

Theses of University Doctorate (PhD) Dissertation

APPLICATION POSSIBILITIES OF LEAN MANAGEMENT IN THE LOGISTICS OF CONSTRUCTION INDUSTRY

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Debrecen, 2020

1. BACKGROUND OF THE RESEARCH, ITS OBJECTIVES AND THE INTRODUCTION OF THE RESEARCH HYPOTHESES

Lean management became widespread among European production companies at the end of the 20th Century. The companies in the automotive industry were the first to adapt lean philosophy and to apply lean tools. It is evident, considering that the foundation of lean management is the Toyota Production System, developed by Taichii Ohno, thus its basics originate from automotive industry (KRAFCIK, 1988). Upon noticing the success of production companies, several research were initiated in order to apply the toolset of lean management for the development of other diverse processes. The research for the application of lean management in the processes of in construction industry started in the United States, and by now, several practical implementations are carried out in the Nordic countries and also in South America. The processes of the construction industry are of quite special nature, as they are typically project-based, meaning that they are executed in a specific location within a short period of time, thus in comparison with production processes, the lean toolset has to be applied with different methodology. Basically, I can establish that the application of lean management in the processes of the construction industry was successful, although the difficulties of its initiation also became evident. In the course of my research, I both oversaw and participated in the integration of lean management into logistic processes as well as in its development multiple times. While conducting several projects, I managed to achieve significant success in the introduction of this philosophy in the field of warehousing, as well as in the application of lean methods in storage processes. It is evident, that the application of lean in the field of logistics, encompasses significant economic possibilities.

Upon seeing these possibilities provided by the application of lean in the field of logistics and the execution of lean developments in the construction industry, I chose the possible applications of lean management in the logistic processes of construction industry as the subject of my research.

The main objective of my research is to unveil the reasons behind the decreased efficiency observed in the construction industry in comparison with manufacturing industry, as well as providing suggestions concerning the implementation of the future “catch-up” of the

efficiency of the processes of the construction industry. In international practice, there are examples for the fragmented application of lean management. My objective is the development of the systematic application of lean in the processes of the construction industry.

The basic hypothesis of my dissertation is the overview and analysis of specialized literature, and according to my own research, to demonstrate that the initiation of lean management that is successfully used in the processing industry is not only possible in the processes, but also in the logistics of construction industry, and that its use results in significantly increased efficiency for each member of the supply chain of construction industry, while pull principle material supply can also be initiated.

I hereby summarize my objectives – included in the first chapter of my dissertation – in the following points:

- C1. Comparison of the processes of construction- and processing industry according to their level of development; identification of the reasons of efficiency-related differences, and the analysis of the effects of different industrial characteristics upon work processes.
- C2. Allocating construction industry logistics as a field of profession, identifying its characteristics, collecting the main objectives and functions of the profession, and the definition of construction industry logistics according to these informations.
- C3. Classification and analysis of the case studies and specialized literature that describe the application of certain tools of lean management in the field of construction industry and following the evaluation of the outcomes, determining which tools could be applied efficiently in the logistics of construction industry.
- C4. Overview of project-planning methodologies and their available software support, analysis of their practical applicability through case studies, allocation of development directions.
- C5. Overview of the current situation of domestic construction industry, on the one hand in regards of major economic processes, on the other hand from the aspect of the current development state of the supply chain; by the help of the outcomes of the

survey, deciding whether domestic construction companies are fit for the initiation of lean-based material supply methods at present.

C6. Initiation of lean-based material supply methodologies in the logistics of domestic construction industry, overview of previous case studies, and according to the observations of domestic initiation, revealing the application possibilities of these tools at the level of the supply chain.

My secondary hypotheses connected to the objectives and the main hypothesis are as follows:

- H1. Despite the significantly different characteristics of construction industry and processing industry, the lean methodologies that are successfully used in processing industry, could be effectively adapted in construction industry too, considering certain limitations and particularities.
- H2. The initiation of lean management into construction industry can reduce the environmental impacts of construction projects in a significant extent.
- H3. A comprehensive industrial survey of domestic construction industry sector and the execution of the projects of practical initiation helps to confirm that the industry sector needs development in several areas, both on industrial (supply chain) level, and on the level of the development of factory processes before the introduction of pull principle material supply.
- H4. Stock management and ordering, as well as material usage measurement functions could be efficiently integrated into the project-planning methodologies applied in lean construction industry and its supporting softwares, thus facilitating real-time stock management. Temporal stock controls can be executed automatically by the use of intelligent tools, according to the guidelines of Industry 4.0. The implementation of pull principle system facilitates the use of “just in time” philosophy, thus significantly reducing the amount of stock kept at the construction premises.

2. INTRODUCTION OF THE DATABASE AND THE APPLIED METHODS

I constructed my dissertation by the use of classic research methodology opportunities. I conducted both primary and secondary research in order to thoroughly investigate the subject. At present, there is neither any professional organization dealing with the application of lean in construction industry in Hungary, nor significant Hungarian research in the subject, thus I included the outcomes presented by international organizations into my research. In present domestic practice, lean management is not used in the construction industry, thus these case studies were also only available from international practices. In the course of the research, beyond the most recognized internet-based publication databases (Science Direct, Web of Science, and Google Scholar) I also relied on the outcomes published by the Lean Construction Institute until 2019.

