55	*-19*	79	52	*-27*	84	69	*-15*	89	76	*-13*	93	76	*-17*
	Mean:		***-4,03***			***-8,80***			***-8,01***			***-7,19***			***-7,95***			***-9,02***
Standard Deviation:			**11,36**			**11,36**			**9,07**			**6,87**			**6,27**			**5,51**

Table 8.3.3-1 Mean and standard deviation of weekly progress (%) in Part B Building (Block 1).

- The average of the Δ was −7.5%. This indicates that, on average, the works were late by 7.5% in comparison to the theoretical weekly schedule.
- The mean standard deviation of the Δ was 8.7. This indicates that most of the weekly progress fell between -7.5 + 8.7 = +1.2% and -7.5 – 8.7 = -16.2% compared to theory.
- Exploiting the data, as in the table above, gives an indication of both the volatility of the works (standard deviation of weekly progress) and how the weekly targets were reached (average of weekly progress).

Again, the limited possible reference to the existing literature of comparable sites at the time of the research makes it difficult to assess whether the levels of both the average of weekly works target attained and stability can be considered low or high.

The data measured in block 1 provided the researcher with a baseline for comparing the measures made on the following blocs through the research circles.

8.4 Measures from block 2: application of takt planning. Focus on week 44 to 49

Takt planning was explained at this point, and the sequence of the works was agreed upon by the phase master plan made following the LPS format; the same measurements as in Block 1, following the same method, were undertaken in Block 2. Both blocks had similar apartments (shape, size and technical complexity).

The contractors were asked to move from one apartment to the next according to the takt defined conjointly. The available buffer resources, when the apartment was smaller (the works were finished before the end of the week), were used to work in the common and technical areas. The companies were asked to commit weekly to the closing aim of the next takt area to be addressed.

8.4.1 Measures from the weekly work plan

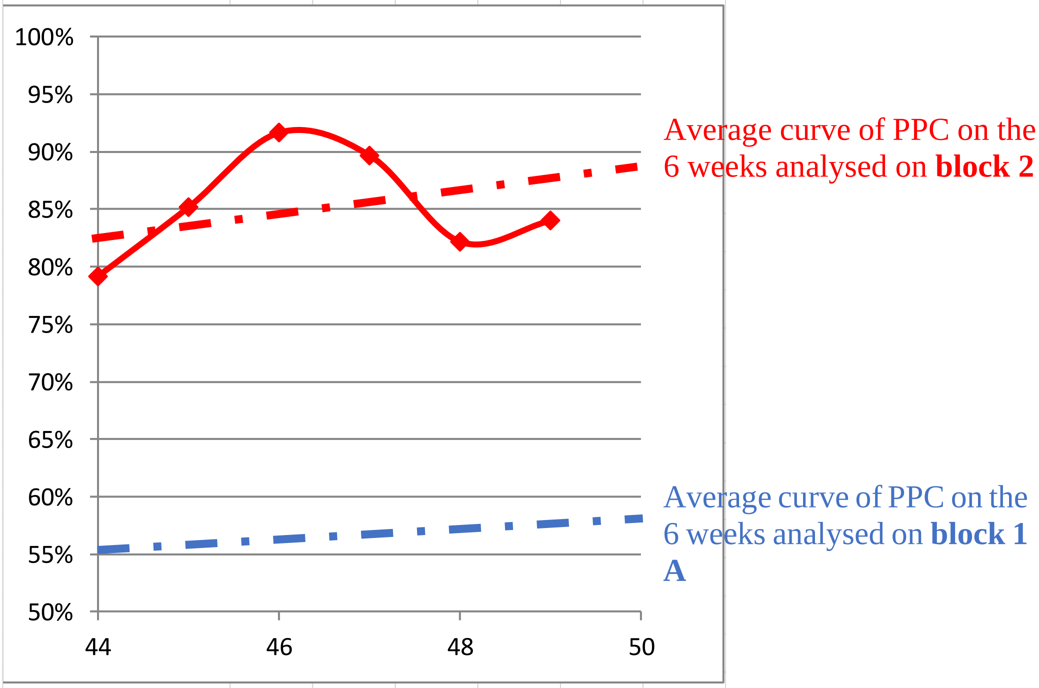
This section presents the results of the data collection made from the works in block 2 where takt-based planning was being tested in an attempt to improve flow stability through fostering work pace regularity and identifying smaller batches of works that would be more manageable then macro tasks in the organisation.

The WWP was drawn up following the same protocol as in block 2. The measures were carried out over a period of 6 weeks (week 44 to 49); the apartments of block 2 were comparable with the ones of block 1. The contractors were the same as in block 1. This section presents the results of the WWP and compares these results with those of block 1.

The graph below presents the PPC measures collected on site over the period analysed.

Bloc 2 : PPC graph weeks 44 to 49

Week :	**44**	**45**	**46**	**47**	**48**	**49**
PPC :	79%	85%	92%	90%	82%	84%



Graph 8.4.1-1 Evolution of the PPC in bloc 2 from week 44 to 49

The average of the PPCs during the period was 85%. Again, given the limited data available on comparable sites, it is difficult to state whether this score is high or low. However, this score, which can be compared to the 58% of block 1A, represents a significant step forward in the reliability of the promises given in the WWP. The tendency in the graph showed that this score continued to move up, which is confirmed later in the works of block 2, where the PPC levelled at around 70 - 80%.

8.4.2 Measure of the weekly quantity of works achieved in block 2

The progress of the works were measured over a six-week period, from week 44 to week 49. The following table presents the results of the measures collected.

Measures of PROGRESSES on Bloc 2						
Week	44	45	46	47	48	49
Apt	AP	AP	AP	AP	AP	AP
C01	75%	82%	88%	95%	97%	100%
C02	73%	82%	90%	97%	97%	100%
C03	72%	78%	86%	95%	97%	100%
C04	68%	79%	94%	101%	97%	100%
C05	68%	75%	82%	90%	97%	100%
C06	70%	78%	86%	93%	97%	100%
C07	67%	75%	82%	88%	95%	100%
C08	65%	72%	79%	85%	91%	100%
C09	68%	72%	79%	86%	92%	100%
C10	65%	73%	78%	85%	92%	100%
C11	68%	74%	77%	78%	85%	92%
C12	65%	71%	77%	85%	93%	96%
C13	60%	62%	66%	70%	77%	88%
C14	63%	65%	74%	81%	87%	94%
C15	60%	66%	74%	79%	84%	91%
C16	50%	60%	69%	77%	83%	89%
C17	49%	62%	69%	70%	75%	82%
C18	50%	57%	64%	65%	73%	81%
C19	51%	58%	62%	70%	77%	86%
C20	49%	56%	64%	70%	74%	81%
C21	44%	58%	64%	72%	76%	83%
C22	44%	52%	59%	70%	76%	81%
C23	40%	45%	54%	62%	67%	76%
C24	42%	48%	53%	61%	68%	75%
C25	45%	50%	55%	63%	68%	73%
C26	39%	44%	52%	60%	67%	72%
C27	36%	48%	54%	55%	63%	68%
C28	34%	38%	46%	53%	57%	66%
C29	39%	42%	48%	55%	56%	62%
C30	43%	45%	49%	55%	59%	67%
C31	39%	48%	58%	63%	70%	74%
C32	41%	45%	50%	51%	59%	67%
C33	38%	44%	52%	59%	63%	69%
C34	35%	42%	49%	55%	61%	66%
C35	33%	40%	46%	52%	55%	64%

Table 8.4.2-1.1Measurement of actual works progress (%) in Block 2 from week 44 to week 49

In contrast to block 1 (both part A and B), there was no discontinuity in the layers of the works carried out each week, indicating that there was no discontinuity in the flow of works that was carried out in each apartment, each week.

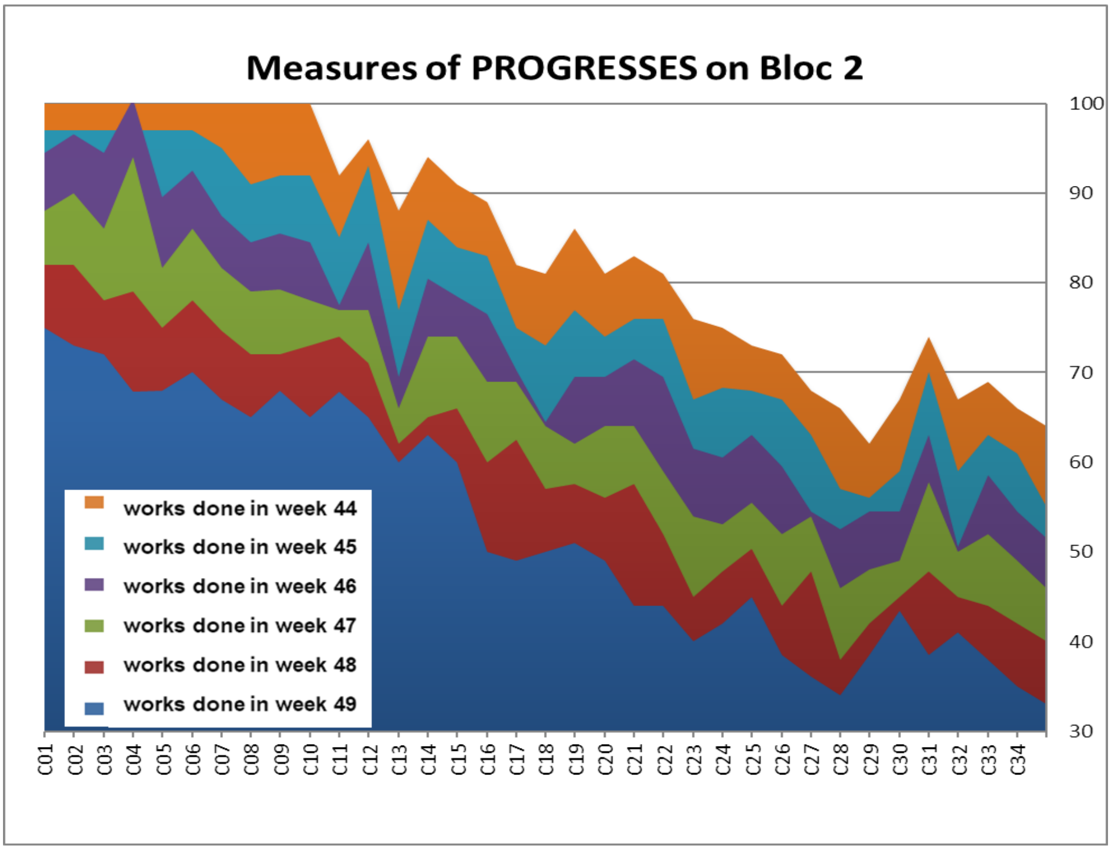


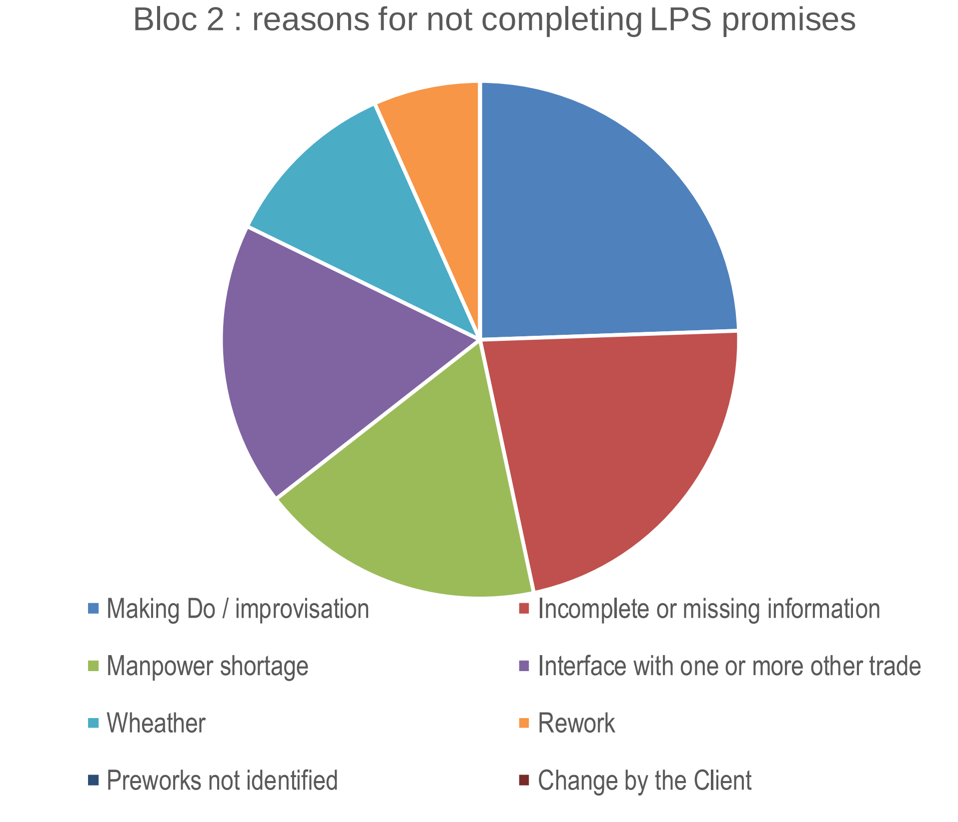
Figure 8.4.2-1 Measurement of works progress (%) (Block 2) from week 44 to week 49

The continuity in the workflow observed in block 2 indicates that the contractors on site were provided with all the resources needed to perform certain tasks and that the site area was ready (with pre-works completed and space accessible). As observed in the first measures in block 1, manpower shortages and the direct consequences of others' lack were the two most important reasons for not completing the promises made in the WWP . As previously stated, the shortage of manpower came from the limited resources that an SME can allocate to each site and arbitration regarding the resource allocation was carried out each week, depending on the capacity of the site to absorb the resource and make progress to make profits.

The table and graph below illustrate the data recorded for block 2 regarding the reasons for not completing the promises made in the collaborative phase of the LPS. The reasons came from the self-assessment of the site foremen.

Bloc 2 : reasons for not completing LPS promises

Direct consequence of others' lack	23	26%
Overestimation of the production capability	20	23%
Making Do / improvisation	11	13%
Incomplete or missing information	10	11%
Manpower shortage	8	9%
Interface with one or more other trade	8	9%
Wheather	5	6%
Rework	3	3%
Preworks not identified	0	0%
Change by the Client	0	0%
Late material / broken	0	0%



Graph 8.4.2-1 Reasons for not completing the LPS promises in block 2

The measures from block 2 showed a change in the reasons for not completing the LPS promises:

1) While in block 1 “manpower shortage” (21%), “direct consequence of others' lacks” (17%) and “making do/improvisation” (13%) represented half of the reasons for not completing promises, the reasons were different in block 2. “Direct consequence of others' lacks” (26%) and “overestimation of the production capability” (23%) represent nearly half of the reasons.
2) Simultaneously, in block 2, the reason “manpower shortage” was down to 9 % while “Overestimation of the production capability” rose to 23%, compared to the 6% in block 1.
3) “making do and improvisation” stayed at 13%.

Point 1) illustrates a switch in the organisation of the contractors, who were engaged in feeding the site in block 2 with resources so long as it could absorb them, thus avoiding wasting money on unused resources, which is, essentially, manpower. Also, as “direct consequence of others' lacks” rose from 17% to 26%, it seems that the coordination and time buffer needed to be improved.

From point 2), the contractors seem to have been more ambitious in their plans during the collaborative planning phase of the LPS as, despite the availability of their staff, “overestimation of the production capability” became a major reason.

Point 3) illustrates that making do, which stayed at a constant level, was still well anchored in the site’s organisation.

It was then necessary to further investigate the data to better understand the situation as observed on site from a search for production flow stability perspective. The analysis of the standard deviation in the following section presents the results from the calculation of the variance of the progress from one week to the next as an indicator of the regularity of the works.

8.4.3 Measure of the weekly regularity of the works in block 2

Based on the same takt time that determined the progress possible in theory, the data were compiled the same way as they were for Block 1 and are presented in the table below.

	44	45		46		47		48		49	
	Actual	Actual	Δ	Actual	Δ	Actual	Δ	Actual	Δ	Actual	Δ
C01	75	82	*7*	88	*6*	95	*7*	97	*3*	100	*3*
C02	73	82	*9*	90	*8*	97	*7*	97	*1*	100	*3*
C03	72	78	*6*	86	*8*	95	*9*	97	*3*	100	*3*
C04	68	79	*11*	94	*15*	101	*7*	97	*-4*	100	*3*
C05	68	75	*7*	82	*7*	90	*8*	97	*8*	100	*3*
C06	70	78	*8*	86	*8*	93	*7*	97	*5*	100	*3*
C07	67	75	*8*	82	*7*	88	*6*	95	*8*	100	*5*
C08	65	72	*7*	79	*7*	85	*6*	91	*7*	100	*9*
C09	68	72	*4*	79	*7*	86	*6*	92	*7*	100	*8*
C10	65	73	*8*	78	*5*	85	*7*	92	*8*	100	*8*
C11	68	74	*6*	77	*3*	78	*1*	85	*8*	92	*7*
C12	65	71	*6*	77	*6*	85	*8*	93	*9*	96	*3*
C13	60	62	*2*	66	*4*	70	*4*	77	*8*	88	*11*
C14	63	65	*2*	74	*9*	81	*7*	87	*7*	94	*7*
C15	60	66	*6*	74	*8*	79	*5*	84	*6*	91	*7*
C16	50	60	*10*	69	*9*	77	*8*	83	*7*	89	*6*
C17	49	62	*13*	69	*7*	70	*1*	75	*5*	82	*7*
C18	50	57	*7*	64	*7*	65	*1*	73	*9*	81	*8*
C19	51	58	*7*	62	*4*	70	*8*	77	*8*	86	*9*
C20	49	56	*7*	64	*8*	70	*6*	74	*5*	81	*7*
C21	44	58	*14*	64	*6*	72	*8*	76	*5*	83	*7*
C22	44	52	*8*	59	*7*	70	*11*	76	*7*	81	*5*
C23	40	45	*5*	54	*9*	62	*8*	67	*6*	76	*9*
C24	42	48	*6*	53	*5*	61	*7*	68	*8*	75	*7*
C25	45	50	*5*	55	*5*	63	*8*	68	*5*	73	*5*
C26	39	44	*5*	52	*8*	60	*8*	67	*8*	72	*5*
C27	36	48	*12*	54	*6*	55	*1*	63	*9*	68	*5*
C28	34	38	*4*	46	*8*	53	*7*	57	*5*	66	*9*
C29	39	42	*3*	48	*6*	55	*7*	56	*2*	62	*6*
C30	43	45	*2*	49	*4*	55	*6*	59	*5*	67	*8*
C31	39	48	*9*	58	*10*	63	*5*	70	*7*	74	*4*
C32	41	45	*4*	50	*5*	51	*1*	59	*9*	67	*8*
C33	38	44	*6*	52	*8*	59	*7*	63	*5*	69	*6*
C34	35	42	*7*	49	*7*	55	*6*	61	*7*	66	*5*
C35	33	40	*7*	46	*6*	52	*6*	55	*4*	64	*9*
Standard Deviation :		**2,87**		**2,13**		**2,44**		**2,59**		**2,22**	

Table 8.4.3-1 Measurements of the weekly work (%) variations in Block 2

As the standard deviation indicates concerning the distribution of the progress, the larger the standard deviation, the larger the volatility of the work. The mean of the standard deviations of the progress over the six-week period observed for block 2 was 2.4, fluctuating between 2.13 in week 46 and 2.87 in week 49. Compared to the 4.5 of part A, scheduled only with the LPS, the improvement in works volatility was sensible. Improvement from block 1was also visible on site (not a single health and safety issue problem was reported) and the flow of works was measured twice as many times as before. From the self-assessment of the foremen, focusing on a weekly takt forced them to consider smaller pieces of work and to better anticipate the resources that were needed and allocated for the following two weeks. Two foremen (with 5 years and 8 years of work experience) shared that it was the first time they had planned as far as two weeks in advance, their typical organisation being based solely on experience and "push in emergency" coordination and supply. Their view was that their traditional way of organising the works was the only one that could cope with the disorganisation of traditional construction sites, but that they understood and promoted the organisation tested on block 1 and 2. All the other foremen insisted, at this point, on the importance that every other contractor played the game honestly. This shows that they had started to be aware of the importance of integrating others into the system and that they themselves should be responsible for the information they shared With their colleagues.

The focus on smaller cells of works done at a regular pace helped raise the quality of the coordination of the works. However, it was necessary to further analyse the data to understand the gain in workflow stability. The following section develops how close to the ideal line the works were made on site.

8.4.4 Measure of the weekly stability of the works in block 2

As in block 1, the data was compiled to extract the stability index (to measure distance from the linear layer target), and the figures are presented in the table below.

	44			45			46			47			48			49		
	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ
C01	75	75	0	80	82	2	85	88	3	89	95	5	94	100	6	99	100	1
C02	74	73	-1	79	82	3	83	90	7	88	97	8	100	100	0	100	100	-
C03	73	72	-1	77	78	1	82	86	4	87	95	8	100	100	0	100	100	-
C04	71	68	-4	76	79	3	81	94	13	86	100	14	100	100	-	100	100	-
C05	70	68	-2	75	75	0	80	82	2	85	90	5	89	97	8	100	100	-
C06	69	70	1	74	78	4	79	86	7	83	93	9	88	100	12	100	100	-
C07	68	67	-1	73	75	2	77	82	4	82	88	5	87	95	8	100	100	0
C08	67	65	-2	71	72	1	76	79	3	81	85	4	86	91	5	90	100	10
C09	65	68	3	70	72	2	75	79	4	80	86	6	85	92	7	89	100	11
C10	64	65	1	69	73	4	74	78	4	79	85	6	83	92	9	88	100	12
C11	63	68	5	68	74	6	73	77	4	77	78	0	82	85	3	87	92	5
C12	62	65	3	67	71	4	71	77	6	76	85	8	81	93	12	86	96	10
C13	61	60	-1	65	62	-3	70	66	-4	75	70	-6	80	77	-3	85	88	3
C14	60	63	3	64	65	1	69	74	5	74	81	7	79	87	8	83	94	11
C15	58	60	2	63	66	3	68	74	6	73	79	6	77	84	7	82	91	9
C16	57	50	-7	62	60	-2	67	69	2	71	77	5	76	83	7	81	89	8
C17	56	49	-7	61	62	2	65	69	4	70	70	0	75	75	0	80	82	2
C18	55	50	-5	60	57	-3	64	64	0	69	65	-5	74	73	-1	79	81	2
C19	54	51	-3	58	58	-1	63	62	-1	68	70	2	73	77	4	77	86	9
C20	52	49	-3	57	56	-1	62	64	2	67	70	3	71	74	3	76	81	5
C21	51	44	-7	56	58	2	61	64	3	65	72	6	70	76	6	75	83	8
C22	50	44	-6	55	52	-3	60	59	-1	64	70	5	69	76	7	74	81	7
C23	49	40	-9	54	45	-9	58	54	-4	63	62	-2	68	67	-1	73	76	3
C24	48	42	-6	52	48	-5	57	53	-4	62	61	-1	67	68	2	71	75	4
C25	46	45	-1	51	50	-1	56	55	-1	61	63	2	65	68	3	70	73	3
C26	45	39	-7	50	44	-6	55	52	-3	60	60	0	64	67	3	69	72	3
C27	44	36	-8	49	48	-1	54	54	0	58	55	-4	63	63	0	68	68	0
C28	43	34	-9	48	38	-10	52	46	-6	57	53	-5	62	57	-5	67	66	-1
C29	42	39	-3	46	42	-4	51	48	-3	56	55	-1	61	56	-5	65	62	-3
C30	40	43	3	45	45	0	50	49	-1	55	55	0	60	59	-1	64	67	3
C31	39	39	-1	44	48	4	49	58	9	54	63	9	58	70	12	63	74	11
C32	38	41	3	43	45	2	48	50	2	52	51	-2	57	59	2	62	67	5
C33	37	38	1	42	44	2	46	52	6	51	59	7	56	63	7	61	69	8
C34	36	35	-1	40	42	2	45	49	4	50	55	4	55	61	6	60	66	6
C35	35	33	-2	39	40	1	44	46	2	49	52	3	54	55	1	58	64	6
	Mean:		-2,00			0,05			2,25			3,23			3,88			5,36
Standard Deviation:			3,81			3,60			4,13			4,65			4,52			3,98

Table 8.4.4-1Mean and standard deviation of weekly progress (%) in Block 2.

Determining the difference in the theoretical (levelled) progress and the actual progress measured on site provided objective data that directly reflected how much the works on site had followed the ideal path. A positive Δ indicates the site was ahead of schedule (time had been gained and completion would be rescheduled sooner). A negative Δ indicates the site was behind schedule (time had been lost and completion needed to be rescheduled for later).

While the works still suffer from instability, improvement in the works progress output is notable from block 1:

- From the progress of the 175 week/apartment measured in block 2 following the takt scheduling approach, 19 showed progress below the 4.8% target, which was 11% on average. This figure should be compared to the 48% measured in block 1 A to show that the weekly works target was significantly better attained following the takt approach than following the LPS approach in the context of this research.
- The average of the Δ was 2.1%. This indicates that, on average, the works were finished 2.1 % earlier than on the theoretical weekly schedule. In block 1A, the works were 7.5% late, on average. The difference of 9.6% between these two measures means that the works in block 2 following takt planning were executed nearly 10% faster than in block 1 A following the LPS.
- The mean standard deviation of the Δ was 4.1. This indicates that most of the weekly progresses fell between -6.2% (or -2.1% - 4.1%) and 4.0% (or 2.1% + 6.1%) from the theoretical weekly schedule. This -6.2% to 4.0% dispersion of works executed in block 2 following takt planning is to be compared with the -16.2% to +1.2% of block 1A, where the blocks were executed following the LPS.

Exploiting the data as in the table above indicates both the volatility of the works (standard deviation of weekly progress) and how the weekly targets were reached (average of weekly progress). Improvement in the workflow stability was notable, as the above shows. Not only were the works executed more quickly than in the theoretical schedule, but the flow was more regular from week to week.

However, as with block 1, the limited possible reference to the existing literature on comparable sites (residential units made by SMEs) at the time of the research makes it difficult to assess whether the levels of both the averages of weekly works target attained in block 2 and the stability can be considered high or low.

The research in block 2, given the same nature of the apartments and the companies as those in block 1, shows that the application of takt planning has proved to be beneficial in the search for g a stable workflow. However, the figures show that some instability still existed in the output of the scheduling system whish needed to be addressed.

The research made in the next block (3) introduced a visual management system based on kanban to assist the discipline; given that the discipline (or lack of making do) had been identified as the next main issue in seeking a fully stable flow of works on site.

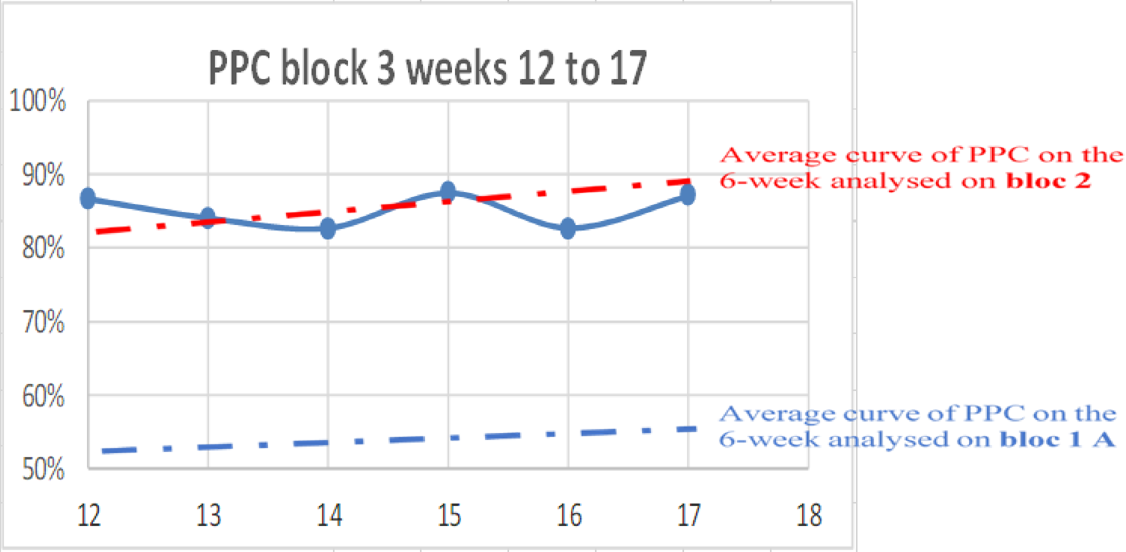
8.5 Measures from block 3. Application of kanban

This section presents the results of data collection made from the works in block 3 where a kanban-based visual tool was tested to try to improve flow stability through fostering discipline in the organisation.

8.5.1 Measures from the weekly work plan

The WWP was drawn up following the same protocol as in block 2. The measures were carried out over a period of 6 weeks (week 12 to 17), on the 33 significant apartments from Block 3 (the penthouses have been excluded from the research as they were not similar to nor comparable with the other apartments). The contractors were the same as in block 2. This section presents the results of the WWP and compares these results with those of the previous blocks. The graph below presents the PPC measures.

Week :	12	13	14	15	16	17
PPC block3 weeks 12 to 17	87%	84%	83%	88%	83%	87%



Graph 8.5.1-1 Evolution of PPC on block 3 from week 12 to 17

The average of the PPCs during the period was 85%. Again, given the limited data available on comparable sites, it is difficult to state whether this score was high or low. However, the score can be compared to the 85% of block 2.

It is interesting to note that the PPC score reached the same level but that the score was more regular from week to week in block 3 than in block 2, where the PPC showed a high degree of variation. The tendency in block 3, as shown in the graph, is that this score levelled out at between 80 to 90%. This was confirmed later in the works of block 2.

It is to be noted at this point that the group of contractors had succeeded in raising the PPC consistently from block 1 to block 3:

- Levelled PPC in block 1: 60% to 70%
- Levelled PPC in block 2: 70% to 80%
- Levelled PPC in block 3: 80% to 90%

As improvement of the workflow predictability through measuring the PPC is the main goal of the LPS, from this perspective, the researcher can conclude that the results measured on site reach the LPS goal.

More analysis of the measures and data are, however, needed to draw conclusions on the impact of the system developed in this research concerning the stability of the works. The following section develops this point.

8.5.2 Measure of the weekly quantity of works achieved in block 3

The measures of the weekly progresses were made following the same protocol as in block 2. The measures were carried out over 6 weeks, on the 33 significant apartments from Block 3 (the penthouses were excluded from the research as they were not similar to nor comparable with the other apartments). The progress on the apartments ranged from 20% to 75% at the beginning of the measure and from 38% to 100% at the end of the measure. The table below presents the results of these measures.

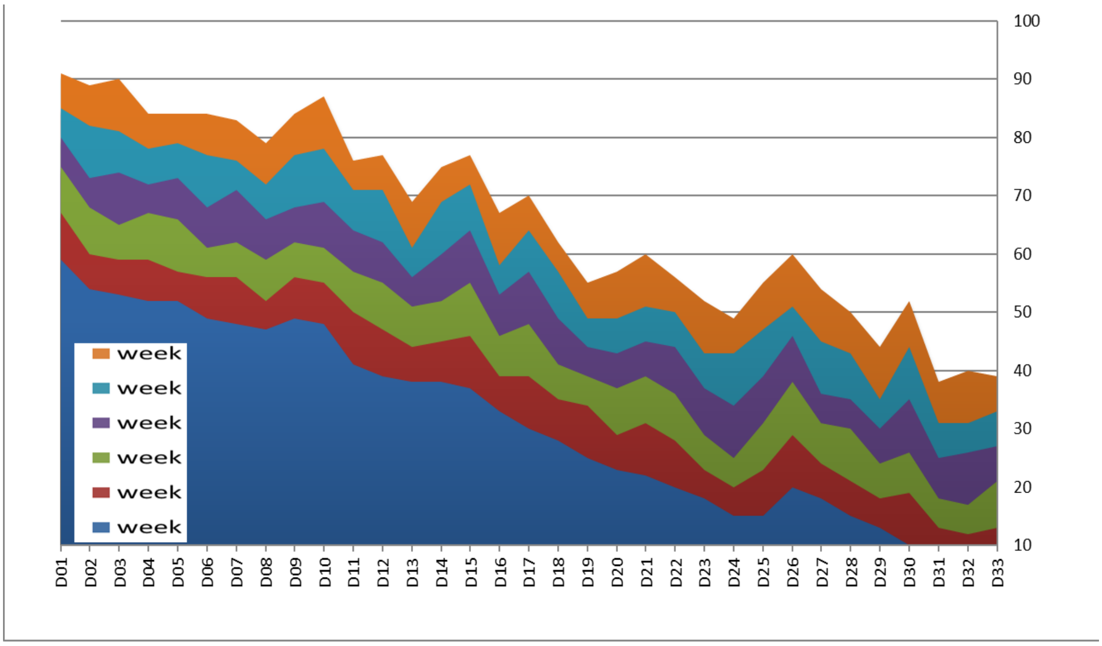


Figure 8.5.2-1 Measurement of works progress (%) Block 3 in weeks 12 to 17

	12	13	14	15	16	17
	Actual	Actual	Actual	Actual	Actual	Actual
D01	59	67	75	80	85	91
D02	54	60	68	73	82	89
D03	53	59	65	74	81	90
D04	52	59	67	72	78	84
D05	52	57	66	73	79	84
D06	49	56	61	68	77	84
D07	48	56	62	71	76	83
D08	47	52	59	66	72	79
D09	49	56	62	68	77	84
D10	48	55	61	69	78	87
D11	41	50	57	64	71	76
D12	39	47	55	62	71	77
D13	38	44	51	56	61	69
D14	38	45	52	60	69	75
D15	37	46	55	64	72	77
D16	33	39	46	53	58	67
D17	30	39	48	57	64	70
D18	28	35	41	49	57	62
D19	25	34	39	44	49	55
D20	23	29	37	43	49	57
D21	22	31	39	45	51	60
D22	20	28	36	44	50	56
D23	18	23	29	37	43	52
D24	15	20	25	34	43	49
D25	15	23	31	39	47	55
D26	20	29	38	46	51	60
D27	18	24	31	36	45	54
D28	15	21	30	35	43	50
D29	13	18	24	30	35	44
D30	10	19	26	35	44	52
D31	7	13	18	25	31	38
D32	6	12	17	26	31	40
D33	5	13	21	27	33	39

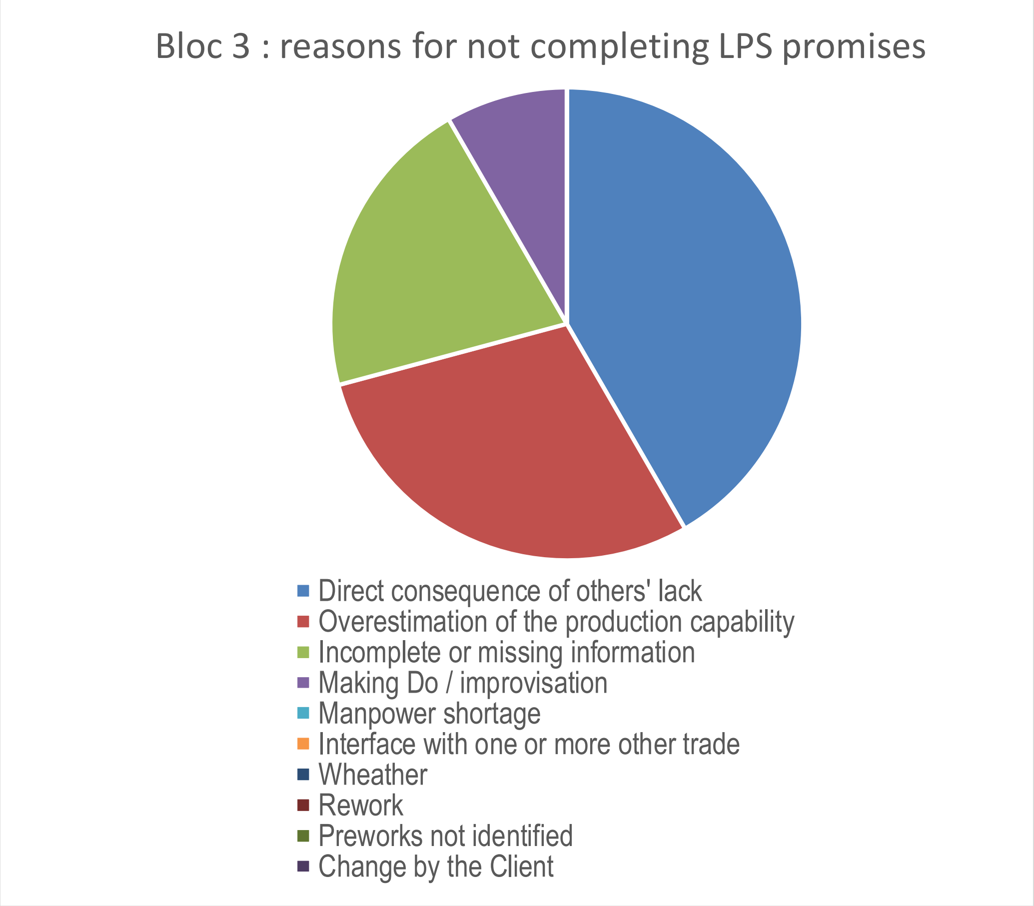
Table 8.5.2-1 Measurement of works progress (%) in Block 3.

The graph above illustrates the results of the accumulated progress from week 12 to week 32 and shows layers of progress that tend to be more regular than in the previous blocks. The analysis of the standard deviation in the following section presents the results from the calculation of the variance of the progress from one week to the next as an indicator of the regularity of the works.

The table and graph below illustrate the data recorded in block 2 regarding the reasons for not completing the promises made in the collaborative phase of the LPS. The reasons were provided by and categorised based on the self-assessment of the site foremen.

Bloc 3 : reasons for not completing LPS promises

Direct consequence of others' lack	10	42%
Overestimation of the production capability	7	29%
Incomplete or missing information	5	21%
Making Do / improvisation	2	8%
Manpower shortage	0	0%
Interface with one or more other trade	0	0%
Wheather	0	0%
Rework	0	0%
Preworks not identified	0	0%
Change by the Client	0	0%
Late material / broken	0	0%



Graph 8.5.2-1 Reasons for not completing the LPS promises in block 3

The measures from block 3 show an evolution of the reasons for not completing the LPS promises:

- While in block 1 “manpower shortage” (21%), “direct consequence of others' lacks” (17%) and “making do/improvisation” (13%) represented half of the reasons for not completing the promises, in block 2, “Direct consequence of others' lacks” (26%) and “overestimation of the production capability” (23%) represent nearly half of the reasons. In block 3, the direct consequence of the others’ lack represents nearly half of the reasons for not completing the works.
- In block 2, the reason “manpower shortage” was down to 9 %, and “Overestimation of the production capability” stood at 23% (6% in block 1), “manpower shortage” was at 0% and “Overestimation of the production capability” rose up to 29%.
- While “incomplete or missing information was at 11% in block 2 and 8% in block 1, it rose to 21 % in block 3.
- While “making do and improvisation” was at 13% in block 1 and in block 2, it fell to 8% in block 3.

From Point 1) coordination and the time buffer still had to be improved; however, the domino effect was visible. When a contractor could not complete the works as planned in the WWP, the other organisations did not have enough time/alternative works buffer to absorb the effect of the failure. This effect was mechanical through the tension created in the chain of works sequence. If there was a fourth block, the researcher would certainly propose working on slightly loosening the chain so that the system could better absorb the daily variations yet keep a stable workflow.

Point 2) confirms the switch in the organisation of the contractors who engaged themselves to feed the site in block 2 with resources if it could absorb them, thus avoiding the wasting of money on unused resources (essentially, manpower). The contractors confirmed they had been more ambitious in their plans during the collaborative planning phase of the LPS (as in block 2). This tends to confirm point 1) and the tension on the workflow chain.

Point 3) confirms that that making do, which stayed at a constant level in block 1 and 2, is now a problem in block 3 which must be addressed and illustrates that a better scheduling organisation allows more attention to be paid to and anticipation of the production, leading to less making do on site.