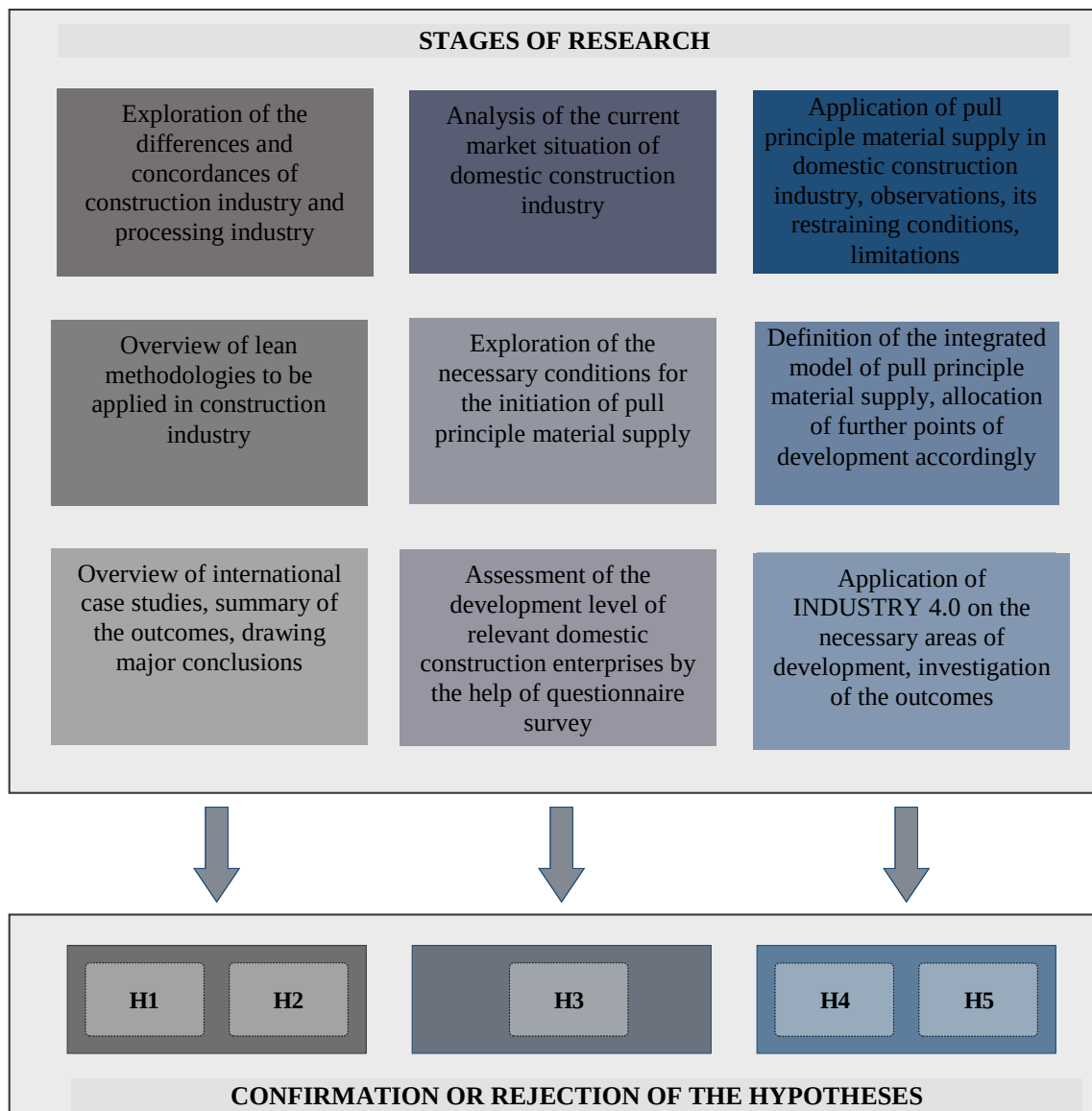


Figure 1.: The model of research

Source: Respective edit

After the review of domestic and international specialized literature, I determined the main focus of the research. The review of specialized literature reveals that in the logistics of construction industry, certain tools are used in a “fragmented” manner. The main focus of my research is to explore the integration possibilities of these tools, and their further development along the principles of Industry 4.0; while also exploring domestic adaptation possibilities. I deemed necessary to explore the current development level of domestic construction industry companies, and to highlight the points that need further development in order to be available for the application of lean management in the logistic processes of domestic construction industry.

2.1. Primary data collection

As the first step of the national-level professional interview survey conducted between 2014 and 2018, I determined the main objectives of the survey, since the questions of the interviews had to be constructed according to these. The main objectives of the personal interviews were as follows:

- Exploration of the relationship between construction companies and their suppliers, as well as the present supplier structure. Concerning these relationships, it was an important aspect that as a result of the survey I would be able to determine, which relationship management model (transaction-oriented model, relationship-oriented model, strategic partner relationship) MORAUŠZKI - LAJOS, (2016) characterizes the domestic construction industry, since it basically determines how “just in time” could be applied.
- The survey should depict an accurate picture about order management processes. What systems and communication channels are used for sending the orders, what are the ways for confirming these, and are there any monitoring methods to verify the fulfilment of these orders. The survey had to provide answers whether domestic companies possess a standard system for managing and tracing their orders, and if the answer is no, are there at least certain elements of these available.
- In the course of the survey I had to identify, what kind of raw material management system domestic companies use at present. How the use of certain materials is

administered, how the registration process of these materials is conducted. The main question is whether domestic construction companies possess accurate data about their stock, and what is the level of reliability for these data. That is because if the existing stock data are not sufficiently reliable, neither “Kanban”, nor “just in time” could be included in the material supply processes, since both of these essentially require accurate data about the stock amounts.

- In order to make the supply of materials predictable, it is necessary to know the standard execution time period of different construction operations, since these standard time periods constitute the basis for the calculation of the predicted completion times of specific work processes, in other words, to estimate the pace of diminishment of certain raw materials. If these temporal data are present, their sufficient accuracy still needs to be tested.
- In order to schedule the supply of materials, the companies need to have a project plan with details on the level of operative operations, which is also revised time to time, thus making the project plan suitable to estimate accurate raw material demands in advance.

The next step was to determine the methodology of the interviews. Choosing the appropriate methodology for the interviews is essential regarding the efficiency of the data collection. There are three basic types of interviews that are typically used in the course of most research (NICKEY, 1995):

- Structured questionnaire survey, containing closed yes-no questions and classification requests.
- Open questionnaire survey, containing mostly closed yes-no questions and classification request, however, there are also some questions that provide opportunity for explicit, detailed replies. There is no way to deviate from the questionnaire, asking additional questions is not possible. (ROGERS, 2018).
- Exploratory professional interview that includes questions that provide opportunity for explicit replies, in which the respondents have the opportunity to explain their detailed point of view or opinion. These interviews are not closed, there is an

opportunity to ask additional questions, if the interviewer deems it necessary. (NICKEY, 1995), (GUBRIUM et al., 2012).