Again, it was then necessary to investigate further the data collected to better understand the situation as observed on site from a production flow stability perspective. The analysis of the standard deviation in the following section presents the results from the calculation of the variance of the progress from one week to the next as an indicator of the regularity of the works.

8.5.3 Measure of the weekly regularity of the works in block 3

Initial Measures of PROGRESSES on YSAYE - VARIATION OF WEEKLY PROGRESSES											
	12	**13**		**14**		**15**		**16**		**17**	
	Actual	Actual	Δ	Actual	Δ	Actual	Δ	Actual	Δ	Actual	Δ
D01	59	67	*8*	75	*8*	80	*5*	85	*5*	91	*6*
D02	54	60	*6*	68	*8*	73	*5*	82	*9*	89	*7*
D03	53	59	*6*	65	*6*	74	*9*	81	*7*	90	*9*
D04	52	59	*7*	67	*8*	72	*5*	78	*6*	84	*6*
D05	52	57	*5*	66	*9*	73	*7*	79	*6*	84	*5*
D06	49	56	*7*	61	*5*	68	*7*	77	*9*	84	*7*
D07	48	56	*8*	62	*6*	71	*9*	76	*5*	83	*7*
D08	47	52	*5*	59	*7*	66	*7*	72	*6*	79	*7*
D09	49	56	*7*	62	*6*	68	*6*	77	*9*	84	*7*
D10	48	55	*7*	61	*6*	69	*8*	78	*9*	87	*9*
D11	41	50	*9*	57	*7*	64	*7*	71	*7*	76	*5*
D12	39	47	*8*	55	*8*	62	*7*	71	*9*	77	*6*
D13	38	44	*6*	51	*7*	56	*5*	61	*5*	69	*8*
D14	38	45	*7*	52	*7*	60	*8*	69	*9*	75	*6*
D15	37	46	*9*	55	*9*	64	*9*	72	*8*	77	*5*
D16	33	39	*6*	46	*7*	53	*7*	58	*5*	67	*9*
D17	30	39	*9*	48	*9*	57	*9*	64	*7*	70	*6*
D18	28	35	*7*	41	*6*	49	*8*	57	*8*	62	*5*
D19	25	34	*9*	39	*5*	44	*5*	49	*5*	55	*6*
D20	23	29	*6*	37	*8*	43	*6*	49	*6*	57	*8*
D21	22	31	*9*	39	*8*	45	*6*	51	*6*	60	*9*
D22	20	28	*8*	36	*8*	44	*8*	50	*6*	56	*6*
D23	18	23	*5*	29	*6*	37	*8*	43	*6*	52	*9*
D24	15	20	*5*	25	*5*	34	*9*	43	*9*	49	*6*
D25	15	23	*8*	31	*8*	39	*8*	47	*8*	55	*8*
D26	20	29	*9*	38	*9*	46	*8*	51	*5*	60	*9*
D27	18	24	*6*	31	*7*	36	*5*	45	*9*	54	*9*
D28	15	21	*6*	30	*9*	35	*5*	43	*8*	50	*7*
D29	13	18	*5*	24	*6*	30	*6*	35	*5*	44	*9*
D30	10	19	*9*	26	*7*	35	*9*	44	*9*	52	*8*
D31	7	13	*6*	18	*5*	25	*7*	31	*6*	38	*7*
D32	6	12	*6*	17	*5*	26	*9*	31	*5*	40	*9*
D33	5	13	*8*	21	*8*	27	*6*	33	*6*	39	*6*
		Mean	**6,7**		**7,1**		**7,1**		**6,9**		**7,2**
Standard Deviation:			**1,4**		**1,3**		**1,5**		**1,6**		**1,4**

Table 8.5.3-1 Measurements the weekly work (%) variations in building (Block 3)

As the standard deviation indicates in the distribution of the progress, the greater the standard deviation, the greater the volatility of the work. The standard deviation of the progresses from a week another went from 1.36 in week 16 to 1.49 in week 13 with a mean of 1.44. In comparison, block 2 mean was 2.4 fluctuating between 2.13 and 2.87 (table 9.1-3 & 9.1-6) and block 2's mean was 4.51 fluctuating between 4.00 and 4.94 (table 9.2-2). The average of the means is 11.12%, which indicates that, on average, the works were completed 11.12% earlier than planned.

The application of a visual tool to foster discipline in implementing the plans on site helped raise the quality of the coordination of the works and regularity of the production. However, further analysis of the data is needed to understand the gain in workflow stability. The following section develops how close to the ideal line the works were made on site.

8.5.4 Measure of the weekly stability of the works in block 3

As in block 1 and 2, the data were compiled to extract the stability index (how far from the linear layer target), and the figures are presented in the table below.

Determining the difference in the theoretical (levelled) progress the actual progress measured on site provided objective data that directly reflected how much the works on site followed the ideal path. A positive Δ indicates the site is ahead of schedule (time is gained and completion should be rescheduled earlier). A negative Δ indicates the site is behind schedule (time is lost and completion should be rescheduled later). As in blocks 1 and 2, the data were compiled to extract the stability index (how far from the linear layer target), and the figures are presented in the table below.

	12			13			14			15			16			17		
	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ	Theory	Actual	Δ
D01	60	75	*15*	63	81	*18*	68	84	*16*	73	89	*16*	77	93	*16*	82	99	*17*
D02	58	69	*11*	62	72	*10*	66	76	*10*	71	79	*8*	76	82	*6*	81	87	*6*
D03	57	68	*11*	60	72	*12*	65	75	*10*	70	79	*9*	74	83	*9*	79	87	*8*
D04	55	67	*12*	58	71	*13*	63	76	*13*	68	81	*13*	73	85	*12*	78	91	*13*
D05	54	67	*13*	57	70	*13*	62	74	*12*	66	80	*14*	71	86	*15*	76	92	*16*
D06	52	64	*12*	55	70	*15*	60	76	*16*	65	79	*14*	70	84	*14*	75	87	*12*
D07	51	63	*12*	54	68	*14*	59	71	*12*	63	77	*14*	68	83	*15*	73	89	*16*
D08	49	62	*13*	52	66	*14*	57	72	*15*	62	75	*13*	67	81	*14*	71	85	*14*
D09	48	64	*16*	51	69	*18*	56	75	*19*	60	80	*20*	65	86	*21*	70	92	*22*
D10	46	63	*17*	49	69	*20*	54	73	*19*	59	77	*18*	64	80	*16*	68	85	*17*
D11	45	56	*11*	48	61	*13*	53	67	*14*	57	70	*13*	62	73	*11*	67	78	*11*
D12	43	54	*11*	46	58	*12*	51	64	*13*	56	68	*12*	61	72	*11*	65	75	*10*
D13	42	53	*11*	45	56	*11*	50	59	*9*	54	64	*10*	59	67	*8*	64	70	*6*
D14	40	53	*13*	43	56	*13*	48	61	*13*	53	66	*13*	58	70	*12*	62	74	*12*
D15	39	52	*13*	42	57	*15*	47	61	*14*	51	64	*13*	56	68	*12*	61	72	*11*
D16	37	48	*11*	40	53	*13*	45	59	*14*	50	64	*14*	55	69	*14*	59	73	*14*
D17	36	45	*9*	39	49	*10*	44	52	*8*	48	57	*9*	53	62	*9*	58	68	*10*
D18	34	43	*9*	37	49	*12*	42	53	*11*	47	58	*11*	52	63	*11*	56	66	*10*
D19	33	40	*7*	36	43	*7*	41	46	*5*	45	49	*4*	50	54	*4*	55	59	*4*
D20	31	38	*7*	34	41	*7*	39	46	*7*	44	52	*8*	49	55	*6*	53	58	*5*
D21	30	37	*7*	33	41	*8*	37	47	*10*	42	52	*10*	47	58	*11*	52	63	*11*
D22	28	35	*7*	31	38	*7*	36	43	*7*	41	47	*6*	45	53	*8*	50	57	*7*
D23	27	33	*6*	30	39	*9*	34	43	*9*	39	46	*7*	44	50	*6*	49	54	*5*
D24	25	30	*5*	28	33	*5*	33	39	*6*	38	42	*4*	42	48	*6*	47	54	*7*
D25	24	30	*6*	27	34	*7*	31	39	*8*	36	44	*8*	41	47	*6*	46	51	*5*
D26	22	35	*13*	25	40	*15*	30	43	*13*	35	46	*11*	39	52	*13*	44	55	*11*
D27	21	33	*12*	24	37	*13*	28	43	*15*	33	49	*16*	38	54	*16*	43	59	*16*
D28	19	30	*11*	22	36	*14*	27	41	*14*	32	45	*13*	36	50	*14*	41	53	*12*
D29	18	28	*10*	21	34	*13*	25	37	*12*	30	42	*12*	35	46	*11*	40	52	*12*
D30	16	25	*9*	19	29	*10*	24	35	*11*	29	38	*9*	33	44	*11*	38	49	*11*
D31	15	22	*7*	18	25	*7*	22	31	*9*	27	34	*7*	32	38	*6*	37	44	*7*
D32	13	21	*8*	16	27	*11*	21	30	*9*	26	33	*7*	30	37	*7*	35	43	*8*
D33	12	20	*8*	15	26	*11*	19	31	*12*	24	36	*12*	29	39	*10*	34	43	*9*
Mean:			***10,39***			***11,82***			***11,66***			***11,14***			***10,93***			***10,77***
Standard Deviation:			**2,90**			**3,43**			**3,45**			**3,72**			**3,93**			**4,19**

Table 8.5.4-1 Initial Measures block 3 - weekly progress deviation from the theoretical

While the works still suffer from instability, improvements in the works stability are notable from block 2:

- From the progress of the 198 week/apartment measured in block 3 where discipline on site was fostered by the application of a visual kanban tool, 0% showed progress below the 4.8% target. This figure should be compared to the 11% of block 2 and 48% measured in block 1-A, which show that the weekly works target was always met or overpassed in the context of this research.
- Note: If there had been a fourth block in this research, the weekly ambition of the works would have to been raised to avoid the comfort zone and help the group continue improving the scheduling system in the search for a fully stable workflow.
- The average of the Δ is 11.7%. 2.1%. This indicates that, on average, the works were made 2.1 % earlier than the theoretical weekly schedule. This has to be compared to the measures in block 1-A and 2. In block 1A, the works were 7.5% late on average and in block 2 the works were 2.1% early. This means that the works were executed nearly 10% more quickly in block 2 than in block 1, and nearly 20% faster in block 3 than in block 1.
- The mean standard deviation of the Δ was 3.6. This indicates that most of the weekly progress fell between -15.3% (or -11.7% - 3.6%) and -8.1 % (or -11.7% + 3.6%) from the theoretical weekly schedule. The -15.3% to – 8.1% average dispersion of works executed in block 3 with kanban should be compared with the -6.2% to 4.0% dispersion of works executed in block 2 following takt planning and with the -16.2% to +1.2% of block 1A, where the blocs were executed following the LPS.

Exploiting the data in the table above gives us an indication of both the volatility of the works (the standard deviation of weekly progress) and how the weekly targets were reached (the average weekly progress). Improvements in the workflow stability were notable, as the above shows. Not only were the works executed more quickly than the theoretical schedule, but the flow was more regular from week to week.

However, as in block 1 and 2, the limited possible reference to the existing literature of comparable sites (residential units made by SMEs) at the time of the research makes it difficult to assess whether the levels of both the average of the weekly works targets attained in block 2 and the stability can be considered low or high.

From the research in block 3, given the same nature of the apartments and companies as in block 1, it can be concluded that the application of kanban as a visual discipline-fostering tool proved beneficial in the search for a stable workflow.

The figures showed that there still was some workflow instability in the system output. The proposed scheduling system needs to be improved by future research in the search for a stable workflow.

8.6 Conclusions from the research on blocks 1 (A &B), 2 and 3

From the data collected and analyses made in the above sections, the performance of the works have been significantly improved:

- On average, the works were executed nearly 10% more quickly in block 2 than in block 1, and nearly 20% more quickly in block 3 than in block 1.
- Most of the works were executed between 8% and 15% more quickly than planned in the theoretical weekly schedule.

Although it is not clear at this point whether the improvement in the works volatility was a cause-consequence or a correctional effect, the implementation of the LSP focused on smaller cells of work and carried out at a regular pace (takt planning) coupled with a discipline-fostering system (kanban) helped raise the quality of the coordination of the works and allowed the workmen to reach higher scheduling expectations through enhanced production performance.

The following sections present the conclusions that can be drawn from the research on the three blocks.

8.6.1 Measure of the weekly quantity of works achieved

The limit on measuring only the weekly quantity of works carried out on site was quickly met. Apart from being important data for the contractors to prepare invoices, pay the workmen, order material based on the remaining quantities, etc., the indicator calculated was of limited used for managing the works on site. The possible conclusions and corrective actions were only linked to past activities, with very limited understanding of the statistical funnels. Peaks and valleys could be determined, but this was insufficient for determining whether the works were following a positive or negative trend until they reached their conclusion. The planning was hypothetical, and it was very difficult to calculate or estimate the date of the end of the works. Reactions from the management on the site were then taken "live", at the time, in the hope that the situation would improve. In most situations, the conclusion was that the site lacked production resources and that the trades should reinforce their capacity in materials and workmen. Of course, the site physical buffer capacity was limited and reinforcement in these conditions eventually proved mostly useless.

This illustrates how most works' scheduling and reaction to delay is managed in the traditional construction industry. The analysis of the standard deviation in the following section presents the results from the calculation of the variance of the progress from one week to the next as an indicator of the regularity of the work.

8.6.2 Measure of the weekly regularity of the works

Table 9.6-1 summarises the averages of weekly progress from block 1 following the traditional approach to block 3, where a kanban system was implemented. The mean of weekly progress was 6% (block 1.1). Despite the application of the LPS in block 1.2, this figure did not increase, as envisaged. The slight increase to 6.1 was not considered significant. However, the average of standard deviation decreased by 10% - from 4.9 to 4.5. this suggests that, despite the works not being completed more quickly, they were more regular following the implementation of the LSP. The implementation of takt planning in block 2 had a more tangible effect. The mean of progress increased to 6.3 which, although moving in the right direction, could not be considered significant. The standard deviation decreased by 55%, from 4.5 to 2.5. This reflects better coordination and a decrease in making do on site. The peaks and valleys in the cumulative progresses (over-activity and under-activity) observed in block 1 and 2 started to disappear, with the flow of work becoming more levelled.

The introduction of kanban in block 3 confirmed the flow-levelling tendency, the mean of weekly progress increased to 6.9% and the average standard deviation decreased to 1.4%. The 0.9% increase in the weekly progress from block 1 to block 3 (from 6.0 to 6.9) means a 15% increase in the pace of the works.

Weekly progresses				
	Lowest %	**Average %**	**Highest %**	***StD***
Traditional Approach (bloc 1.1)	4,1	**6,0**	9,8	*4,9*
Last Planner (bloc 1.2)	5,0	**6,1**	8,0	*4,5*
Takt Time (bloc 2)	5,6	**6,3**	7,0	*2,5*
Kanban (bloc 3)	6,7	**6,9**	7,2	*1,4*

Table 8.6.2-1 Averages of weekly progress and standard deviations (%)

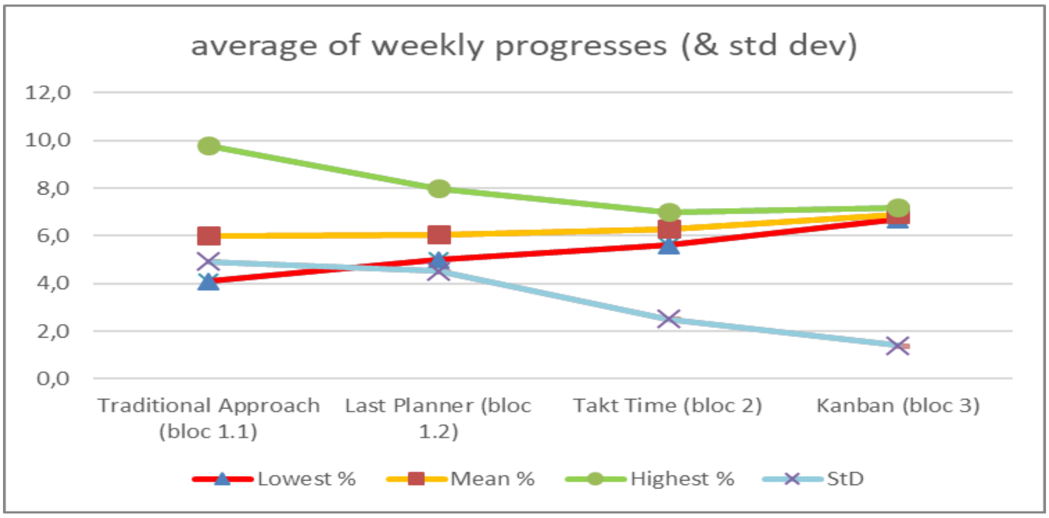


Figure 8.6.2-1 Average of weekly progress & StD)

The funnel created by the two boundaries of averages of weekly progress (higher and lower measures) narrows and the average increases from block 1 to block 3, as illustrated in the following figure (9.6-2), illustrate the decreasing volatility of the number of works completed from one week to the next.

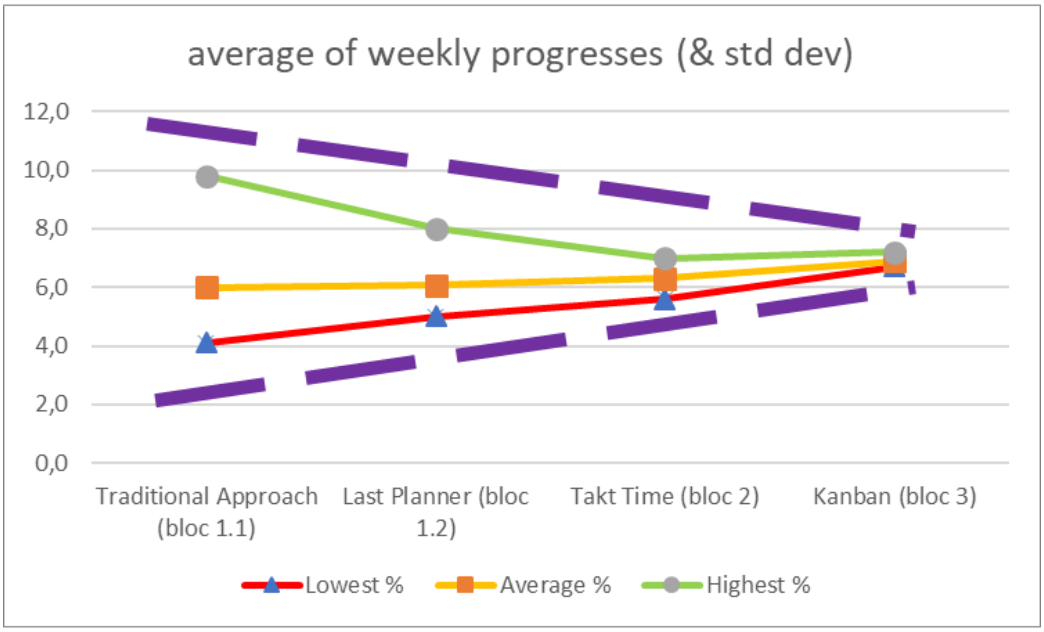


Figure 8.6.2-2 Average of weekly progress

This narrowing funnel was measured and illustrated in the standard deviation curve that decreases from 4.9% in block 1 to 1.4% in block 3. This means production flow reached 64% of possible stability from block 2 to block 3.

8.6.3 Measure of the weekly stability of the works

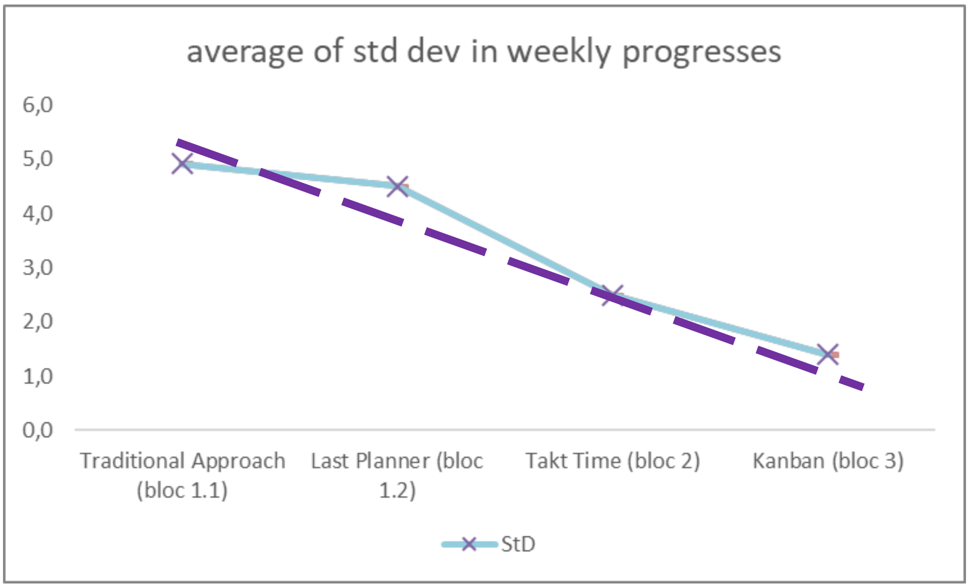


Figure 8.6.3-1 Average of StD in weekly progress

Table 9.6-1 summarises the averages of weekly gaps between the weekly progress measured on site and the ideal levelled plan, from block 1 following the traditional approach to block 3, where a kanban system was implemented.

Weekly "levelled" plan Met				
	Lowest %	**Average %**	**Highest %**	***StD***
Traditional Approach (bloc 1.1)	-9,00	**-7,50**	-4,00	*8,41*
Last Planner (bloc 1.2)	-3,70	**0,94**	3,10	*5,23*
Takt Time (bloc 2)	-2,00	**2,13**	5,36	*4,11*
Kanban (bloc 3)	10,39	**11,12**	11,82	*3,60*

Table 8.6.3-1 Average and StD weekly gaps between the weekly progress measured on site and the ideal levelled plan (%)

The following figure (9.6-1) illustrates the above.

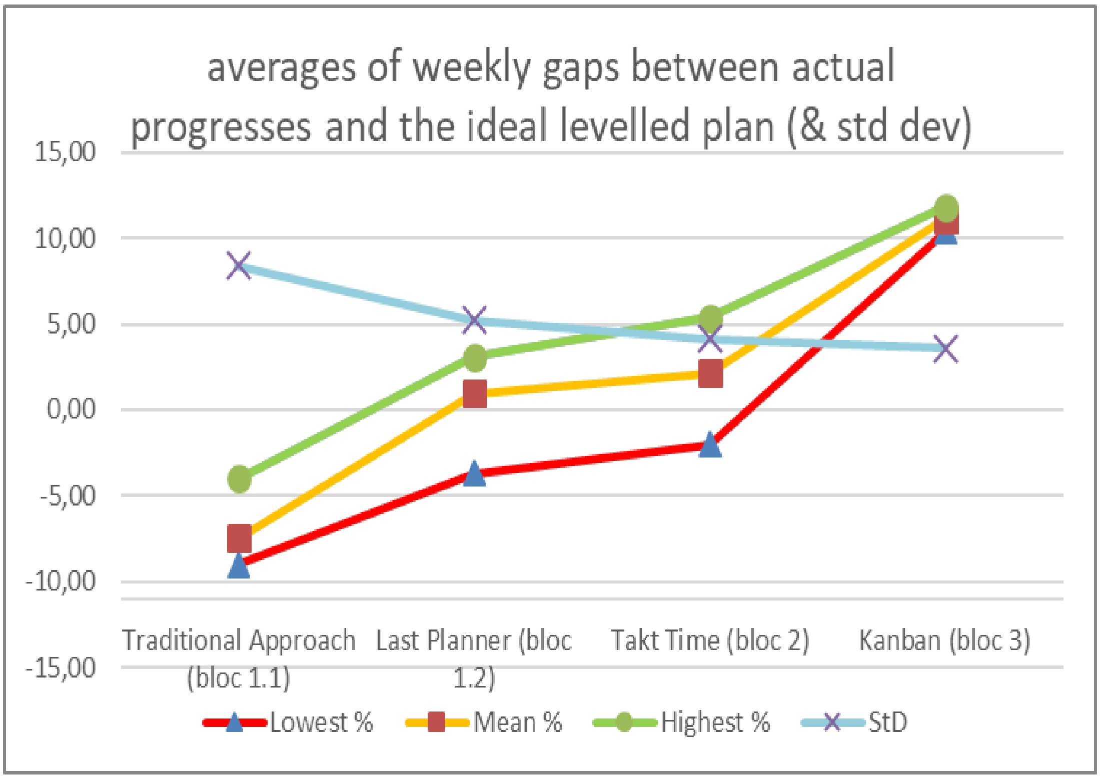


Figure 8.6.3-2 Average and StD weekly gaps between the weekly progress measured on site and the ideal levelled plan (%)

The funnel created by the two boundaries of averages of weekly gaps between the weekly progress measured on site and the ideal levelled plan (higher and lower measures) narrows while the average increases from block 1 to block 3, as illustrated in the following figure (9.6-5):

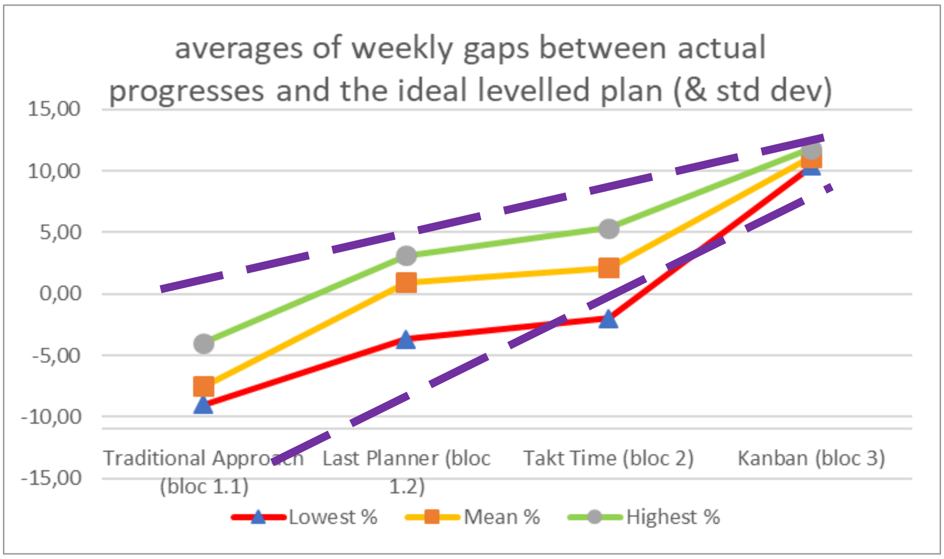


Figure 8.6.3-3 Average weekly gaps between weekly progress measured and ideal levelled plan (%)

This narrowing funnel is measured and illustrated in the standard deviation curve, which decreases from 8.41% in block 1 to 3.6% in block 3.

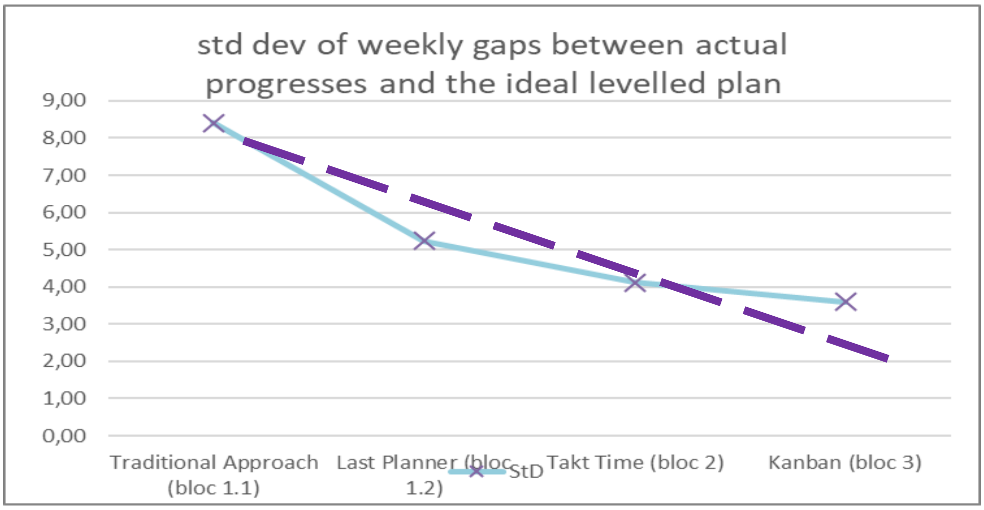


Figure 8.6.3-4 StD of weekly gaps between actual progress and the ideal levelled plan

Hence, production flow reached 64% of the possible stability from block 1 to block 3.

8.7 Section summary

The level of lack of discipline, despite the implementation and maturity of the lean tools among the team was unexpected.

The production flow reached 64% of the possible stability from block 1 to block 3. This measure shows the result of the implementation of the tools and methods presented and presents encouraging opportunities for future research.

The results in terms of safety, planning reduction and quality improvement were notable. Despite the system proving to be duplicable in the three blocks, no evidence yet proves duplicability on other construction sites. The key success factor was not fully determined.

9 Tangible impacts of the research

This chapter introduces the visible effects that the approach developed on site has produced, as the researcher has observed them. Although the cause- consequence effect is still difficult to prove at this stage, and that some correlational effect should be considered, some direct consequences of the research should be considered, and future research encouraged to help refine the stability approach for SMEs proposed in this thesis.

The first section of this chapter, Section 9.1, *Lead time reduced*, presents the results regarding the reduction of the lead time of the construction site as measured versus the time planned initially by the real estate developer. Not only has the time been reduced, but the safety on site (as perceived and measured) has been dramatically improved following the inception of the research. Section 9.2, *Safety improved*, develops this aspect. The cost of the construction has also been reduced because of the better organisation, which is presented in Section 9.3. *Cost Reduced*. Although the level of the effect of learning is not clear, and that the costs and time have been reduced, it can be seen from the measures that the quality on the site has improved dramatically, as presented in Section 9.4, Snag *works reduced*.

Finally, based on the above, while paragraph 10 , *Summary of the research*, proposes a global synthesis of the research, paragraph 10.4, ***Erreur ! Source du renvoi introuvable.***, proposes the scope of research be widened and the implementation of the approach presented in this thesis investigated to validate the cause and consequence effect and the correlational the effect and, hence, the duplicability of the system in wider contexts.

9.1 Lead time reduced

The 15% increase in the pace of the works from block 1 to block 3 measured over the 6-week period observed (as explained in 9.6.2) has been kept across all of the construction of the last block. The initial planning foresaw a 22-month construction period for block 3 (from foundations to full handover). The actual duration was 18 month (-18% from initial planning). The actual gain was even higher given that the 22 months above did not consider the delay due to bad weather. Traditionally, in Belgium, the works on site are blocked for a total of 1.7 months (rain in autumn, snow in winter, high temperatures in summer). The gain in time through the application of the lean approach should then be compared with the likely weather-related shift: i.e., 1.7/12*22 = 25 months. Therefore, the likely actual gain can be calculated as follows:25-18 = 7 month (-30% from the initial plan).

9.2 Safety improved

- **Safety:** No major accidents were reported.

9.3 Cost Reduced

At the beginning of the research, the client, a Brussels-based subsidiary of an international Scandinavian-based Group, had started an internal project to gain a competitive advantage in delivering more quickly, of better quality and cheaper. Although the cost reduction was not the main driver, it was an important indicator, immediately measurable from phase to phase. the Client sought to reduce costs by 5% with the help of lean practices within the timeline of the lean project, a four-year plan. the Client shared the financial data presented in the table below.

Year	Phase	Construction cost in €/m² : total building cost divided by adjusted area m²	Percentage savings on construction cost in €/m² compared to "IV" (%)	Savings on construction cost in €/m² compared to "IV" (k€)
2011-13	IV	1.205	0,0%	-
2013-15	V	1.199	-0,4%	24
2014-16	VI	1.181	-1,9%	180
2015-17	VII	1.121	-7,0%	473

Table 8.6.3-1 Savings per phase from block 1 to block 3 (source: the Client)

The construction cost they obtained in the previous phase, which was delivered in 2013 (sum of the costs from the contractors, i.e., excluding project fees, overhead, studies, etc.) was €1,205 per square metre. This cost ratio was considered a good performance, thought to have been brought about thanks to a high level of management and control of the contractors.

The construction costs of block 1, of identical shape and construction principles as the previous phases, has proven to be 0.4% cheaper. This saving can be added to the savings in management and supervision made possible by the application of the LPS (not calculated) and to the savings fathered by the very limited, almost nominal, number of snags works, (6).

The construction costs of block 2 of identical shape and construction principles as the previous block, amounted to €1,199 per square metre, or a 1.9% decrease from the previous phase. Given the time reduction and snag-free results made in block 1, the contractors proposed an aggressive tender price for block 2.

When asked to tender again on block 3, all the contractors, on the basis of the time reduction and experience gained in block 2, proposed a price even lower than in block 2. The total cost of construction decreased to €1.121 per square metre, or 7.0% lower than for the previous phase.

9.4 Snag works reduced

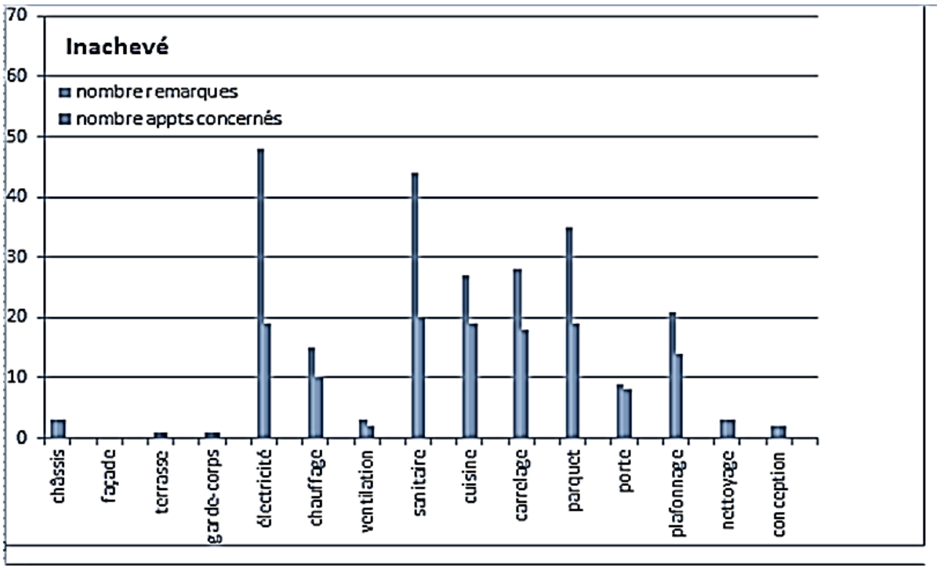
The main ambition of the Client in testing and adopting a lean approach was to reduce the number of snag works. The results of the traditional project management approach in the previous phase led to an improvement in comparison to the previous phases (snags reduced by 60%) but it was still thought their numbers could be lowered.

The table below shows the number of works that were not completed at completion:

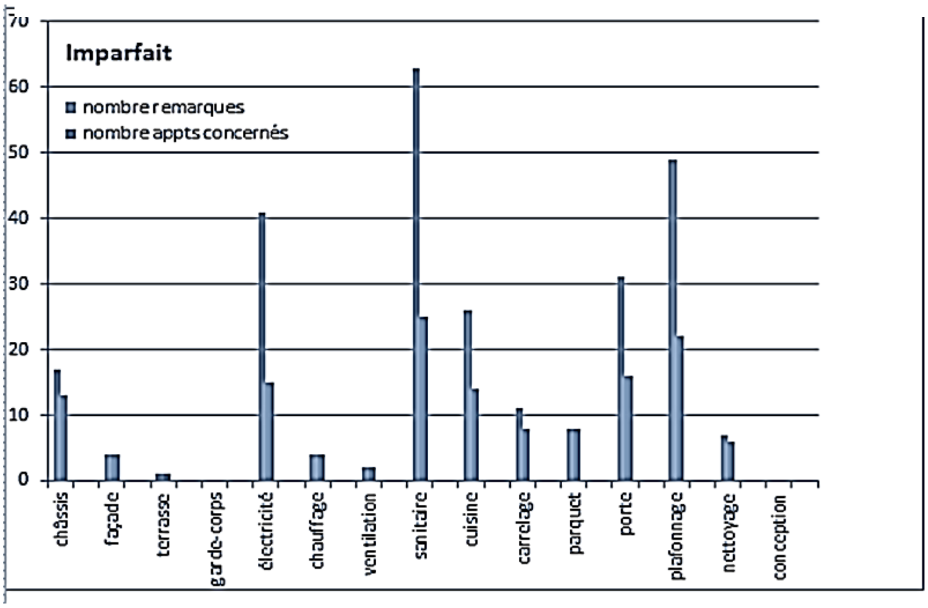
	SNAG WORKS AT COMPLETION (handover)	
	remaining works	**quality problems**
Windows	3	18
Façade	0	5
Terrace	1	3
Metal works	1	2
Electrical	48	40
Heating	10	5
Ventilation	3	3
Mechanicals	43	65
Kitchen	19	28
Tiling	18	12
Flooring	19	8
Joinery	8	32
Plastering	13	49
Cleaning	4	7
Design	2	0
Total	**192**	**277**
Average (on 35 apts)	**5**	**8**

Graph 8.6.3-1 Number of snagging works at the completion of the works (owner handover) in the last phase.

Out of the 35 apartments that comprised the last block of the previous phase, a total of 469 snag works were detected at completion (handover to the client). Of these, 192 were works that still remained to be completed or involved missing equipment, and 277 were quality issues or involved non-functioning equipment. This amounted to an average of 13 snag works per apartment. This level was considered by the client as average compared to the apartment sites they had been developing for the past 15 years. This average had never been questioned and was considered by the client to be a constraint of the construction industry.



Graph 8.6.3-3 Number and typology of works remaining to be completed at completion of the works (owner handover) in the last phase



Graph 8.6.3-2 Number and typology of imperfections works to be made good at completion of the works (owner handover) in the last phase

The works in Block 1 were completed 18% more quickly than planned, as can be seen in paragraph 10.1. This means that the apartments could have been handed over to the end client 3 months earlier than expected, with the traditional level of quality. It was decided by the client to use part of the time buffer to handover completion to double-check every item that traditionally appeared on the snag list. The real estate developer had no legal obligation to transfer the apartment to the client owner/consumer before the original planned date. About a month was then devoted to completing quality checks on site to ensure a high level of quality in the end project.

The works in Block 2 and Block 3 were completed even more quickly than block 1, with an improved live quality. The workmen had created a time buffer to focus on quality and not only on quantity. The more in advance the site, the better its intrinsic quality, the more time there is to be allocated to impeccable end-product quality.

The number of snags or incomplete works in block 1 across the 35 apartments amounted to six in total, to be compared to the (15 x 35 =) 525 that would have been expected following a traditional project management approach.
The number of snags or incomplete works in block 2 across the 65 apartments, amounted to zero, to be compared to the (15 x 65 =) 975 that would have been expected following a traditional project management approach. The number of snags or incomplete works in block 2 across the 65 apartments amounted to zero, to be compared to the 15 x 45 =) 675 that would have been expected following a traditional project management approach.

Consequently, across the three blocks observed, the client and the trades were expected to face a total of 2175 snags or incomplete works. A large proportion of these works would have to have been completed while the customer was living in the apartment, leading to common issues such as communication, meeting difficulties, disturbances, noises and dirt and general nuisance.

All of this end of site management generally lasted over a couple of months and could easily be extended to six months, a long period during which the trade workmen would not be bringing value, simply correcting an abnormal situation. The workmen could not invoice either the time or the materials. All this phase was produced at the cost of the trades. In addition to this, the real estate developer had to face the clients' dissatisfaction, which grew with time after the handover.

From the above, it is clear that the whole snag period generates costs, frustration and widespread dissatisfaction on all sides. The system implemented in block 1 to block 3 helped reach zero-snag works at handover, a long-time secret dream of the client.
Table 10.4-1 presents the number of snag works per block, compared to what would be expected under a traditional approach.