In the course of the preliminary industrial surveys conducted in 2012 and 2013, it became evident that most of the terms included among the objectives are unknown for the majority of the industrial participants, thus I had to exclude the questionnaire survey methods, because of the risk that due to their lack of knowledge, the respondents would not have been able to provide appropriate answers, and asking additional questions would have been necessary. Because of the above reasons I decided to conduct exploratory (personal) professional interviews, which provided the opportunity for me to receive in-depth knowledge about the processes and the development level of the given company, and according to this knowledge I became able to decide whether a certain company is fit for the given criteria. An exploratory professional interview provides the opportunity to ask additional questions, and to explain certain questions further occasionally, which I deemed as necessary concerning the respondents' low level of proficiency in lean management.

Following the establishment of the objectives of the survey, the next step is to determine the framework of sampling, namely to choose the construction companies that are worth visiting in the course of the survey, since the above described professional areas are relevant to them. In order to determine the framework of the sampling, I had to understand the structure of domestic construction projects. Following this, I have determined the sphere of companies that could constitute the sampling framework of the research, in which my criteria were based on the results of secondary data collection; in the determination of the characteristics of domestic construction companies, ÉVOSZ (Professional Association of Construction Companies) provided significant aid. In order to be able to generalize the replies of the surveyed companies, I had to conduct data analysis and check representative qualities, to confirm that the professional interview survey is representative, and I can establish generalized statements concerning the whole of the multitude. The interviews were conducted between 2014 and 2018, the reason for the length of this four-year period is that in order to have as many sample elements as possible, I pursued to interview the vast majority of relevant domestic companies.

At the same time, during the first round of market surveys, it became evident that a big part of the subcontractors only sign to execute certain partial tasks, exclusively providing

human resources and machinery; the management of raw materials is not a typical subject of subcontracts, thus in their case the completion of the survey is not relevant either. As international practices also imply, the management and handling of materials is only considered as a significant issue in case of greater projects, since in case of smaller projects, the participants are able to estimate the consumption of materials with appropriate accuracy, due to their professional experience; and also, in case of these projects, one man is enough to coordinate the different stages of the project. The survey is worth conducting in case of such companies that possess relevant experience concerning greater projects, since companies with only a couple of projects of major significance do not have well-established standards, as these processes are only in the stage of formation yet. In the Hungarian market of construction industry, a lot of participants do not maintain a decent market behaviour. Obviously, these companies are also not relevant regarding the survey, as their raw material management is also influenced by motivations induced by their dishonest behaviour beyond the usual market aspects, which would only distort the outcomes of my research.

As a conclusion of the above statements, a company can be included in the sampling framework of the research, if the following conditions are fulfilled:

1. The company not only oversees the coordination and delivery of the tasks, but also undertakes project integration functions in projects with more significant volume.
2. If the company is a subcontractor of the project, it not only provides human resources and machinery, but also attunes a relevant raw material assortment during the course of the project.
3. The company already coordinated several major construction projects (considering the present Hungarian market situation these are typically government-funded projects), so it has well-established processes for the systematic management of materials.
4. The company maintains a fundamentally honest business behaviour, namely, it has no such motivations induced by dishonest operations that deviate from classic market motivations.

In the quest for such companies, ÉVOSZ (Professional Association of Construction Companies) provided help, by presenting a list about the relevant companies, and also by helping to filter out those that are non-relevant. In case of companies with dubious

relevance, I decided whether the company fulfils the above criteria by a preliminary interview. According to this, 19 construction companies that actively operate in Hungary fulfilled the above conditions, so they constitute the sampling framework, or in other words the relevant multitude for my survey. The low number of companies can be explained by the fact that the recession significantly reduced the number of enterprises, and also by the quite small number of major construction projects. Out of the 19 companies, a comprehensive survey could be conducted in case of 15 companies; in two cases I did not receive sufficient information for the evaluation. Thus, the selection rate of my professional interview survey is 78.94%, considering the relevant majority.

In the course of phrasing the questions I took the two basic rules of interview making into consideration, which are as follows:

1. Do not ask questions that could affect the response of the respondent (suggesting questions) (ROGERS, 2018).
2. Do not ask for more than one information within a question (GUBRIUM et al., 2012).

Upon composing the list of questions, I paid special attention that the length of the interview would not exceed the critical time period of 60-90 minutes, after which the concentration and interest of the respondent could significantly decrease. (GUBRIUM et al., 2012).

After conducting the interviews, I have examined whether they qualify to be representative. The necessary number of samples is significantly lower at professional interviews than by questionnaire surveys (DWORKIN, 2012). The methodically necessary number of samples is determined by the so called “saturation” (MASON, 2010). Saturation means a point in the course of data collection, when it becomes evident that further interviews do not provide relevant new information in the data collection anymore (DWORKIN, 2012). I can establish that in case of the valid interviews, the majority of the replies were directed towards one quite specific direction; it is evident that there is an established development level in Hungary, which is quite homogenous especially at industrial level, thus the survey can be considered as representative. In the course of the evaluation of the interviews, according to the outcomes of the sample and the number of elements, I determined how much chance there is that the statistical sampling does not represent the multitude properly. Concerning the implementation of pull principle material supply, I have established 5 criteria, and based

on the replies, I determined, how much chance there is, that there are any individuals in the multitude, whose characteristics diverge from the outcomes of the sample. If the chance of expected discrepancy from the observations of the sample is very low in the surveyed multitude, than in case of a sample without any discrepancies, and a certain level of reliability we can establish that there is no diversion within the given multitude (LOLBERT, 2004).

Certain questions of a professional interview survey are not yes-no questions, but ones with multiple outcomes, often the difference between outcomes means only small elements. In order to promote statistic evaluation, in the course of evaluation I used Likert scale. The first step in the creation of the scale was to set the “best” and “worst” outcomes, based on preliminary industrial surveys and international studies; these constitute the two endpoints of the scale, and then I determined the categories between these, while paying special attention that in accordance with the even bin values, the developmental increase between the categories would also represent even values (KEHL, 2012).