		Number of snagg works	
	Nbre of Apt	Expected	Actual
Ysaye (block 1)	35	525	6
Chopin (block 2)	65	975	0
Vivaldi (block 3)	45	675	0
Total	145	2175	6

Table 8.6.3-1 Quality result at handover

10 Conclusion: Summary of findings and contribution

This chapter starts by presenting a summary of the research (11.1). Then, each of the objectives stated in Chapter 1 Section 1.4 are reviewed and an indication of how the research provided answers is given in Section 11.2. The contribution to knowledge that is provided by this thesis via the research is then stated in Section 11.3. Finally, Section 11.4 concludes this chapter by broadening the scope for future research that could test, develop and refine the approach proposed in this research.

10.1 Summary of the research

The table below recalls the path followed by the research over the three blocks of the development project together with the main characteristics of each iteration.

	Bock 1				Block 2			Block 3
Research paragraph	-	6.1	6.2	6.3	7.1	7.2	7.3	8.1
Proposed tools and protocols	None-classical PM (reference)	LPS	5S	Make Ready	Design and Technical improvements	Stability indicator	Takt time initiated with LPS	Kanban
Analysed period	6 weeks	6 weeks	6 weeks	6 weeks	6 weeks	6 weeks	6 weeks	6 weeks
Person in charge of scheduling	Client's PM	Client's PM	Client's PM	Client's PM	Client's PM	Client's PM	Client's PM	Client's PM
Directly involved	Trade contractors	Trade contractors	Trade contractors	Trade contractors	Trade contractors	Trade contractors	Trade contractors	Trade contractors
Data collection	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
Number of apartments	14	22	35	35	64	64	64	45
Average stand dev of progresses	4.9 %	4.5 %	(4.5%)	(4.5%)	(4.5%)	(4.5%)	2.5 %	1.4 %
Average Δ from theory	- 7.5 %	0,9 %	(0,9%)	(0,9%)	(0,9%)	(0,9%)	2.1 %	11,1 %
Workflow stability index	**8,4**	**5,2**	**(5,2)**	**(5,2)**	**(5,2)**	**(5,2)**	**4,1**	**3,6**

Table 8.6.3-1 Summary of the research over the three blocks

10.2 Achievement of the aim and objectives of the work

This research aimed to better understand the effects of the implementation of flow-based management systems on medium-size sites. Based on the observations and measures made on site, the concept of stability and related workflow tools have helped answer both this research question and the problem of time delays and quality issues in the three-block apartment development project in which this research is grounded.

This section presents and discusses how the research met the objectives as listed in (1.4.1), *Objectives of the research*.

10.2.1 Objective 1: understanding the problem

An important focus in the literature review was to gain a deeper understanding of the research problem, which was the non-implementation of flow-based management systems in the field of SMEs working on apartment developments.

Some of the main findings from the literature review were :

- The environment of this research is complex and requires a deep knowledge of it to understand the flows and constraints involved in it (Chapter 1 Section 1.2.1 *A complex* environment).
- Pull systems in this context are not fully correlated with the concept of stability (Chapter 2 Section 2.3.2 *Pull system and stability*).
- The concept of flow had not been fully addressed in this context (Chapter 2 Section 2.5.6) *The concept of flow in the construction industry*).
- The literature lacked research on the implementation of lean construction and, by extension, on flow management systems addressed in the SME world (Chapter 2 Section 2.7 *Lean Construction research on SMEs*)
- The above explains the origin of the problem shared by the practitioner and which this thesis proposed to address (Chapter 5 Section 5.2 *Problem of the practitioner (a real estate* developer)).
- There was a need to investigate beyond the Last Planner™ System in the search

for a stable workflow (Chapter 7, Section 7.2 *Beyond PPC, need for a stability indicator. development of research Stage 2.2*).

- The human factor in the success of creating a stable workflow had been underestimated (Chapter 8 Section 8.1 *Human factor bias: introduction of discipline and kanban*).

10.2.2 Objective 2: understanding the current theory about planning and scheduling,

This section presents an overview of the historical development of the scheduling approach in the construction industry as a major development in the search for production flow management in the construction industry. Even if some construction projects are run using limited planning, not to say no planning at all, others are managed following CPM (Chapter 2 Section 2.5.1), while others are run following takt planning (Chapter 2 Section 2.6.4).

Between these two latter approaches, the use of LPS (Chapter 2 Section 2.5.2) and, later, the search for a continuous flow (Chapter 2 Section 2.5.3) needed to be divided into batches (Chapter 2 Section 2.5.4) before the data could be incorporated into the planning considerations (Chapter 2 Section 2.5.5); then takt planning helped create and maintain a rhythm in the pace of the works (Chapter 2 Section 2.6.4).

10.2.3 Objective 3: identifying the advances in planning and scheduling arising from manufacturing and lean thinking,

The following section answers this objective by focusing the on the two main sections that present the most applicable pull approaches from both manufacturing and construction perspectives. While Chapter 2, Section 5, In *search of production stability in the construction industry: importing flow theories and pull* systems from the manufacturing industry and developing dedicated approaches, presents the manufacturing advances, Chapter 2, Section 6 Linking manufacturing and construction flows.

10.2.4 Objective 4: to analyse current scheduling practice and determine its limits (in terms of applicability and performance)

While 6.1.2 clarifies the problem, Chapter 6, Section 6.1.2.1 focusses on the inadequacy of the initial planning, 6.1.2.2 points out how the works were desynchronised and Chapter 6, Section 1.2.7 presents the problem from the practice of scheduling on site. Chapter 7, Section 7.7.2 then develops the need to integrate an indicator for stability over the LPS PPC measures. Chapter 7, Subsection 7.3.5 then proposes a Justification for the use of Takt Planning as a complement to the Last Planner™ System LPS.

10.2.5 Objective 5: to develop, test and measure the impacts of a pull system based on LPS using a longitudinal case study.

The research presented in this thesis has been achieved through a longitudinal case study that has shown the growth and implementation of iterative phases in developing and applying flow-based approaches.

The initial development of a solution first arose from the adaptation of the WWP (LPS) in the search for more transparency (Chapter 6, Section 6.1.4) The solution was further developed with the adaptation of 5S to the site as a complement to the WWP, as presented in Chapter 6, Section 6.2.4. The work completed and presented in chapter 6, Section 6.3.3 follows the path by adapting the make ready approach.

Then, as a side effect that needed to be addressed, the search was oriented toward a more technical approach, as is described in Chapter 7, Section 7.1.4 on the adaptation of the technical design to reduce construction issues on site and facilitate the implementation of the flow management following this development. And, measuring the impact of the system proposed, it passed through the development of a stability indicator (Chapter 7, Section 7.2.3).
Finally, while Chapter 7, Section 7.3.4 presents how takt planning was adapted to continue developing the solution, Chapter 8, Section 8.1.4 pushes the approach further

in the search for workflow stability with the integration of kanban-based visual scheduling.

10.3 Contribution to the body of knowledge

The findings of the research revealed that there is a lack of understanding of the concept of flow and the concept of stability; only a few examples exist in the literature. This research detailed how the concept of stability emerged through the three building blocks, how the different tools from lean management were tested and implemented to create a new level of flow management. The findings from the instantiations of the research and the data from the client real estate developer have provided strong evidence that achieving a more stable production flow on site helped solve the old three-dimensional problem: how to build faster, cheaper and of better quality.

It was found that the application of the LPS itself was not sufficient to find an answer to the problem and that integrating other approaches, such as 5S, takt time and kanban, helped to achieve a focus on workflow stability and to building an answer to the problem associated with mid-size apartment development made by SMEs.

Investigation into the implementation of flow-based management by SMEs to stabilise production flow made it possible to address a gap in the body of knowledge: understanding the effects of the application of flow-based management systems on medium-size sites (€2−50 million work turnover) made by medium-sized companies (20–200 employees) and produce tangible outcomes and impacts in the three-block site investigated.

Very little literature had been found in this field. The work undertaken in the context of the research and developed in this thesis, by demonstrating that the concept of stability can be applied to the construction industry through the application of flow-based management tools from the manufacturing industry, contributes to filling the gap in the body of knowledge.

However, while reducing delays and improvements in both the quality of the work and safety on site were measured in the context of this research, future research is needed to investigate the qualitative cause-consequence and correlational effects. Analysing naturally occurring circumstances and the implementation of the stability index in other contexts such as large apartment blocks and/or larger contractors, which are not addressed in this research, would help the growth of understanding of the concept of workflow stability.

Finally, it should be remembered that the context of this research is spread across most countries and the problems addressed by the research are common issues faced everywhere. Unfortunately, research on this field is still lacking. It is hoped that the outcome of this research will help further researchers investigate in this direction.

10.4 Further research

10.4.1 Developing the workflow stability index

Planning performance is widely assessed by measuring, for each task in a schedule, the difference between the planned and the actual progress. Some tasks can be completed late, others early. The average of those measurements usually provides the average performance. It is very rare to find an SME that uses integrated progress methods such as earned-value management, mainly because linking the financial aspect to the actual and planned progress proves too complex to be well addressed in companies of this size. The simpler, the better on site, so the measurement should be practical, easily put in place on site and regularly updated, being based on objective observations from the site. Hence, the basis of the measure will be provided by measuring the actual cumulative physical progress on site. To consolidate schedules from multiple sources into a single document, each party must provide a schedule with comparable levels of detail at both the scheduling time unit (e.g., months, weeks, or days) and the scheduling window (e.g., one week, four weeks, two months, or whole project duration), during which the measurements will be made. This constraint will probably raise the need for the training of the contractors at the earliest stages of the project.

Some contractors with well-defined work packages and few interactions with other trades may be able to look three months ahead, whereas others with changing work packages and more interaction may be able to look only two weeks ahead. In that case, all parties should understand that there is only a small benefit, if any benefit at all, to looking much farther than what their scheduling ability (reliability) permits.

In this approach, scheduling with tasks under one day (exceptions for the milestones) is fruitless at this point. The tasks should first be parsed as elements of a week, given that site meetings are most often held on a weekly basis. The scheduling window must also allow for flexibility, depending on the situation on-site, and a tight focus on some points or coordination details can be useful.

10.4.2 Optimising and focusing on the scheduling-measuring process

The decision-making process is largely delayed when the decision-makers are given more information than they can process (Galbraith, 1974). Information provided must thus be screened and carefully selected from the source to ease the process and effort in compiling it. The remaining information should be necessary and sufficient. The hypothesis made in the system presented here is that exploiting the measurement of the actual progress, at regular intervals, should provide sufficient information to assess the performance of the site scheduling in search of a continuous and stable workflow.

These on-site measures can be compiled and consolidated because they are presented at the same detail level across all contractors.

Another benefit of using a coordinated schedule generated from multiple work plans is that the planner and the site manager can detect the conflicts (doubles, gaps, technical issues, unclear predecessors, et.) by examining the relationships between all the parties. Taking measures to avoid these conflicts and working on improving the scheduling hypothesis on site are then made possible.

10.4.3 Develop a computer tool to support interactive planning

The objective of a computer tool is to assist the site team (planner and site managers) in the collection and treatment of the information needed by the system. The development of the tool is envisaged in two stages: (a) a simple excel sheet to collect and order the information from the site, and (b) an integrated program for a tablet pc (or iPad) that is linked to visual management to lead each team to the best location at which to work each day, with a computed treatment of the progress entered by the site managers. The first stage of development has been running on a residential construction site in Brussels since 2014. After the tool reaches an acceptable level of validation, it will be further developed into an application that all site managers will have at the next pilot sites.

10.4.4 Apply the computer tool to construction and design

The design phase faces the same desynchronisation and delay issues as the sites. The objective here is to provide the designers (architects, specialists, engineers, client representatives, and so forth) with an alternative approach based on the same search for continuous and stable flow. The flow in the design phase is mainly constituted from information with some movements of physical WIP (printed drawings, samples, mock-ups, etc.) while the flow in the construction phase is mainly physical, where all the information should have been transmitted beforehand. So far, the research has shown that there is a need to investigate beyond the traditional work coordination tools and methods.

The application of the advanced lean coordination tools LPS has shown that it could be a complement in the search for work robustness. Adapting and applying the takt principle to the construction industry has created a new scheduling system, based on research and the measurement of work stability and continuity. These two concerns have dramatically changed the observed work patterns.

The implementation of takt planning on-site has been met with encouraging results so far, both in terms of lead time and work snag reduction. The last phase (Block 3) will offer a unique opportunity to test the new system from the beginning of the construction site, and to measure its impact. From the data collected on site, following the generation of the case study, conclusions will be drawn and further developments proposed.

10.5 Final comments

The real estate developer, considering this experience, decided to generalise the findings as a new project management approach for further real estate developments: three new sites were running as such as these lines are being written, following the end of the research on the 3-block development project presented in this thesis.

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11 Appendix

This chapter presents the data collected by the researcher. Section 11.1 presents the data from the Weekly Work Plan from week 26 to week 31, section 11.2 the data from the Weekly Work Plan from week 26 to week 31 and section 11.3 the data from the Weekly Work Plan from week 12 to week 17. The data collected were the promises made by the foremen, whether completed the following week or not (marked 1 or 0 accordingly)

11.1 WWP BLOCK 1 A (weeks 26 to 31)

BLOC 1 A

Weekly Work Plan: Week 25

E: 46 PPC **18%**

Apt	Lot	Activité de la semaine	Je 19/6	Ve 20/6	Sa 21/6	Lu 23/6	Ma 24/6	Me 25/6	Promesse Tenue ?
A2	Elec	Tracage implantations appartements bloc A (fin)	X X	X X		X	X		0
A2	Elec	Réalisation des saignées et percements (fin)	X X	X X		X	X		0
A2	Elec	Evacuation des crasses / déchets	X X	X X		X	X	X	0
A0	Elec	Tubes alimentations tableaux		X X					1
A0	Elec	Réalisations éventuels changements (plans)		X		X X			0
A2	Elec	Pose des blochets				X X	X	X	0
A21	Elec	Cablage					X	X X	0
A22	Elec	Cablage					X	X X	0
B2	Elec	Tubage					X	X	0
A21	Plombier	Décharges		X X		X			0
A22	Plombier	Décharges		X X		X			0
A24	Plombier	Décharges		X X		X			0
B21	Plombier	Tuyautage				X X	X X		1
B22	Plombier	Tuyautage				X	X X		0
B23	Plombier	Tuyautage				X	X X		1
B21	Plombier	Décharges (début)					X	X X	0
B22	Plombier	Décharges					X	X X	0
B23	Plombier	Décharges					X	X X	0
A31	Chauffagiste	Discage et cassage				X X			1
A32	Chauffagiste	Discage et cassage				X X			1
A33	Chauffagiste	Discage et cassage				X X			1
A34	Chauffagiste	Discage et cassage				X			0
A31	Chauffagiste	Tuyautage				X	X		0
A32	Chauffagiste	Tuyautage				X	X		0
A33	Chauffagiste	Tuyautage					X X	X	0
A34	Chauffagiste	Tuyautage					X X	X	0
A31	Chauffagiste	Rebouchage saignées remontées radiateurs						X	
A32	Chauffagiste	Rebouchage saignées remontées radiateurs						X X	1
A33	Chauffagiste	Rebouchage saignées remontées radiateurs						X X	1
A34	Chauffagiste	Rebouchage saignées remontées radiateurs						X	0
A0	Plafonneur	Préparation des chassis (calfeutrements)	X X	X		X			0
B0	Plafonneur	Préparation des chassis (calfeutrements)		X X		X			0
A2	Plafonneur	Préparation des chassis (calfeutrements)				X	X		0
B2	Plafonneur	Préparation des chassis (calfeutrements)				X	X		0
B0	Plafonneur	Plafonnage				X	X		0
A0	Plafonneur	Plafonnage moitié						X	0
AB0	Chapiste	Pur				X	X		0
A0	Chapiste	Chape de finition					X	X X	0
AB1	Plafonneur	Bétopor	X	X		X			0
AB3	GO	nettoyage appartements	X	X				X	0
5	GO	terminer le silicat stein + poutres (fin)	X	X		X	X	X	0
AB0	GO	Reprises GO	X	X		X			0
A4	GO	Pose des blocs de plâtre (3 Apts)	X X	X X		X X	X		0
AB3	GO	Pose des châssis	X X	X X		X			0
AB4	GO	Pose des châssis				X	X X	X X	0
N/A	GO	Remblais périphériques				X	X X	X X	0

BLOC 1 A

Weekly Work Plan: Week 26

E: 33 PPC **52%**

Apt	Lot	Activité de la semaine	Je 26/6	Ve 27/6	Sa 28/6	Lu 30/6	Ma 1/7	Me 2/7	Promesse Tenue ?
AB5	GO	Poutres		X X					1
A2	GO	Blocs silicates		X X					1
AB4	GO	Décoffrage		X					0
A0	GO	Nettoyage		X					0
AB5	GO	Décoffrage poutres				X X	X X		1
AB5	GO	début charpente						X	0
AB5	GO	Pose seuils châssis					X X		1
AB1-3	GO	Reprises, calfeutrages et finitions béton (fin)	X	X X		X X	X X	X	0
B2	Plombier	Mise sous pression et rebouchage	X X						1
AB3	Plombier	Traçage		X X					1
AB3	Plombier	Disque				X X			1
B3	Plombier	Tubage					X X	X X	1
B31	Chauffagiste	début Tuyautage et fin	X	X X					0
B32	Chauffagiste	début Tuyautage et fin	X	X X					0
B33	Chauffagiste	début Tuyautage et fin	X X	X					0
A3	Plafonneur	Préparation châssis (hors calfeutrements coulissants)	X	X					0
B3	Plafonneur	Préparation châssis (hors calfeutrements coulissants)				X X			1
B4	Plafonneur	Préparation châssis (hors calfeutrements coulissants)					X	X	0
A0	Plafonneur	Plafonnage						X	0
A01	Chapiste	chapes de finitions ciment	X X						1
A02	Chapiste	chapes de finitions ciment	X X						1
A03	Chapiste	chapes de finitions ciment		X X					1
B01	Chapiste	chapes de finitions ciment		X X					1
B02	Chapiste	chapes de finitions ciment				x X			1
B13	Chapiste	chapes de finitions ciment				x			0
B11-12	Chapiste	chapes de finitions ciment					X X		1
AB2	Chapiste	Bétopor					X		0
B21	Chapiste	chapes de finitions ciment						X	0
B22	Chapiste	chapes de finitions ciment						X	0
2B	electricien	tubage			x x				1
2AB	electricien	rebouchage		X	X	X			0
3A	electricien	Traçage					X X		1
3A	electricien	Saignées					X	X	0

BLOC 1 A

Weekly Work Plan: Week 27

E: 50 PPC 70%

Apt	Lot	Activité de la semaine	Je 3/7	Ve 4/7	Sa 5/7	Lu 7/7	Ma 8/7	Me 9/7	Promesse Tenue ?
tr 8	plombier	placement des coliers dans trémies 8	x x						1
tr 8	plombier	colonnes Geberit T8		x x					1
4	plombier	traçage +4				x x			1
4	plombier	disquer/casser +4					x x		1
4	plombier	alimentation +4						x X	1
4B	éléctricien	disquer/casser +4	X X						1
T8	éléctricien	pose des échelles à câbles T8	x X						1
4B	éléctricien	placemnet des blochets		x x					1
4B	éléctricien	nettoyage		x o					0
4A	éléctricien	disquer/casser +4		x x					1
4A	éléctricien	nettoyage				x o			0
4A	éléctricien	sceller les blochets				x x			1
4AB	éléctricien	câblage				x x	x x	x x	1
A14-A13	plaquiste	structure faux plafond	x x						1
B11/12	plaquiste	structure faux plafond		x x					1
B13	plaquiste	structure faux plafond		x x					1
A21-A22	plaquiste	structure faux plafond				x o			0
A23-A24	plaquiste	structure faux plafond				x o			0
B21	plaquiste	structure faux plafond					x x		1
B22_B23	plaquiste	structure faux plafond						x x	1
A3	plafonneur	plafonnage				x x	x x	x x	1
A1	enduiseur	enduisage mur/plafond				x x	x x	x o	0
A11	carrreleur	carrelage mur/sol	x x	x o					0
A13	carrreleur	carrelage mur/sol				x o	x o		0
A14	carrreleur	carrelage mur/sol					x o	x o	0
A51-A52	chauffagiste	traçage +5	x x						1
A51-A52	chauffagiste	disquer/casser +5		x x					1
B51	chauffagiste	traçage +5				x x			1
B51	chauffagiste	disquer/casser				x x			1
B51	chauffagiste	tuyautage					x	x x	0