I have classified each company into one of the categories according to their responses received from the interviews, and then I evaluated the received data according to the scale values.

Concerning the received values, I have determined the multitude variance, which shows the extent of the different characteristics of the replies (BAKER et al., 2016). If the value of multitude variance is lower than the critical value, the multitude correspond with normal distribution, and according to the average value and the multitude variance, global conclusions can be drawn concerning the multitude (BAKER et al., 2016).

The affected companies required total anonymity in order to undertake the participation in the survey, thus in the course of the evaluation of the outcomes neither their name, nor their exact replies can be revealed.

Following the analysis and evaluation of professional interviews, according to the outcomes I determined the lean tools and elements whose initiation I wanted to examine in practice. Due to the size and the temporal limitations of the dissertation I did not have the opportunity to deal with the initiation of the complete lean toolset. According to the observations drawn from the survey, I appointed the joint initiation and investigation of pull principle material

supply and Last Planner System. Besides, another objective was to examine the use of Industry 4.0 in the logistics of construction industry.

I had the opportunity to initiate, as well as investigate the effects of pull principle material supply and Last Planner System at two, characteristically different construction companies. In 2018-2019, within a time period of 15 months, lean management was altogether initiated in 6 projects. During practical implementation, I have established the following objectives of investigation:

- To determine the necessary organizational conditions for the efficient use of lean management, with particular respect to the creation of project structure.
- Create a management system for Last Planner System and pull principle material supply at the two different companies – I developed a management application concerning the projects in MS Excel environment.
- Investigation of the effects of Last Planner System upon the accuracy of project plans, and to see whether its use can reduce temporal delays.
- Investigate the effects of the application of pull principle material supply upon the construction industry supply chain, as well as on the extent of the supplies stored at the construction premises. Investigate the effects of the initiation of Kanban system, determine the conditions whose fulfilment is necessary to reduce stock sizes in domestic construction industry.
- According to the observations regarding their initiation, creation of a model concerning the adaptation of integrated pull principle material supply and project planning into domestic construction industry.

2.2. Secondary Data Collection

The objective of secondary data collection is to organize the international observations and outcomes that are linked to the introduction of pull principle material supply in the logistics of construction industry. I have conducted the secondary data collection from 2010; until nowadays, using the most recent research outcomes; at the beginning I exclusively focused on the application of lean management, but from 2012, I concentrated on the use of lean management in construction industry and in its logistic processes.

The steps of secondary data collection:

1. Exploring the introduction of the tools that promote the adaptation of pull principle material supply in the logistics of construction industry. The goal is to decide, which tools could be adapted in construction industry logistics. Concerning the tools that prove to be applicable according to preliminary observations, the purpose of data collection is to establish what kind of conditions need to be fulfilled, or what kind of limitations are necessary for the efficient use of the given tool in the logistics of construction industry.
2. The next objective is to classify the practices and case studies that are available for the joint application of these tools. According to the related outcomes and introduction methodologies, the goal is to find the model in which these tools can be applied most efficiently in the field of the logistics of construction industry. It is also necessary to determine the exact field of the application for the given tools.
3. One of the main characteristics of the logistics of construction industry is the work is project based, thus similarly to processing industry, appropriate connection between production planning and material supply is indispensable for the execution of pull principle material supply. In the logistics of construction industry, the compliance of project planning methodology and its connection to material supply processes is essential for the execution of pull principle material supply. Following the allocation of the most suitable project planning method, it is necessary to sort out, how the connection between project planning and material supply was implemented in the previous case studies, whether there are any application models regarding this, and these models could be improved further.
4. The organized knowledge and the developed model highlighted the areas whose development is necessary for the efficient adaptation of pull principle material supply in the logistics of construction industry. In my research, I highlighted some possible technical solutions that fit to the principles of INDUSTRY 4.0, concerning the areas in the need of development, thus the objective of the last phase of secondary data collection is to present the technologies – including their possible areas of application – that can help in the development of the above areas.

The fundamental objective of secondary data collection is to organise the previously achieved international outcomes, and according to these, to draw conclusions concerning the necessary limitations and constraining conditions for the application of pull principle material supply. How certain system parts need to connect to each other, how can the integration of project planning and material supply be implemented? Beyond the most recognized internet-based publication databases (Science Direct, Web of Science, és Google Scholar), the representative status of the secondary data collection was provided by the detailed analysis of the presentations of the Lean Construction Institute (LCI) annual conference, that was created to promote the application of lean in construction industry. LCI incorporates all of the international authorities of scientific life who pursue to integrate lean into construction industry, therefore their annual conferences include the introduction of the latest professional results.

3. THE MAIN DEDUCTIONS OF THE DISSERTATION

3.1. The highlighted outcomes of the primary research

Therefore, according to the above listed objectives, in the course of primary data collection between 2014 and 2018, I conducted professional interviews consisting of 60 questions, at the companies that were chosen according to the previously mentioned conditions. Each of the interviews were done personally. Following the completion of the interviews I aimed to investigate the introduction of the “just in time” and the “last planner system” in practice. I have implemented the initiation of the “just in time” and the “last planner system” in case of 6 projects at two Hungarian construction companies. A partial objective of the projects was to investigate the effects of initiation on other processes at the company; on the other hand to make estimations in order to create the comprehensive model of pull principle material supply based on the observations concerning the initiations. I summarize the main observations and outcomes of the survey and the initiations below:

Concerning sub-contractors I can establish that concerning the selection of suppliers, the decisive factors are price and reliability, thus the participants typically have a transaction-oriented model on their mind. The regression-caused decrease in the number of suppliers made the construction companies realize that a supplier who they can cooperate with in a reliable partnership, can mean significant advantage in the market competition, so they orient themselves more and more towards this strategic direction. According to the interviews I can establish that several partner-level cooperation start to take shape between users and suppliers in domestic construction industry.

According to the survey, the assortment of raw material used during construction projects is significantly lower than in processing industry; the replies imply that in case of line constructions, 20-30 different materials are used, while in case of structural constructions, there are 40-50 different kinds. The management of ordering processes can be implemented in a quite large number of ways, thus in the course of the survey of the current domestic practices I used Likert scale measurements (NEMOTO - BEGLAR, 2014). According to the preliminary estimations I have created five different categories. According to the value of variance I can establish that the sampling shows normal distribution, and according to the

received values I can determine that domestic construction companies do not possess a registration system that would be suitable for the classification of suppliers.

The raw material management systems that domestic construction companies use, significantly diverge, thus in case of their survey I used Likert scale, since this methodology is suitable for the management of different methods. An important criteria was that the number of categories would not be too high, thus I merged the cases that were identical concerning their effect on the material supply chain. I collected the possible material management methodologies according to international publications and the observations of domestic first-round surveys. The objective is to determine, in what extent do domestic construction companies possess an up-to-date stock management system.

Table 1.: Likert-scale categories used during the survey of stock management processes of domestic construction industry

Levels of stock management systems	Scale value
The received materials are registered in the management system retrospectively according to the bills, and they are immediately written off from the stock; thus the stock that is registered in the management system is constantly zero; there is no other management system	1
Besides registering and writing off materials in the management system, there are regular inspections to measure and register the stock that is present at the construction site on paper basis	2
Besides registering and writing off the materials in the management system, the received amount of materials is recorded, and during regular inspections, the stock that is present at the construction site is measured and registered. The recording of received stock is done in excel tables or on paper basis.	3
Besides registration and immediate write-off, the received amount of materials is recorded, and according to the actual daily implemented tasks, the amount of used materials, and the remaining stock is estimated; during regular inspections, the stock that is present at the construction site is measured and registered.	4
The received amount of materials is recorded, and the amount of used materials is either constantly registered, or there is a standard amount of material supply for certain work phases, thus according to the completed tasks, the daily material loss can be calculated. These transactions are recorded in a local management system, thus the site manager can see the size of the actual stock; however, on the level of the complete enterprise, the available stock of separate projects is not visible.	5
The received amount of materials is recorded, and the amount of used materials is either constantly registered, or there is a standard amount of material supply for certain work phases, thus according to the completed tasks, the daily material loss can be calculated. These transactions are recorded in a central registration system, thus the site manager can see the size of the actual stock; and on the level of the whole enterprise, the available stock for separate projects is also visible; enterprise-level stock management becomes possible.	6

Source: Respective edit

According to international case studies, out of the above defined 6 methodologies, only real-time local and global registration systems are able to support the introduction of “just in time” (PHENG - SHANG, 2011). Due to the significant inconsistencies that occur during construction processes, retrospective registration systems are not suitable for the execution of just in time transfers (PHENG - MENG, 2018). Retrospective local registration was only implemented at 13% of the companies participating in the survey. According to the value of variance, we can establish that the sampling shows normal distribution, and according to the survey we can establish that the registration of the stock that is present at the construction sites is very underdeveloped. Real-time, enterprise-level stock management was unavailable in case of all surveyed participants. In our country, the management of the stock stored at the construction premises is typically poorly developed; the amount of stock is assessed visually, which could be one of the reasons for the high level of material loss issues that characterize construction projects.

I can basically establish that domestic construction companies does not have time standards concerning the certain construction tasks. Most often they estimate the time consumption of certain phases according to their own observations. Concerning technological processes (fastening of concrete, drying, etc.) the companies have temporal data. None of the surveyed construction companies apply a fixed project planning methodology; regarding softwares, the image is quite diverse, there were respondents who use a project planning software specially developed for construction industry, some of them use Microsoft Project, and others plan their projects in Excel.

One of the main objectives of the survey was to investigate, how the software support of project planning – as the most important part concerning the logistics of construction industry – correlate with the observed exceeding of project completion deadlines. In order to be able to implement the investigation, I have organized the examined projects into clusters according to their applied project planning software support.

After the collection of the data I examined whether there is any significant diversion between the clusters concerning the extent of latency to the deadline. The first step was to create a box chart that depicts the extent of delay of the projects of the specific clusters in weeks.

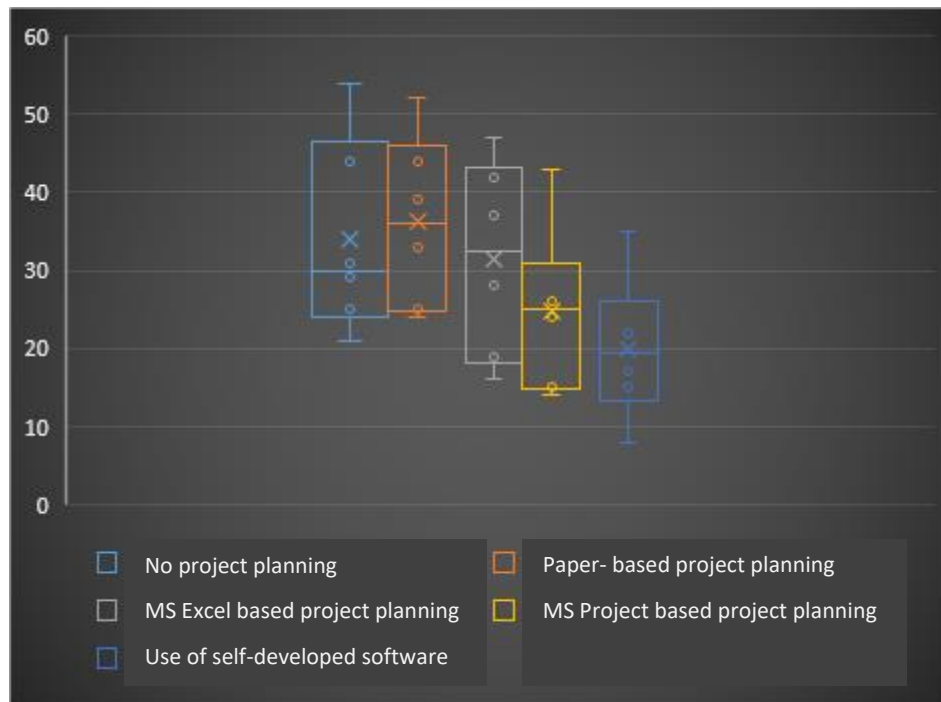


Figure 2.: The rate of exceeded deadlines of the projects in certain clusters in number of weeks; illustrated in a box chart