BLOC 1 A

Weekly Work Plan: Week 28

63 PPC ### 56%

Apt	Lot	Activité de la semaine	Je 10/7	Ve 11/7	Sa 12/7	Lu 15/7	Ma 16/7	Me 24/9	Promesse Tenue ?
B00	Plomberie	Pose des bains et tub	X						1
A01	Plomberie	Pose des bains et tub	X						1
A02	Plomberie	Pose des bains et tub		X					1
B01	Plomberie	Pose des bains et tub		X					1
R+4	Plomberie	Mise sous pression A/ TEST		X					0
						X			
R+4	Plomberie	Mise sous pression B/ TEST		X					0
						X			
Cage A ou B	Plomberie	Décharges en trémie				X	X	X	0
4B	Plafonneur	plafonnage		X	X				1
A01	Plafonneur	Enduisage 2ième couche		X	X				0
B01	Plafonneur	Enduisage 2ième couche		X	X				0
R+5	Gillion	Béton pente		X					0
						X			
TT	Gillion	Plots béton fixation garde corps		X					1
TT	Gillion	Seuils sous châssis		X		X			1
TT	Gillion	Cimentage façade + Isolant	X	X		X	X	X	1
S/SOL	Gillion	Fermeture des joints de prémurs		X		X	X	X	0
				X					
TT A	Gillion	Reprise des linteaux (0-1-2)	X	X					1
			X	X					
TT B	Gillion	Reprise des linteaux (0-1-2)				X	X		1
						X	X		
TT	Gillion	Mise en place d'un double service alimentation eau des barraques	X						1
A11	Carreleur	faience + Tablier	X	X					1
A14	Carreleur	faience + Tablier	X	X					1
A13	Carreleur	faience + Tablier		X					1
A14	Carreleur	faience + Tablier		X					1
A02	Carreleur	faience + Tablier				X			0
						X	X		
B02	Carreleur	carrelage				X			0
B02	Carreleur	faience + Tablier					x		0
0-1-2 A/B	Enduiseur	finir sdb	X	X					1
3A	Enduiseur	sdb - cuisine				X			1
3B	Enduiseur	sdb - cuisine					X		1
4A	Enduiseur	sdb - cuisine						x	0
4B	Enduiseur	sdb - cuisine						x	0
A32	Chapes	chapes	X						1
A31	Chapes	Chapes		X					1
A33	Chapes	chapes		X					0
						X			

BLOC 1 A

Weekly Work Plan: Week 29

PPC ## 55%

Apt	Lot	Activité de la semaine	Je 17/7	Ve 18/7	S 19/7	Lu 22/7	Ma 23/7	Me 24/9	Promesse Tenue ?
5B	MSB	Cornières	X						0
B	LAURENT	Evacuations	X	X		X	X		1
2A	GRANIP	Fin Carrelage	X	X					0
	INVENT	Installation des ventilo double flux						X	1
	GILLION	Reprise élévations communs							0
B02	GRANIP	Carrelage cuisines et sanitaire				X			1
A5	RODOLPHE	rainurage et cablage	X x	X x		X x	X x	X x	1
RdC	BATI	commencer faux plafonds WC gainés				X o	X o	X o	0
5A	BATI	Faux plafonds RF	X x	X x					1
5B	BATI	Faux plafonds RF (fin)			X x	X o	X o	X o	0
4A	BATI	Enduits		X x	X x				1
4B	BATI	Enduits				X x	X x	X x	1
TTZ	BATI	FIN reprises finitions	X o	X x		X x	X x	X x	0
TTZ	LAURENT	Fin alim galva commun	X o						0
2B	LAURENT	Pose tub + bains	X x	X x					1
2A	LAURENT	Pose tub + bains (FIN)				X x	X x	X o	0
3A	MSB	Lissage	X x	X x	X o				0
3B	MSB	Lissage				X o	X x		0
3A	MSB	Reprise des linteaux	X x						1
4B	MSB	Cornières (Fin)				X o	X o	X o	0
4A	MSB	Lissage				X o	X o	X o	0
5	GILLION	Fin pare vapeur(fin)	X x	X x		X o	X x	X x	0
A	RODOLPHE	Tirage de câble	X x						1
A	RODOLPHE	Saignées cage escalier	X x	X x					1
CB	RODOLPHE	Tirage de câble				X x			1
B	RODOLPHE	Saignées cage escalier				X x			1
B	RODOLPHE	câblage cage escalier					X x		1
B	RODOLPHE	Tirage de câble alimentation						X x	1
5A	RODOLPHE	disquer / casser + Scellement blochets	X x	X x					1
5A	RODOLPHE	câblage				X x	X x		1
B51	GILLION	Fermer Trémie T3	X o						0
B51	SOCQUET	Mise sous pression	X x						1
1B	SOCQUET	Pose raditeurs (porte serviettes)	X x	X x					1
2B	SOCQUET	Pose raditeurs (porte serviettes)	X x	X x					1
1A	SOCQUET	Pose raditeurs (porte serviettes)				X x	X x	X x	1
2A	SOCQUET	Pose raditeurs (porte serviettes)				X x	X x	X x	1
5	SOCQUET	Intervention pour pose cheminée				X x	X o		0
5	GILLION	Etanchéité toiture						X	
5A		Betopor						X o	0

BLOC 1 A

Weekly Work Plan: Week 30

PPC ## 53%

Apt	Lot	Activité de la semaine	Je 24/7	Ve 25/7	S ##	Lu 29/7	Ma 30/7	Me 24/9	Promesse Tenue ?
		PLACEMENT DU KIT DE COMPTAGE ELEC + GAZ				X x	x		0
T6	LAURENT	Trémie (fin)				X x	X x	X x	1
T3	LAURENT	Trémie	X x	X x					1
T2	LAURENT	Trémie	X x	X x					1
COM	LAURENT	livraison adoucisseur				X 0			0
EXT	GILLION	Déplacement échaffaudage	X x						1
A0	SOCQUET	Pose raditeurs				X x	X x		1
B0	SOCQUET	Pose raditeurs						X x	1
AB	SOCQUET	Réparation des tuyaux palier (isolant)	X x						1
RdC	SOCQUET	Livraison Porte serviettes	X x						1
A4	RALINA	Lissage	X x	X x		x	x	x	0
EXT	GILLION	Démontage Grue Ysaye		X x					1
EXT	GILLION	Montage Chopin				X x	x		0
SSOL	GILLION	Coulage de la poutre noyée						X 0	0
SSOL	RODOLPHE	Placement des dalles de comptage (support TGBT)		X x					1
A1	RODOLPHE	Equipement électrique				X x	X x	X x	1
TTZ	RODOLPHE	Mise en place tableaux communs							
TTZ	RODOLPHE	Mise en place éclairage sur douilles chantier						X 0	0
B13	CUISINISTE	Placement	X x	x					0
B11	CUISINISTE	Placement		X 0					0
B01	CUISINISTE	Placement				X 0		x	0
B02	CUISINISTE	Placement				x	X x		0
SSOL	FLOOR	Livraison des portes sous sol (caves)				X x			1
SSOL	FLOOR	Placement portes caves				X x	X x	X x	1
0-1-2	INVENT	Livraison des groupes double flux						X x	1
5	CHAPES	Bétopor	X x						1
5A	CHAPES	Chapes finitions		X x		X x			1
5A	CHAPES	Paliers				X x			1
B51	CHAPES	Chape finition					X x		1
TTZ A	CHAPES	Chapes Paliers (ATTENTION, ACCES LIMITE)					X	X x	0
RDC A-B	CHAPES	Chape isolante		X x					1
A21	CARRELEUR	carrelage cuisine		X					0
A22	CARRELEUR	carrelage cuisine		X					0
A24	CARRELEUR	carrelage cuisine				X			0
A21	CARRELEUR	faiences cuisine / SDB				X			0
A22	CARRELEUR	faiences cuisine / SDB					X		0
A24	CARRELEUR	faiences cuisine / SDB						X	0
TTZ	MAGIC FLOOR	Livraison de parquet				X		x	0
TTZ	BELGO PARQ	Prise de mesures humidité intrinsèque					X x		1
TTZ	CUISINISTE	Livraison 6 cuisines					X 0		0
EXT	GILLION	Remblaiement partie avant du bâtiment	X x	X x					1
EXT	GILLION	Pare vapeur (fin)	X x	X x					1
EXT	GILLION	Multiplex + Isolant + EPDM				X 0	X 0	X 0	0
EXT	GILLION	Pose garde corps (façade arrière)				X x	X x	X x	1
EXT	GILLION	Montage échaffaudage sur partie avant	X x	X x					1
ESC A	GILLION	Réparation cages escalier				X	X	X x	0

BLOC 1 A

Weekly Work Plan: Week 31

PPC ## 59%

Apt	Lot	Activité de la semaine	Je 31/7	Ve 1/8	S 2/8	Lu 5/8	Ma 6/8	Me 24/9	Promesse Tenue ?
SSOL	GILLION	Rampe accès sous sol (handicapé)				X 0	X x	X x	0
3	LAURENT	Bains et Tubs		 x		X x	X x	X 0	0
3	JM	Pose portes Palières	X x	X x					1
1B	BELGO PARQ	Préparation parquet	X x	X x		X x	X x	X x	1
		Pose des portes intérieures				X 0	X x	X 0	0
T8	INVENT	Trémie jusqu'au 4ième	X x	X 0		X x	X x		0
	GILLION	Couvre murs 5ième			X x	X x	X x	X x	1
	BELGO PARQ	Plinthes et profilés seuils						X 0	0
	SIBELGA	Rdv pour ouverture compteur						X 0	0
T5	GILLION	Fermeture gaine technique jusqu'au 4ième					X x		1
T6	GILLION	Fermeture gaine technique jusqu'au 4ième					X x		1
T8	RODOLPHE	Terminer gaine technique jusqu'au 4ième	X x	X x					1
T8	INVENT	Terminer gaine technique jusqu'au 4ième				X x	X x	X x	1
T3	GILLION	Fermeture gaine technique jusqu'au 4ième				X x	X x		1
T2	BATIRALINA	Fermeture GIPROC jusqu'au 4ième				X x	X x		1
T6	GILLION	Fermeture				X x	X x		1
T6	BATIRALINA	Enduisage						X 0	0
T3	BATIRALINA	Enduisage						X 0	0
T11	LAURENT	Terminer gaine technique jusqu'au 4ième	X x	X x		X x	X x	X 0	0
A	RODOLPHE	Tirage câble	X x	X x		X x	X x	X 0	0
	RODOLPHE	Réception AIV				X 0			0
	TOUS	Que la lumière soit (enfin)						X 0	0
0-3	RODOLPHE	Pose interrupteurs	X x	X 0		X x	X x	X 0	0
A	JM	Fin chapes paliers (enfin)			X x				1
1A	GILLION	Déplacer chapelle		X x					1
3	SOCQUET	Livraison radiateur					X x		1
	JM	Livraison cuisine						X 0	0
	GILLION	Reprise toiture (percements)							
	GILLION	Crépis façade Nord							
1A	BATIRALINA	Enduisage plaques GIPROC	X x	X x		X x			1
2AB	BATIRALINA	Enduisage plaques GIPROC					X x	X x	1
1B	BELGO PARQ	Pose du parquet		X x	X x				1
2B	BELGO PARQ	Pose du parquet		x x	X x				1
A	BELGO PARQ	Pose du parquet							1
3-4-5	MANUFAR	Pose des portes palières (fin)	X x	X x		X x	X x	X 0	1
3	SOCQUET	Pose des radiateurs					X x	X x	1

BLOC 1 A

Weekly Work Plan: Week 32

PPC 63%

Apt	Lot	Activité de la semaine	Je 7/8	Ve 8/8	S 9/8	Lu 12/8	Ma 13/8	Me 24/9	Promesse Tenue ?
A23	Bruynzeel	pose cuisine	X x	X x					1
T11	GILLION	Fermeture gaine technique DU RdC	X x						1
A02		pose parquet		X x					1
A02		Débarras	X x						1
A	BIJFLOR	Pose chambranles	X x	X x					1
A0-3	BJFLOR	Pose portes		X x		X x		X x	1
T7	LAURENT	Terminer gaine technique jusqu'au 4ième						X x	1
	LAURENT	Pose baignoires et tubs + 2 cassolettes extérieures	X 0	X 0					0
5	SOCQUET	Pose radiateurs	X x	X x					1
A03	LAURENT	Livraison appareils sanitaires et installation		x x					1
T13	RODOLPHE	Tirage câbles trémies	x x					x x	1
T12	RODOLPHE	Tirage câbles trémies	x x					x x	1
	JM	pose cuisine	X x						1
5AB	RODOLPHE	Equipement				x x			1
AB	RODOLPHE	levée des remarques		x 0		x x		x x	0
RDC AB	RODOLPHE	sortir les câbles videoparlephonie	x 0						0
ext	RODOLPHE	placer foureau tv/tel		x x		x x			1
AB	RODOLPHE	placer socquets + ampoules dans les cages d'escalier		x 0					0
B	BATI-RALINA	plafonnage cage descalier	x x						1
A	BATI-RALINA	plafonnage cage descalier		x x	x x	x x			1
RDC/1/2	BATI-RALINA	enduisage FP		x x		x x		x x	1
RDC/1/2	BATI-RALINA	finition angles		x x		x x		x x	1
RDC/1/2	BATI-RALINA	percements ds gyproc pour ventilation		x 0		x 0		x 0	0
RDC/1/2	BATI-RALINA	fermeture des FP dans les WC et SDB		x 0		x 0		x 0	0
B	LAURENT	raccord décharge DF plafonnier		X 0					0
A13	BATI-RALINA	Placement trape DF		x 0					0
toiture	GILLION	réalisation des modification de la toiture						x 0	0
chaufferie	GILLION	saignée + passage pour ventilation basse chaufferie		x 0				 x	0
Cave	LAURENT	trainante en geberit	x x					x x	1
A03	LAURENT	Appareillage		x x					1
4	LAURENT	pose des tubs + bains		x x				x x	1
5/chauff	LAURENT	tuyauterie en galva+hydrant incendie	x x	x x				x 0	0
4A	LAURENT	calorifugeage des tuyaux						x 0	0
RDC-AB		Livraison appareils sanitaires						x 0	0
terasse/façade	GILLION	placement des dep	x x	x x				x x	1
façades	GILLION	placement des bardages	x x	x x				x 0	0
4 et 5	GILLION	couvres murs			x 0				0
5	GILLION	pose isolant	x x	x x		x x		x x	1
5	SOCQUET	placement des radiateurs	x x	x x					1

BLOC 1 A

Weekly Work Plan: Week 33

PPC ## 67%

Apt	Lot	Activité de la semaine	Je 14/8	Ve 15/8	Sa 16/8	Lu 19/8	Ma 20/8	Me 24/9	Promesse Tenue ?
	LAURENT	2 cassolettes extérieures		X 0					0
AB	RODOLPHE	levée des remarques				X 0	X 0	X 0	0
RDC AB	RODOLPHE	sortir les câbles videoparlephonie					X 0	X 0	0
AB	RODOLPHE	placer socquets + ampoules dans les cages d'escalier					X 0		0
RDC/1/2	BATI-RALINA	percements ds gyproc pour ventilation		X 0		X 0	X 0	X X	0
RDC/1/2	BATI-RALINA	fermeture des FP dans les WC et SDB		X X		X X	X X	X X	1
B	LAURENT	raccord décharge DF plafonnier		X 0				X	0
A13	BATI-RALINA	Placement trape DF						X X	1
toiture	GILLION	réalisation des modification de la toiture				X 0			0
4A	LAURENT	calorifugeage des tuyaux				X X			1
RDC 1-2	LAURENT	Livraison appareils sanitaires				X X			1
façades	GILLION	placement des bardages		X X		X X	X X	X X	1
1er	GILLION	couvres murs	X 0	X 0		X 0	X 0	X 0	0
B21/B23	PARQUET	pose parquet			X X				1
0-2-3	PARQUET	Placement des plinthes			X X	X X	X X	X X	1
0-1-2	LAURENT	Placement appareils sanitaires				X X	X X	X X	1
TTZ	LAURENT	Remontées de ventilations							
TTZ	JM	Livraison de la sous couche accoustique				X X			1
3-4-5	PARQUET	Préparation nettoyage							
3-4-5	JM	Livraison des parquets							1
4-5	RODOLPHE	Equipement				X 0	X 0	X 0	0
TTZ	RODOLPHE	Mise en place de l'éclairage chantier soquets provisoires				X 0	X 0	X 0	0
AB	PARQUET	pose des plinthes							1
A 0-4	BATI-RALINA	Finition des Apts		X X	X X	X X	X X	X X	1
3-5	BATI-RALINA	Débarras et nettoyage		X X					1
A03	TOUS	PEINTURE APPARTEMENT TEMOIN				X X	X X	X X	1
A32	BRUYNZEEL	Mise en place cuisine		X X					1
A33	BRUYNZEEL	Mise en place cuisine				X X	X X		1
A34	BRUYNZEEL	Mise en place cuisine					X X	X X	1
0-2	BIJFLOR	Mise en place des portes manquantes				X X	X X		1
TTZ	Régies	Raccord Gaz					X X	X X	1
B01	GRANIPIERRE	terminer carrelage		X X					1
B01	GRANIPIERRE	joints				X X			1
B02	GRANIPIERRE	Faiences				X X			1

BLOC 1 A

Weekly Work Plan: Week 34

PPC ## 60%

Apt	Lot	Activité de la semaine	Je 21/8	Ve 22/8	Sa 23/8	Lu 26/8	Ma 27/8	Me 24/9	Promesse Tenue ?
1er	GILLION	couvres murs	X 0	X 0		X 0	X 0	X 0	0
1A	LAURENT	Placement appareils sanitaires	X x	X x		X x	X x	X x	1
A34	BRUYNZEEL	Levée des remarques					X 0	X 0	0
TTZ	SCHINDLER	Installation de l'ascenseur			X 0	X 0	X 0	X x	0
TTZ	GILLION	Fermeture des trémies	X x	X x		X 0	X 0	X 0	0
TTZ	BATI-RALINA	Plafonnage des trémies				x	x		1
TTZ	JM	Livraison du carrelage	X 0						0
TOIT	GILLION	Percements en toiture	X x						1
TOIT	INVENT	Reprise sorties toitures	X x						1
5AB	GILLION	Pose des garde corps				X 0	X 0	X 0	0
5	GILLION	Crépis				X x	X x	X x	1
	GILLION	Sous faces de balcons + réparations				X 0	X 0	X 0	0
	RODOLPHE	Levée des remarques	X x	X x					1
4	RODOLPHE	Placement des tableaux + tests			X x	X x			1
5	RODOLPHE	Placement des tableaux + tests			X x	X x			1
0-1	RODOLPHE	Plaques de finitions				X x	X x		1
TTZ	RODOLPHE	Livraison parlophone						x	1
TTZ	RODOLPHE	Mise en place de l'éclairage dans les apts				X 0	X 0	X 0	0
TTZ	GILLION	Dépose des chapelles		X 0					0
TTZ	RODOLPHE	Tirage câbles alim jusqu'au compteur	X x	X x		X x	X x	X x	1
5	RODOLPHE	Installation tableau élec			X x				1
0-1	GRANIPIERRE	Resserage des plinthes		X x		X x			1
RDC	JM	Début de réception des appartements				X x			1
B11-12	GRANIPIERRE	Faïence					X 0	X 0	0
B11-12	ABDEL	Pinthes		X x	X x				1
B11-12	BATI-RALINA	Correction de l'aplomb + alignement	X 0	X 0					0
B13	ABDEL	Plinthes et profilés	X x	X x					1
	ABDEL								
A0	ABDEL				X x				1
A2	ABDEL					X 0	X 0		0
TTZ	JM	Livraison parquet				X x			1
A3	ABDEL	Préparation			X 0				
AB3	ABDEL	Test humidité				X 0			0
A3	ABDEL	Parquet						X 0	0
3B	BATI-RALINA	Plafonnage des trémies							1
TTZ		Quid des joins entre plinthes et mur							
TTZ	BATI-RALINA	Levée des remarques	X x	X x		X x	X x	X x	1
0-5	BATI-RALINA	Quid Promat							
	JM	FIN DU TEMOIN (PEINTURES)	X x	X x		X x	X x	X x	1