Source: Respective edit

On the chart, the rectangle-shaped box illustrates the value of 25 and 75% percentile data, while X marks the median value of the data in the given cluster. According to the diagram, I can establish that group 4 and 5 diverge significantly from the first three. In order to determine the significance, I have conducted the Tukey and Scheffe tests from the ANOVA – variance – toolset of SPSS software. Out of the two methodologies, the Tukey-test is the most often used method, having also less discrepancies; the Scheffe-trial is a more conservative method, which only shows significantly different cluster averages in case of large divergence (SAJTOS - MITEV, 2007).

According to the Tukey-test, the averages of the 4th and 5th cluster diverge significantly from the averages of the first three clusters, thus according to this test, I can establish that the use of specific project planning softwares significantly reduce the average value of temporal delay of the projects. In the course of the survey, the respondents who use such specific softwares, marked the upload of the data necessary for the use of the software as major difficulty. At the same time, the collection of these data could provide much more accurate project planning. In order to confirm the level of significance, I executed the more conservative Scheffe-trial too. This test also proved that the averages of the 4th and 5th cluster

diverge significantly from the averages of the first three clusters, thus according to these two tests, I can establish that the accuracy of project planning is significantly affected by the fact whether a specific software is used in the course of the planning of the projects. At the same time, I can also establish that there is no significant difference between the use of a respectively developed application and a general purpose software (in this case MS Project). Two respondents of the survey already heard about lean management, but they weren't able to define its principles and main tools. They did not know about the use of lean in construction industry. None of the surveyed companies plan to initiate lean management at present.

In the course of the interviews I determined which conditions are necessary for the initiation of “just in time” material supply in construction industry projects (Table Table 2., and which ones are currently fulfilled in case of domestic construction companies. During the investigation of the current situation, it became obvious that due to the constantly changing project locations, the “just in sequence” technology, which requires very closely located subcontractors cannot be adapted in construction industry, also, its use is only recommended in case of raw material assortment (WAGNER - CAMARGOS, 2011), thus I ruled any further research related to it. Contrary to processing industry, it is not necessary to reduce the number of suppliers in construction industry, but in order to initiate “just in time” it is indispensable to create partnership level cooperation, which according to the interviews have already started.

Table 2.: Conditions for the execution of “just in time” material supply

Nr.	Condition	Status
1.	Partnership-level cooperation with the suppliers	Done
2.	Standard ordering and tracing system	None
3.	Accurate, up-to-date stock registration system	None
4.	Creating time standards for the implementation of certain work processes	None
5.	Detailed and regularly reviewed project plans	None

Source: Respective edit

Prior to the interviews I determined the conditions for the use of “just in time” material supply in construction industry projects. I have basically determined 5 conditions that are necessary for the initiation of “just in time” in construction industry (Table Table 2.).

Table 2. shows that except for partner-level cooperation the rest of the necessary conditions for the initiation of “just in time” are missing in domestic construction industry. The greatest inadequacy can be traced back into two factors; on the one hand, the lack of stock management systems, on the other hand, although domestic projects have their own project plans, but these plans are neither sufficiently detailed, nor do they contain the detailed material needs of temporal stages; while these plans also lack continuous review in the course of the projects. An ordering system adapted into a standard integrated form is also an essential condition of the initiation of “just in time”, since in the absence of this, the accurate tracing of ordering history is impossible, although it would be important for the evaluation of the suppliers. The lack of detailed project plans can be basically explained by the lack of time standards, since if we cannot calculate the time consumption of certain work processes, the development of a detailed project plan also becomes impossible.

3.2. Pull Principle Material Supply in the Logistics of Domestic Construction Industry

Upon the analysis of international outcomes I can establish that the joint use of “just in time” material supply and LPS results in significant improvement in the field of efficiency (ANDERSSON et al., 1983) (LINDGREN - HJÄRTSTRÖM, 1985). A great advantage of the initiation of “just in time” in construction industry is that it prompts the participants to keep the deadlines (LI et al., 2017). I executed the initiation of Last Planner System and “just in time” in the course of 6 projects at two Hungarian construction companies. The objective of the projects on the one hand was to investigate the effects of the initiation upon other processes at the company, and on the other hand to provide support for the creation of the comprehensive model of the supply chain of pull principle system.

Last Planner System and “just in time” were initiated simultaneously, in a partially integrated manner; in case of both companies, the initiation of weekly level “just in time” proved to be possible, when the orders concerning the following week were determined in the course of the actual weekly planning. In case of the initial projects, the suppliers did not

take part in weekly discussions, but later on, the key suppliers of the projects were also included.

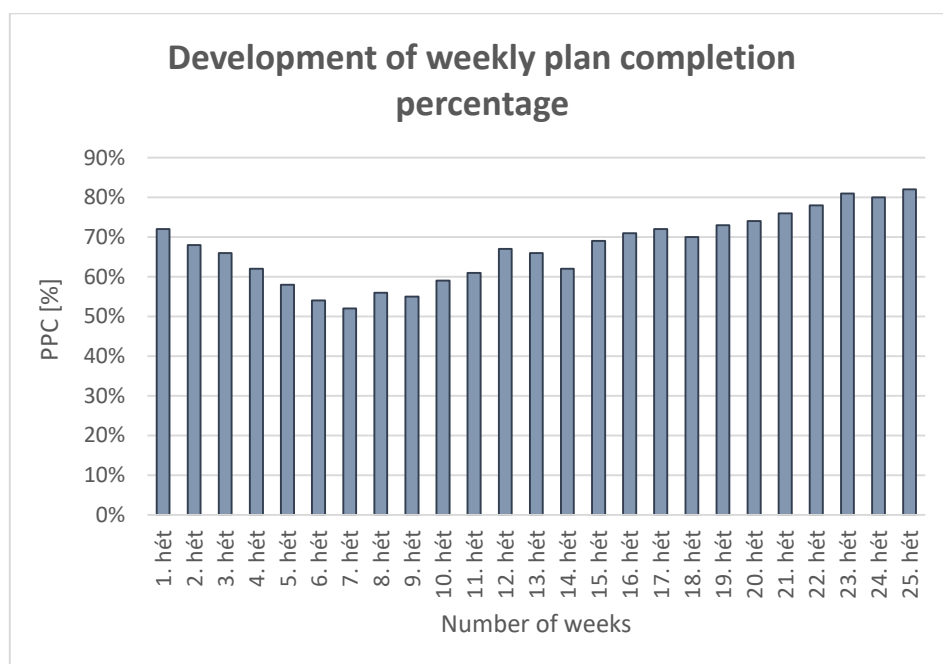


Figure 3.: The development of weekly plan completion percentage

Source: Respective edit

At the first company, the project that was the subject of the second initiation took almost half a year, thus the effects of Last Planner System could be investigated in long term. In case of each projects I observed an initial drop in project completion percentages (Figure Figure 3.). There was no way to use a purpose-specific software for the administration of Last Planner System and the “just in time” based orders at the companies participating in the initiation, so I created a MS Excel-based registry application, which I constantly developed. It was obvious however, that a huge amount of administration and communication was necessary, because the planning of the project, the registration of the orders and stock management could not be handled by an integrated system. I managed to draw the conclusion that for the initiation of pull principle material supply, an integrated informatics system is necessary.

Case studies (ARBULU et al., 2003; BURGOS - COSTA, 2010; PHENG - SHANG, 2011; LI et al., 2017) have shown that the use of Kanban system in construction industry can produce results that are similar to processing industry. Construction industry is a specific environment, so in order to function properly, Kanban techniques need a certain level of

modification; besides, international examples clearly imply that the Kanban system can achieve significant results upon integration into the LPS system (LI et al., 2017).

In the chosen project, Kanban system was initiated both for the handling of supply changes within the work area, and for the order of supplies, which I coordinated with the applied project planning methodology. The estimation of supplier Kanban amounts was conducted according to the needs established in the course of weekly planning.

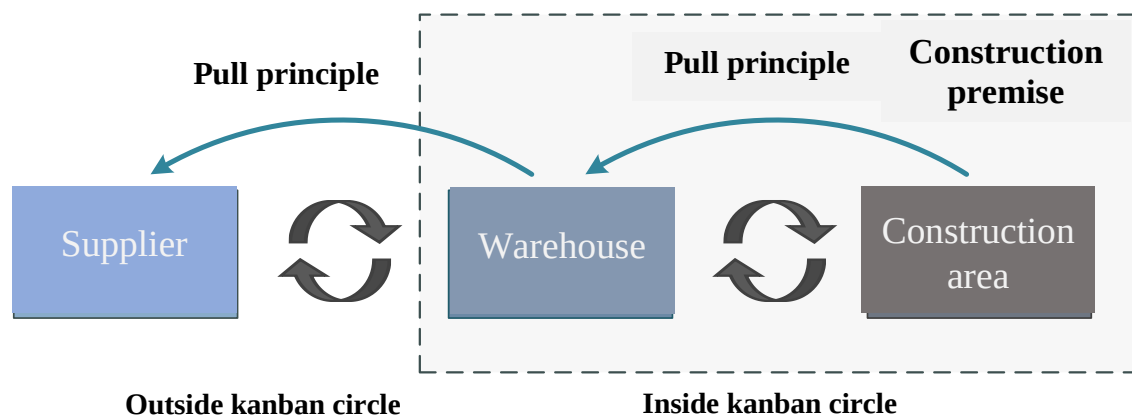


Figure 4.: The structure of the initiated Kanban system

Source: Respective edit

According to the observations of the initiation, I can establish that in order to initiate “just in time” system, the currently applied model of the supply chain in construction industry needs to be reconsidered. In spite of the high levels of stock, the initiation of pull principle material supply and its integration into the process of weekly planning reduced the level of stock stored at the construction site with 12%. Significant further reduction of the stock stored at the construction site without the increase of transportation costs is only possible by the transformation of the supply chain model.

My objective was the development of a supply chain model that facilitates the use of pull principle material supply in the logistics of construction industry. International examples show that the greatest obstacle in the way of the application of “just in time” is the large number of suppliers and their low reliability. As a result of this, from the aspect of supply chain, we can provide the necessary conditions for “just in time” by reducing the number of participants and increasing their reliability with the involvement of a third participant (Figure 5.). The use of logistic centres – in which the raw material ordered from various suppliers is stored and managed – reduces the inconsistency caused by the different

suppliers, and eliminates the accumulation of stock at the construction site. Typically, the materials that are generally used during construction projects (e.g. cement, bricks, mortar etc.) can be stored this way (ARBULU - BALLARD, 2004). It is worth to establish the logistic centre within half a day supply time, so it can significantly reduce the instability of transportation. According to several research, in case of larger distance, a significant buffer of stocks need to be kept at the construction site, because of the instabilities of transportation; within such distance however, daily deliveries are made possible (ARBULU - BALLARD, 2004). Of course, there are some raw materials, in whose delivery the logistic centres do not need to be involved. There are some technological reasons for this: for instance, in case of concrete or asphalt, the material is actually constructed shortly before use, followed by its immediate delivery. In my self-developed model, these materials are still delivered directly. The most significant novelty of my model is that by both at the deliveries to the logistic centres, and by their outwards deliveries I use scheduled round trips, thus establishing the regularity of the supply chain.