BLOC 1 A

Weekly Work Plan: Week 35

PPC ## 54%

Apt	Lot	Activité de la semaine	Je 28/8	Ve 29/8	Sa 30/8	Lu 2/9	Ma 3/9	Me 24/9	Promesse Tenue ?
2A	LAURENT	Placement appareils sanitaires	X x	X x		X 0	X x	X x	0
TTZ	SCHINDLER	Installation de l'ascenseur				X x	X x	X x	1
TTZ	GILLION	Fermeture des trémies	X x	X x					1
TTZ	BATI-RALINA	Plafonnage des trémies	x x	x x					1
	GILLION	Sous faces de balcons + réparations				X 0	X 0	X 0	0
2-3	RODOLPHE	Plaques de finitions				X 0	X 0	x	0
TTZ	RODOLPHE	Mise en place de l'éclairage dans les apts	X x	X x					1
		Tirage câbles alim jusqu'au compteur	X x	X x					1
A12	GRANIPIERRE	carrelage mur	x x						1
A12	GRANIPIERRE	joint		x x					1
5	GILLION	pose des tablettes	x x						1
B11-12	GRANIPIERRE	terminer carrelage		x 0			x	x	0
palier B	GRANIPIERRE	pose carrelage			x x				1
B21		rejointoyage				x x	x x		1
B22		rejointoyage				x x	x x		1
B23		rejointoyage				x x	x x		1
A12	JM	chercher frise !							1
3B	BATI-RALINA	Plafonnage des trémies		X 0		x	x	x	0
ssol	BIJCHEZ	fin portes coupe-feu	X x	X x					1
ssol	GILLION	mur a corriger + construire				X x	x		0
A-B	ABDEL	pose plinthes et profils	x x						1
A14	ABDEL	pose parquet differée							0
B21	ABDEL	pose parquet			x 0				0
	Abdel	test humidité à réaliser chapes +3	x x						1
0AB	ABDEL	Profiles	x 0				x		0
1AB	ABDEL	Profiles	x 0				x	x	0
2AB	ABDEL	Pinthes	x 0				x	x	0
2AB	ABDEL	Profiles	x 0				x	x	0
3A	ABDEL	Parquet, profiles, plinthes	x 0						0
4A	ABDEL	Parquet, profiles, plinthes	x 0						0
B11	BIJCHEZ	1 porte à placer	x						1
B12	BIJCHEZ	1 porte à placer		x x					1
F	GILLION	crépis façade arrière		x x					1
4 et 1	GILLION	dalles sur plot	x x	x x					1
	GILLION	fin pose garde-corps				X x	x x		1
1	GILLION	couvres murs				x 0			0
1	GILLION	bardage					x 0	X 0	0

BLOC 1 A

Weekly Work Plan: Week 36

PPC ## 55%

Apt	Lot	Activité de la semaine	Je 4/9	Ve 5/9	Sa 6/9	Lu 9/9	Ma 10/9	Me 24/9	Promesse Tenue ?
B22	laurent	equipper	x x						1
	laurent	ventilations (sorties)	x x	x x		x 0	x 0	x 0	0
	laurent	ventilation basse (Gaz)	x x						1
A3	laurent	livraison appart		x x					1
ssol	laurent	adoucisseur en service	x x						1
3A	laurent	appareillage				x 0	x 0	x 0	0
communs	RODOLPHE	placement communs	x x						1
communs	RODOLPHE	alim chaufferie	x x	x x					1
3 + 4	RODOLPHE	finition appart + remarques	x x	x x					1
TTZ	RODOLPHE	Placement luminaires extérieurs				x 0	x 0	x 0	0
TTZ	RODOLPHE	Placement éclairage hall				x 0	x 0	x 0	0
TOIT	INVENT	placement des sortie de toiture	x x						1
5ét	INVENT	raccordement 2 buses				x 0	 0	 0	0
TTZ	INVENT	placement des bouches	x x	x x					1
TTZ	Batiralina	percement des plafonds pour bouches	x x						1
B33	NKparket	pose parquet	x x						1
2	NKparket	clôturer pose parquet et accessoires			x 0				0
B21	granipierre	carrelage mur	x x						1
B42	granipierre	pose carrelage	x x	x x					1
B41	granipierre	pose carrelage	x x	x x					1
B43	granipierre	pose carrelage	x x	x x					1
B21	granipierre	pose faïence		 x		x 0	x 0	x 0	0
B42	granipierre	pose faïence				x	x	x x	1
B41	granipierre	pose faïence				x 0	x 0	x x	0
B43	granipierre	pose faïence				x 0	x 0	x 0	1
4eme	GILLION	pose dalle sur plots	x x	x x					1
4eme	GILLION	Garde-corps	x x	x x		x 0	x x		0
rez	GILLION	étanchéité dalle	x x	x 0		x 0			0
rez	GILLION	crépis sur isolant entrées arrière				x 0	x 0		0
parking	GILLION	crépis sur isolant rampe		x x					1
1er	GILLION	couvre-murs			x 0		 x		0
1er	GILLION	bardage				x 0	x 0		0
TTZ	GILLION	réparation escaliers	x x	x x		x x	x x		1
5eme	GILLION	fermeture gaines							0
5eme	Batiralina	plaque RF dans trémies sous charpente	x x	x x					1
T11	gillion	fermer trémies				x 0	x 0	x 0	0
T6	gillion	fermer trémies					x 0	x 0	0
T8	gillion	fermer trémies						x 0	0

BLOC 1 A

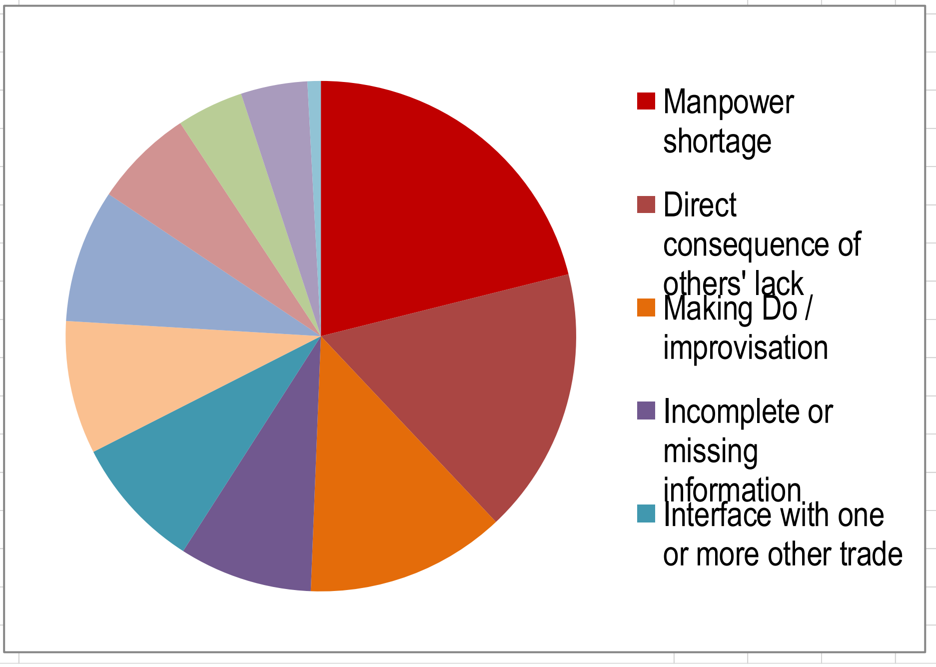
Weekly Work Plan: Week 37

E: ## PP(## 68%

Apt	Lot	Activité de la semaine	Je 11/9	Ve 12/9	Sa 13/9	15/9	Lu 16/9	Ma 17/9	Me 24/9	Promesse Tenue ?
+5 A-B	Nk parquet	pose parquet	x 0				x 0		x 0	0
+3A-B	Laurent	Appareillage	x x							1
+4A-B	Laurent	Appareillage		x x			x x	x x	x x	1
TTZ	Rodolphe	éclairage communs	x x	x x						1
TTZ	Rodolphe	éclairage ext.					x 0	x 0	x 0	0
A-B	MC Décor	préparation des supports et mise en peinture	x x	x x			x x	x x	x x	1
+5	Batiralina	Enduisage FP	x x	x x						1
Abords	Gillion	étanchéité parking		x x			x x	x x	x	1
Abords	Gillion	Enlèvement des calles de soutien sous bassement	x x							1
Abords	Gillion	pose élement T en gébérit pour raccordement logette		x x						1
TTZ	Gillion	Bardages					x x	x x	x x	1
TTZ	Gillion	Grdes corps					x x	x x	x x	1
+5 A	Gillion	Fermeture gaines	x x							1
+5 B	Gillion	Fermeture gaines		x x			x 0	x x	x x	0
+5	Batiralina	Enduisage FP	x x	x x			x x	x x		1
RDC	Batiralina	Ensuisage FP 1er couches		x x						1
RDC	Batiralina	Ensuisage FP couches finale					x x	x x	x x	1
+4 A	Batiralina	Ensuisage FP					x x			1
B23	Batiralina	Pose des trappes + encadrement					x 0	x 0	x 0	0
B33	Batiralina	Pose des trappes + encadrement					x 0	x 0	x 0	0
B43	Batiralina	Pose des trappes + encadrement					x 0	x 0	x 0	0
+5 B	Batiralina	finition plafonnage mural			x 0		x			0
+4 A	Laurent	Appareillage en cours	x x	x x			x x	x x	x x	1
+3 B	Laurent	Appareillage en cours	x x	x x			x x	x x	x x	1
caves	Rodolphe	Finition cablâge	x x							1
caves	Rodolphe	alimentation des caves/parkings	x x							1
TTZ	Rodolphe	appareillage des halls		x x			x 0	x x	x x	0
+3 B	Nk parquet	pose parquet	x x							1
A11	Nk parquet	pose plinthes		x 0						0
+4 B	Nk parquet	Pose parquet					x 0	x 0	x x	0
+1 /2/3/4	MC DECOR	couche de finition plafonds/murs	x x	x x			x x	x x	x x	1

Bloc 1 A : reasons for not completing LPS promises (weeks 26 to 31)

Manpower shortage	50	21%
Direct consequence of others' lack	40	17%
Making Do / improvisation	30	13%
Incomplete or missing information	20	8%
Interface with one or more other trade	20	8%
Late material / broken	20	8%
Wheather	20	8%
Overestimation of the works capability	15	6%
Rework	10	4%
Preworks not identified	10	4%
Change by the Client	2	1%



11.2 WWP BLOCK 2 (weeks 44 to 47)

Bloc 2 — Weekly Work Plan: week 44

E: #REF! PPC **79%**

Apt/Et	Lot	Activité de la semaine	Ve 28/10	Sa 29/10	Lu 31/10	Ma 1/11	Me 2/11	Je 3/11	Promesse Tenue ?
SSOL	Laurent	raccordement boiler	x x						1
TTZ	Laurent	raccordement compteur EF EC	x x						1
TTZ	Laurent	accrocher dévidoirs incendie + raccord	x x						1
TTZ	Laurent	appareiller RDC	x x						1
TTZ	LDPS	protections bain-tub					x x	x x	1
5	GILLION	échafaudage	x		x				0
5	GILLION	isolation sous toiture et PV	x		x				0
5	GILLION	maçonner cheminée	x x						1
5	GILLION	maçonner blocs trémie	x x			x x			1
TTZ	GILLION	monter blocs pour fermeture trémie	x x						1
TTZ	GILLION	aérations ascenseurs	x x						1
Facades	GILLION	crépis sur isolant	x				x	x	0
5	GILLION	monter panneaux GYPROC	x x						1
RDC	GILLION	dégager dalle - rassembler DERNIER JOUR DE GRUE	x						1
4	SOCQUET	placerd radiateur (D)	x x						1
TTZ	DEV	prise de service palier	x x						1
~~3~~	~~DEV~~	~~appareillage appartements~~						x x	~~1~~
SSOL	DEV	sous-sol finition cavettes						x x	1
TTZ	BAT	lever remarque 'laissés derrières" voir liste	x x		x x		x x	x x	1
5	BAT	plafonnage			x x		x x	x x	1
5	BAT	faux plafond RF (D 41)	x		x		x x	x x	0
3	BAT	enduisage plafond					x x		1
4	BAT	enduisage plafond						x	0
4	BAT	enduisage cloisons					x x	x x	1

Bloc 2	Weekly Work Plan: week 45					E:	#REF!	PPC	85%

Apt/Et	Lot	Activité de la semaine	Ve 4/11	Sa 5/11	Lu 7/11	Ma 8/11	Me 9/11	Je 10/11	Promesse Tenue ?
SSOL	SIBELGA	ouverture GAZ			x x				1
SSOL	Socquet	mise en service chaufferie - chauffage 0 - 4				x x	x x		1
TTZ	Laurent	accrocher dévidoirs incendie + raccord			x x	x x	x x	x x	1
SSOL	Laurent	mise en route adoucisseur				x x	x x	x x	1
SSOL	Laurent	raccordement compteur général			x x	x x	x x		1
1er	Laurent	appareillage			x x	x x	x x	x x	1
5	GILLION	isolation sous toiture et PV			x x				1
5	GILLION	pose ZN			x	x	x	x x	0
+4 +1	GILLION	étanchéité terrasses			x	x	x x	x x	0
SSOL	GILLION	pose heraclithe			x x	x x	x x	x x	1
TTZ	GILLION	resserage DIVERS (LISTE)			x x	x x	x x	x x	1
4	SOCQUET	placer sèche serv			x x				1
TTZ	SOCQUET	mise sous p				x x	x x	x x	1
3	DEV	appareillage appartements	x x		x x	x x	x x		1
SSOL	DEV	sous-sol finition cavettes	x x		x	x			0
5	BAT	faux plafond RF (D 41)	x		x x	x x	x x	x x	1
TTZ	BAT	enduisage cloisons			x x	x x	x x	x x	1
4	SOCQUET	placerd radiateur (D)	x x		x x				1
TTZ	DEV	prise de service palier	x x		x x				1
3	DEV	appareillage appartements						x x	1
SSOL	DEV	sous-sol finition cavettes						x x	1
TTZ	BAT	lever remarque 'laissés derrières" voir liste	x x		x x		x x	x x	1
5	BAT	plafonnage			x x		x x	x x	1
5	BAT	faux plafond RF (D 41)	x x		x x		x x	x x	1
3	BAT	enduisage plafond					x x		1
4	BAT	enduisage plafond						x	0
4	BAT	enduisage cloisons					x x	x x	1

Bloc 2	Weekly Work Plan: week 46				E:	#REF!	PPC		92%

Apt/Et	Lot	Activité de la semaine	Ve 11/11	Sa 12/11	Lu 14/11	Ma 15/11	Me 16/11	Je 17/11	Promesse Tenue ?
SSOL	Laurent	mise en route adoucisseur BWT			x x				1
5	GILLION	isolation sous toiture et PV			x x	x x			1
5	GILLION	pose ZN			x x	x x	x x	x x	1
+4 +1	GILLION	étanchéité terrasses			x x	x x	x x		1
Dalle	GILLION	dégager zone avant			x x	x x	x x		1
Dalle	GILLION	étanchéité au dessus rampe PK					x x	x x	1
SSOL	GILLION	pose heraclithe			x	x x	x x		0
TTZ	GILLION	resserage DIVERS (LISTE)			x x	x x	x x	x x	1
FAC	GILLION	Bardage			x x	x x	x x	x x	1
FAC	GILLION	crépis couche fin			x x				1
Dalle	GILLION	démontage grue						x x	1
Dalle	GILLION	pose hourdis						x x	1
RDC	GILLION	soubasst pierre bleue (avant)					x x	x x	1
SSOL	Socquet	mise en service chauff				x x			1
SSOL	Socquet	mise sous eau					x x	x x	1
TTZ	Socquet	sèche serv D12 D25 C43					x x	x x	0
2C	LAURENT	appareillage			x x	x x			1
1D	LAURENT	appareillage					x x	x x	1
SSOL	DEV	alimentation chauffage 5G4			x x				1
5	DEV	Tirer alim D51 et D52			x x				1
TTZ	DEV	reste semaine à définir …					x x	x x	1
C03	DEV	déplacer interrupteur vers hall			x x				1
5 / toit	INVENT	trémies			x	x			1
5	INVENT	horizontales					x x	x x	1

Bloc 2		Weekly Work Plan: week 47				E:	#REF!	PPC	90%
Apt/Et	**Lot**	**Activité de la semaine**	**Ve** 18/11	**Sa** 19/11	**Lu** 21/11	**Ma** 22/11	**Me** 23/11	**Je** 24/11	**Promesse Tenue ?**
5	GILLION	pose ZN				x	x	x	1
+4 +1	GILLION	étanchéité terrasses			 x	x	x	x	0
Dalle	GILLION	dégager zone avant				x x			1
Dalle	GILLION	étanchéité au dessus rampe PK			x x	x x	x x	x x	1
SSOL	GILLION	pose heraclithe			x x	x x	x x		1
FAC	GILLION	Bardage	x x	x x	x x				1
DALLE	GILLION	bétonnage trou de grue	x x						1
DALLE	GILLION	soubassement p bleue	x x						1
TTZ	GILLION	levée remarque - liste	x x		x x	x x	x x	x x	1
FAC	GILLION	pose isolant sur latéraux	x		x	x	x	x	1
2D	LAURENT	appareillage	x x						1
	LAURENT	livraison mob +3 bain tub +5			x x				1
3	LAURENT	appareillage				x x	x x	x	1
TTZ	Socquet	sèche serv D12 D25 C43					x x	x x	1
RDC	GILLION	soubasst pierre bleue (avant)					x x	x x	1
SSOL	Socquet	mise en service chauff				x x			1
SSOL	Socquet	mise sous eau					x x	x x	1
TTZ	Socquet	sèche serv D12 D25 C43				x x	x x	x x	1
2C	LAURENT	appareillage			x x	x x			1
1D	LAURENT	appareillage					x x	x x	1
SSOL	DEV	alimentation chauffage 5G4			x x	x x			1
5	DEV	Tirer alim D51 et D52			x x	 x			1
TTZ	DEV	reste semaine à définir …				x x	x x	x x	1
Dalle	GILLION	dégager zone avant			x x	x x	x x	x x	1
Dalle	GILLION	étanchéité au dessus rampe PK					x x	x x	1
SSOL	GILLION	pose heraclithe			x	x x	x x	 x	0
TTZ	GILLION	resserage DIVERS (LISTE)			x x	x x	x x	x x	1
FAC	GILLION	Bardage			x	x x	x x	x x	0
FAC	GILLION	crépis couche fin			x x				1

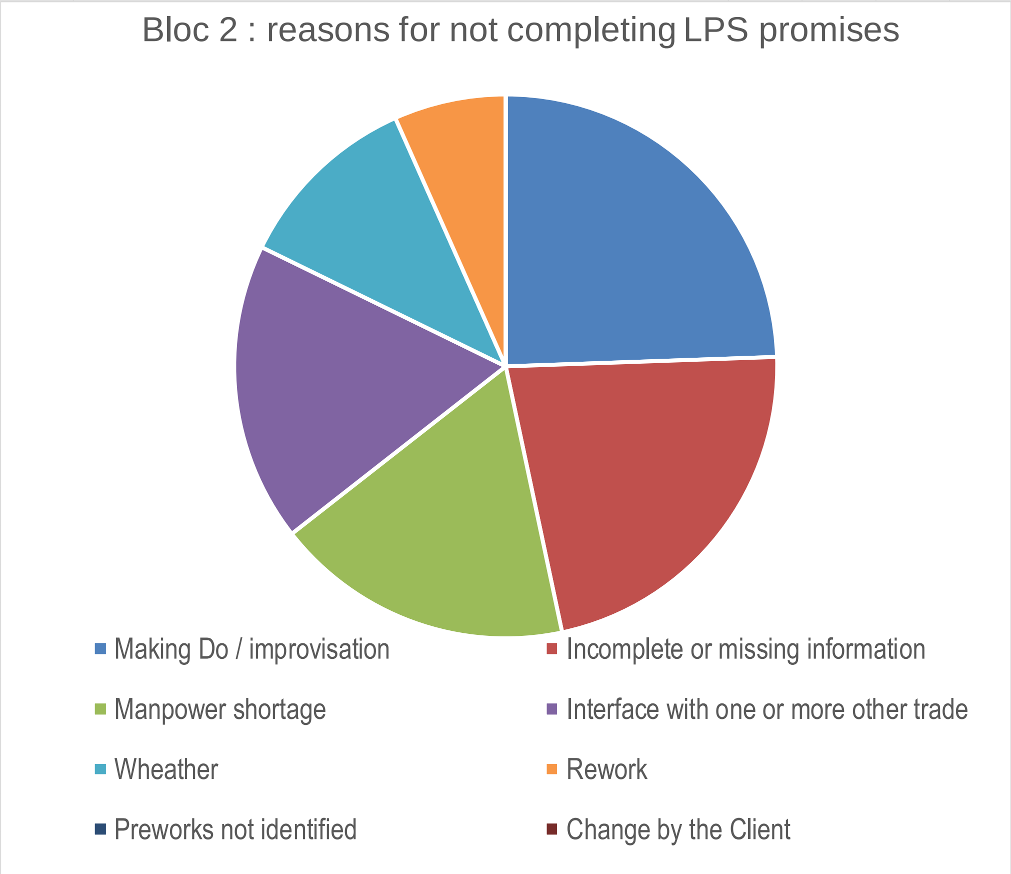
Bloc 2 | **Weekly Work Plan: week 48** | E: #REF! | PPC **82%**

Apt/Et	Lot	Activité de la semaine	Ve 2/12	Sa 3/12	Lu 5/12	Ma 6/12	Me 7/12	Je 8/12	Promesse Tenue ?
	GILLION	FERMETURE TREMIE	x x		x x	x x	x x		1
5	INVENT	gainage horizontal	x x						1
5	INVENT	prises et rejets air	x x						1
RDC	GILLION	etanchéité dalle	x		x x	x x	x x	x x	0
FACADE	GILLION	Réparation intérieur îlot	x x						1
FACADE	GILLION	Facades latérales SAIO YSAYE	x x		x x	x x			1
1	GILLION	Etanchéité +1 terrasses			x x	x x	x x		1
TOIT	GILLION	Toiture Zn	x x						1
TOIT	GILLION	couverture SHED	x x		x x				1
TOIT	GILLION	caisson cheminée					x		0
TOIT	GILLION	Velux					X x		1
SSOL	GILLION	pose heraclithe	x x		x x	x x			1
FAC	GILLION	Bardage			x x	x x	x x		1
FAC	GILLION	DEP	x x		x x				1
FAC	GILLION	démontage échafaudage					x		1
TTZ	GILLION	levée remarque - liste	x x		x x	x x	x x		1
5	GILLION	ressérrages	x x		x x	x x	x x		1
TTZ	GILLION	pose garde corps escalier C					x	x	1
TTZ	Laurent	Chipotages	x		x x				1
TTZ	Laurent	appareiller RDC	x x		x x	x x			1
TTZ	LDPS	protections bain-tub			x x		x x	x x	1
5	GILLION	échafaudage	x		 x				0
5	GILLION	isolation sous toiture et PV	x		 x				0
5	GILLION	maçonner cheminée	x x						1
5	GILLION	maçonner blocs trémie	x x			x x			1
TTZ	GILLION	monter blocs pour fermeture trémie	x x						1
TTZ	GILLION	aérations ascenseurs	x x						1
Facades	GILLION	crépis sur isolant	x x				x x	x	0

Bloc 2		**Weekly Work Plan: week 49**				E:	#REF!	PPC	**84%**
Apt/Et	**Lot**	**Activité de la semaine**	**Ve** 9/12	**Sa** 10/12	**Lu** 12/12	**Ma** 13/12	**Me** 14/12	**Je** 15/12	**Promesse Tenue ?**
ssol	Laurent	pose réduc pression EF	x						1
			x						
4D	Laurent	livraison mobiler sani			x				0
						x			
4D	Laurent	pose mob				x	x	x	1
						x	x		
3D	Eggo	pose cuisine	x						1
			x						
C	Eggo	raccordements		x					1
				x					
2C, 3C	Eggo	pose cuisines			x	x			1
					x	x			
3D	Eggo	pose cuisines					x	x	1
							x	x	
RDC	GILLION	roofing sur dalle (général hors détail et zone lat.)	x						1
			x						
RDC	GILLION	raccord pieds de mur roofing						x	1
								x	
TOIT	GILLION	pose Zinc	x		x	x	x		1
			x			x	x		
FAC	GILLION	Bardage façade AR					x	x	1
							x	x	
FAC	GILLION	DEP	x		x	x	x		1
			x		x	x	x		
	GILLION	FERMETURE TREMIE	x		x	x	x		1
			x		x	x	x		
5	INVENT	gainage horizontal	x						1
			x						
5	INVENT	prises et rejets air	x						1
			x						
RDC	GILLION	etanchéité dalle	x		x	x	x	x	0
					x	x	x	x	
FACADE	GILLION	Réparation intérieur îlot	x						1
			x						
TOIT	GILLION	pose velux	x		x				1
			x		x				
ssol	GILLION	heraclithe	x		x	x			1
			x		x	x			
D	GILLION	garde corps escalier	x						0
						x			
C	GILLION	garde corps escalier			x	x			1
					x	x			
TTZ	GILLION	ragréage escaliers	x						1
			x						
FAC	GILLION	démontage échaf				x	x	x	0
						x	x		
1C	NK	pose parquet			x	x			1
					x	x			
1D	NK	pose parquet				x	x	x	1
						x	x	x	

Bloc 2 : reasons for not completing LPS promises (weeks 44 - 49)

Direct consequence of others' lack	23	26%
Overestimation of the production capability	20	23%
Making Do / improvisation	11	13%
Incomplete or missing information	10	11%
Manpower shortage	8	9%
Interface with one or more other trade	8	9%
Wheather	5	6%
Rework	3	3%
Preworks not identified	0	0%
Change by the Client	0	0%
Late material / broken	0	0%



11.3 WWP BLOCK 3 (weeks 12 to 17)

Block 3		Weekly Work Plan: week 12				E:	#REF!	PPC	87%
Apt/Et	**Lot**	**Activité de la semaine**	**Ve** 20/5	**Sa** 21/5	**Lu** 23/5	**Ma** 24/5	**Me** 25/5	**Je** 26/5	**Promesse Tenue ?**
RDC	Laurent	mise sous pression	x x	x x	x x				1
RDC	EMB	projection PUR 10cm				X	X		1
RDC	EMB	chape ciment					x	x X	0
premier étage	Laurent	mise sous pression			x x	x x			1
2eme	Laurent	TRACER				x x			1
2eme	Laurent	disquer casser					x x	x x	1
trémies	socquet	colonne acier jusque +3 T2 et T12	x x						1
trémies	socquet	mise sous p T2 et T12	x x						1
RDC	socquet	mise sous Pression	x x						1
premier étage	socquet	mise sous Pression	x x						1
ssol	socquet	chaufferie équippée hors chaudiére	x x						1
ssol	socquet	réseau plafond paking	x x						1
+3	GILLION	pose prédalles zone	x x						1
+4	GILLION	pose balcons	x x						1
4	GILLION	ferraillage poutres et dalles	x x		x x				1
+4	GILLION	coffrage colonnes	x x		x x				1
+3	GILLION	bétonage dalle z2				x x			1
+4	GILLION	pose prémurs asc				x	X		0
4	GILLION	pose blocs silicaat						x x	1
4	GILLION	coffrage colonnes et voiles					x x	x x	1
2	GILLION	fin blocs de plâtres		x x					1
2	GILLION	rectification D21		x x					1
3	GILLION	pose châssis et vitrage	x		x x	x x	x x		0
ssol	DEVOG	fourreau coffret gaine technique	x x						1
+1	DEVOG	reboucher saignées			x x				1
RDC	DEVOG	communs			x x				1
+1	DEVOG	tubage (R=4 apts)				x x	x x	x x	1
RDC	BATIRALINA	plafonnage	x x						1
+1	BATIRALINA	plafonnage			x x	x x	x x	x	0
RDC	Batiralina	faux-plafond	x x						1

Block 3		Weekly Work Plan: week 13				E:	#REF!	PPC	84%
Lieu	**Ets**	**Activité de la semaine**	**Ve** 27/5	**Sa** 28/5	**Lu** 30/5	**Ma** 31/5	**Me** 1/6	**Je** 2/6	**Promesse Tenue ?**
+1	EMB	pose sous chape Bétopor				x x			1
+1	Laurent	mise sous pression			x x				1
+2	Laurent	casser, disquer, ramasser nos crasses	x x						1
+2	Laurent	tuber alimentations			x x	x x	x x	x	0
+2	Laurent	décharges						x x	1
+2	Socquet	disquer casser	x x						1
+2	Socquet	tuyauter			x x	x x	x x	x x	1
+2	Socquet	on ramasse nos saletés	x x						1
haut+3	Gillion	betonnage dalle Z2	x x						1
haut+4	Gillion	pose silicaat	x x		x x	x x	x x	x x	1
haut+4	Gillion	coffrage colonnes et voiles	x x		x x	x x	x x	x x	1
RDC	Gillion	barbecue	x x						1
haut+4	Gillion	poutres , cofFrages			x x	x x	x x	x x	1
haut+4	Gillion	préparation ferraillage poutres	x x		x x	x x	x x		1
+3	Gillion	décoffrage	x x		x x	x x	x		0
TTZ	Gillion	pose vitrage	x x						0
+3	Gillion	livraison châssis	x x						1
+1C	Batiralina	plafonnage	x	x x					1
+1D	Batiralina	plafonnage			x x				1
+2C	Batiralina	préparation support et cornières	x x						1
+2D	Batiralina	préparation support et cornières	x x						1
"+1	Devogelaere	câblage	x x						1
+1	Devogelaere	fourreau alimentation colonne	x x						1
+2	Devogelaere	tracer disquer casse			x	x x	x x	x x	0
R+1+2	Devogelaere	prises palières (prises de servic)	x x		x x				1

Block 3	Weekly Work Plan: week 14				E:	#REF!	PPC	83%
Apt/Et	**Lot**	**Activité de la semaine**	**Ve** 3/6	**Sa** 4/6	**Lu** 6/6	**Ma** 7/6	**Me** 8/6	**Je** 9/6	**Promesse Tenue ?**
+2	Laurent	décharges	x x		x x	x x	x x	x x	1
+4	Gillion	pose silicaat	x x		x x	x x	x x	x x	1
haut+4 z1	Gillion	poutres , coffrages	x x		x x	x x	x x	x x	1
+3	Gillion	bloc de plâtres			x x	x x	x x	x x	1
+3	Gilion	pose châssis			x x	x x	x x	x x	1
+2C	Devogelaere	cablage	x x						1
+2D	Devogelaere	disquer casser	x x		x x	x x	x x	x x	1
+2C	Devogelaere	rebouchage saignées	x x		x x	x x			1
+2D	Devogelaere	cablage			x x	x x	x x	x x	1
RDC D	EMB	chape de fintion	x						0
+1 D	EMB	chape de fintion			x	x x	x x		0
+2 C	EMB	CHAPE FINITION						x x	1
Trémies	Laurent	montage colonnes galva	x x		x x	x x	x x	x x	1
Ysaye	Laurent	suspendu parking	x x						1
ttz	Laurent	compteur EC	x x		x x	x x	x x		1
ttz	Laurent	batis WC	x x		x x	x x	x x		1
GT	GILLION	partywall	x x		x x	x x	x x		1
FAC	GILION	décoffrage balcons	x						0
+2 D1 ET 2	INVENT	horizontal	x x						1
ttz	INVENT	carrottage trémies	x x						1
+2	Socquet	mise sous eau	x x						1
+2	Socquet	pose collecteurs	x						0
+2 C	Batiralina	plafonnage			x x	x x	x x	x x	1

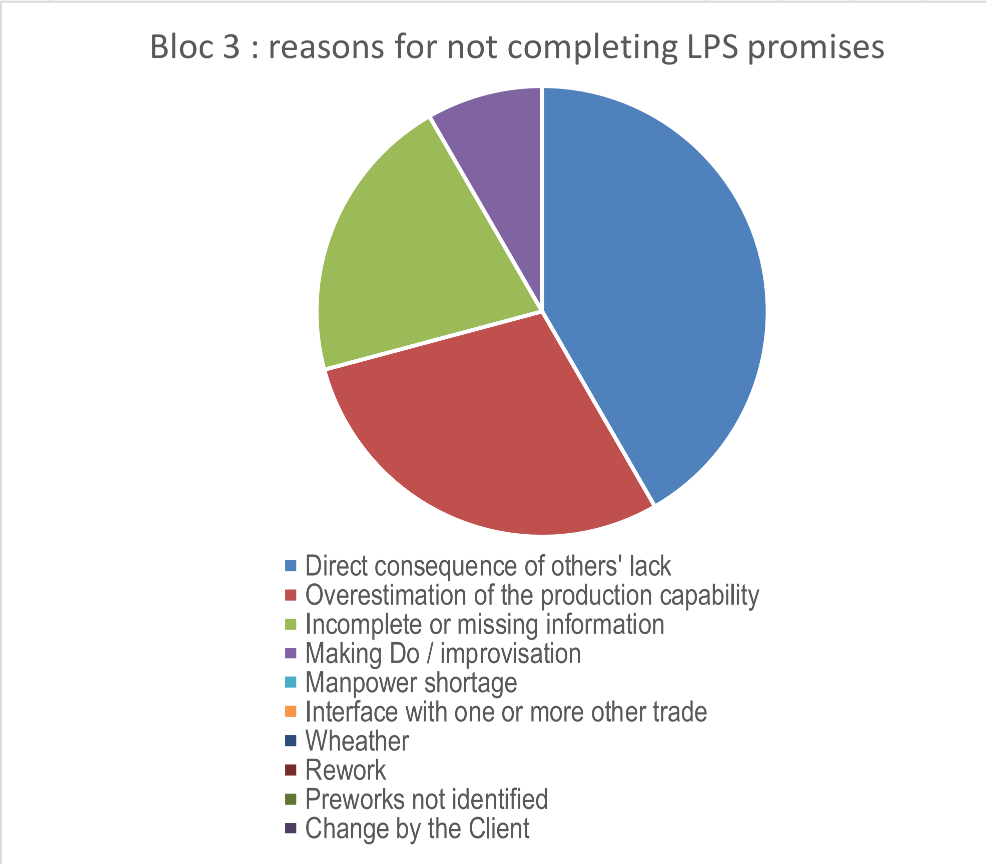
Block 3		Weekly Work Plan: week 15	E:			#REF!	PPC	88%
Apt/Et	**Lot**	**Activité de la semaine**	**Ve** 10/6	**Sa** 11/6	**Lu** 13/6	**Ma** 14/6	**Me** 15/6	**Je** 16/6	**Promesse Tenue ?**
+1 C	EMB	préparation isolant	x x						1
+1 C	EMB	chape de fintion	x x		x x				1
+2	EMB	Bétopor				x x			1
+1D	EMB	préparation isolant					x x		1
+1 D	EMB	chape de fintion						x x	1
+2D	Devog	cablage	x x		x x				1
+3C	Devog	disquer casser			x x	x x			1
+3C	Devog	câbler				x x	x x	x x	1
+3C	Devog	rebouchage					x	x	0
+3	GILLION	bloc de plâtre	x	x	x	x	x	x	0
+4	GILLION	Silicaatsteen	x		x	x	x	x x	0
+4	GILLION	coffrages poutres	x x		x x	x x	x x	x x	1
+5	GILLION	pose prédalles				x x			1
+5	GILLION	pose casquettes					x x		1
+5	GILLION	feraillage dalle				x x	x x	x x	1
+3	GILLION	châssis	x x		x x	x x	x x		1
RDC	GILLION	décoffrage balcons	x x		x	x			1
+2	Laurent	decharges, batis, EC	x x		x x				1
+2	Laurent	mise sous pression	x						1
+3C	Laurent	tracer			x x				1
+3C	Laurent	disquer casser				x x			1
+3C	Laurent	monter colonnes & tuyauter					x x	x x	1
interieur	Laurent	Racordement crépines sous dalle					x x		1
D24	GILLION	monter mur TREMIE 140cm **T9**	x x						1

Block 3		Weekly Work Plan: week 16				E:	#REF!	PPC	83%
Apt/Et	**Lot**	**Activité de la semaine**	**Ve** 17/6	**Sa** 18/6	**Lu** 20/6	**Ma** 21/6	**Me** 22/6	**Je** 23/6	**Promesse Tenue ?**
+5	GILLION	ferraillage dalle	x x	x x	x x				1
+5C D1	GILLION	bétonnage				x x			1
+5D	GILLION	silicaat	x x						1
+5C D1	GILLION	pose casquettes	x x						1
RDC	GILLION	décoffrage balcons	x x						1
RDC	GILLION	débarasser RDC			x	x			0
3D	GILLION	teminer portes cornières		x x					1
2D	EMB	chapes	x x		x x				1
2C	EMB	chapes			x x	x x	x	x	0
3C	EMB	bétopor					x x		1
3C	EMB	preparer isolation						x	0
3C	EMB	chapes						x	0
3D	Socquet	tuyauter	x x		x x				1
3D	Socquet	cintrage et collecteurs				x x	x x	x x	1
3C	Laurent	décharges sol	x x		x x				1
3C	Laurent	reboucher tester			x x				1
3D	Laurent	tracer				x x			1
3D	Laurent	disquer casser				x x	x x		1
3D	Laurent	tuyauter						x x	1
3C	DEVOG	fin cablage	x x						1
3D	DEVOG	tracer	x x						1
3D	DEVOG	disquer casser			x x	x x	x x		1
3D	DEVOG	tubage						x x	1

Block 3		Weekly Work Plan: week 17				E:	#REF!	PPC	87%
Apt/Et	**Lot**	**Activité de la semaine**	**Ve** 24/6	**Sa** 25/6	**Lu** 27/6	**Ma** 28/6	**Me** 29/6	**Je** 30/6	**Promesse Tenue ?**
3C	EMB	chapes	x x						1
3D	Socquet	cintrage et colecteurs	x x						1
3D	Laurent	tuyauter	x x		x				1
3D	Laurent	décharges				x x	x x	x x	1
3D	DEVOG	tubage	x x		x x	x x	x x		1
dalle	GILLION	5S	x		x	x	x		1
ssol	GILLION	5S	x		x	x	x		1
dalle	GILLION	palissade			x x	x x	x		1
5D	GILLION	ferraillage dalle	x x		x x				1
5D	GILLION	pose casquettes	x x						0
5C D1	GILLION	coffrage poutre renversée	x x						1
5D	GILLION	bétonnage dale				x x			1
	GILLION	LIVRAISON SILICAAT			x x	x x			1
4 ext	GILLION	décoffrage					x x	x x	1
5D	GILLION	étanchété provisoire sur trémies plan dalle					x x		1
dalle	GILLION	maçonnerie support soubassement			x	x	x x	x x	0
D32	DEVOG	terminer appart	x x						1
D	Devog	terminer reboucher	x x						1
CD	Devog	communs étages / paliers			x x	x x	x x	x x	1
Ssol	Devog	échelles à cables / supports			x x	x x	x x	x x	1
3D	Laurent	décharges	x x		x x				1
3D	Laurent	batis WC	x x		x x				1
3D	Laurent	rebouchages	x x		x x				1
3D	Laurent	ssol				x	x	x x	1
3D	Laurent	raccord décharge trainante dalle					x x		1
3D	GILLION	raccord décharge trainante dalle					x x		1
1	BATIRALINA	préparation enduisage cloisons			x x	x x	x x	x x	1
RDC	BATIRALINA	fermeture FP			x	x x	x x	x x	1
3D	BATIRALINA	plafonnage				x x	x	x	0
CO2	BATIRALINA	terminer enduit 100%			x			x	0
TTZ	GILLION	décapage bavure béton (4 niveaux prior 3D)	x x		x x	x x	x x	x x	1

Bloc 3 : reasons for not completing LPS promises

Direct consequence of others' lack	10	42%
Overestimation of the production capability	7	29%
Incomplete or missing information	5	21%
Making Do / improvisation	2	8%
Manpower shortage	0	0%
Interface with one or more other trade	0	0%
Wheather	0	0%
Rework	0	0%
Preworks not identified	0	0%
Change by the Client	0	0%
Late material / broken	0	0%



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