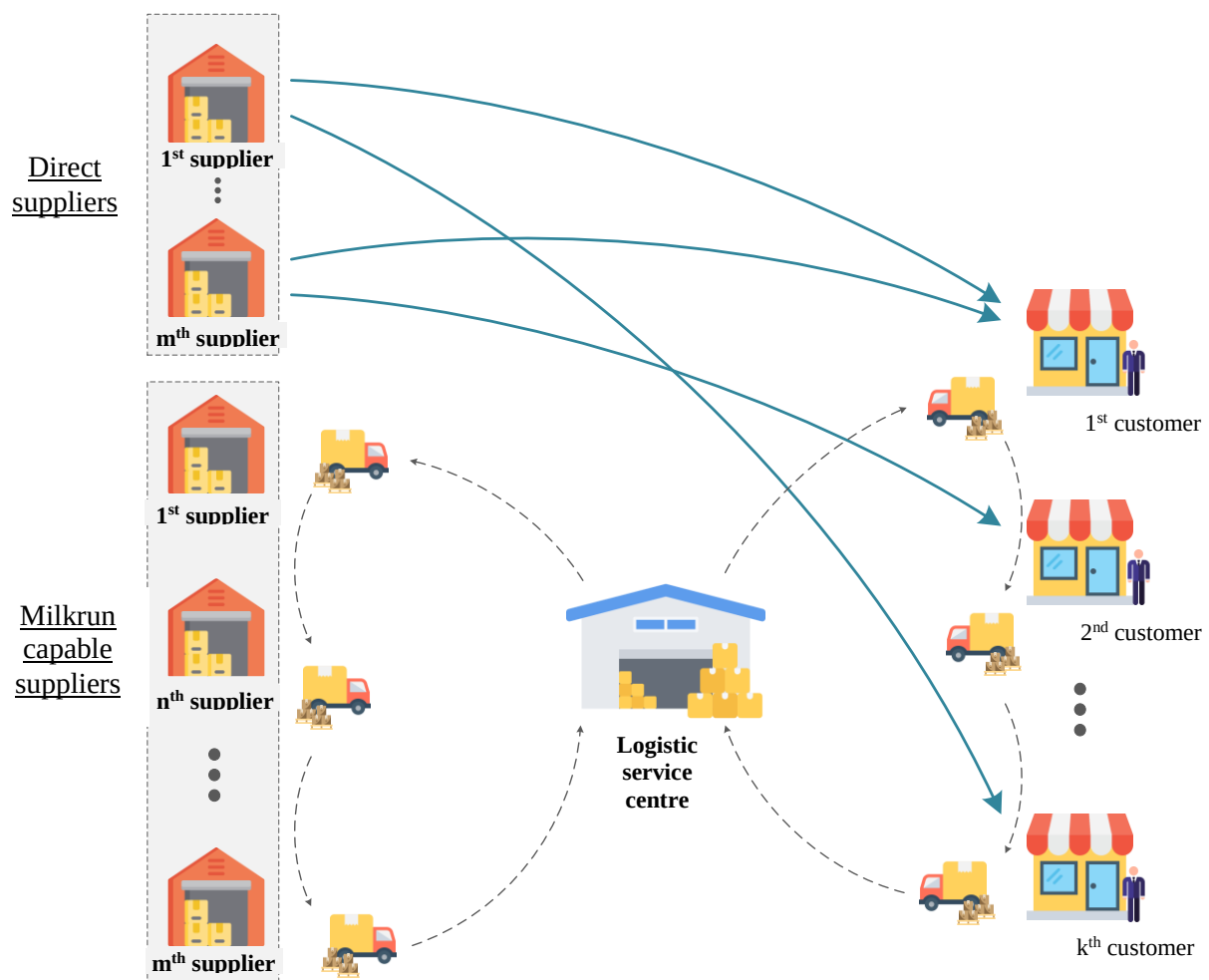


Figure 5.: The model of “just in time” capable supply chain in construction industry

Source: Respective edit

Close communication between the centre and the construction site is an essential requirement for daily deliveries. The implementation of pull philosophy is important, so only the deliveries that conform the real needs occurring at the construction site should be executed. It is apparent that the insertion of logistic centres is a macro-level development, thus it is only viable if several project exploit their benefits simultaneously, thus it is not sufficient to initiate this methodology by a couple of companies in a fragmented manner; the initiation of this new system requires a national, industry-level decision (SZTRAPKOVICS et al., 2014).

In international case studies, in the course of the use of pull principle material supply, the foundation was provided by the initiation of LPS, and the projects were exceptionally successful. However, they pointed out two remarkable deficiencies; on the one hand, the lack of real time stock management, on the other hand, the need for at least partially standardising the orders. In the course of the projects, the weekly plans visualised the expected needs, however, accurate stock sizes were not available, and thus the ordering processes could not be automatized. A possible way to standardise ordering processes is the initiation of Kanban system in the course of the acquisition of raw material. However, the Kanban system can only be inserted into the ordering processes of those raw materials, whose use is relatively constant, and encompasses a significant temporal part of the project (e.g. gravel, cement), these are so-called “Kanban-capable” products (SZTRAPKOVICS et al., 2014). In case of those ingredients that are only used for short periods of time in relation with a specific work process (e.g. specially constructed profiles), the Kanban system cannot be applied. I have created the model of “just in time” adapted to construction industry according to these. The model predefines the management of materials at three different levels, while fitting into the structure of LPS project management system.

The KanBIM system (Figure Figure 6.) is the most advanced project management software in construction industry with LPS support. In order to implement both “just in time” and kanban material supply in the KanBIM system, the extension of the system and the processes is necessary. At present, the KanBIM system mostly concentrates on the conditions of the initiation of certain processes, and on the resources that are necessary for the execution these processes (DAVE et al., 2016). For the adequate support of “just in time” and kanban principle material supply, the KanBIM system also has to cover raw material supply and the

management of ordering processes. Besides the extension of the system, process development is also necessary. The real advantage of the integrated system would be clearly visible, if the raw material needs would be generated automatically, following the implementation of weekly plans; and thereafter, following a manual confirmation they would be sent out to the suppliers. There are two necessary conditions for this: the accurate raw material need of the certain processes, and the possession of adequate raw material supply.

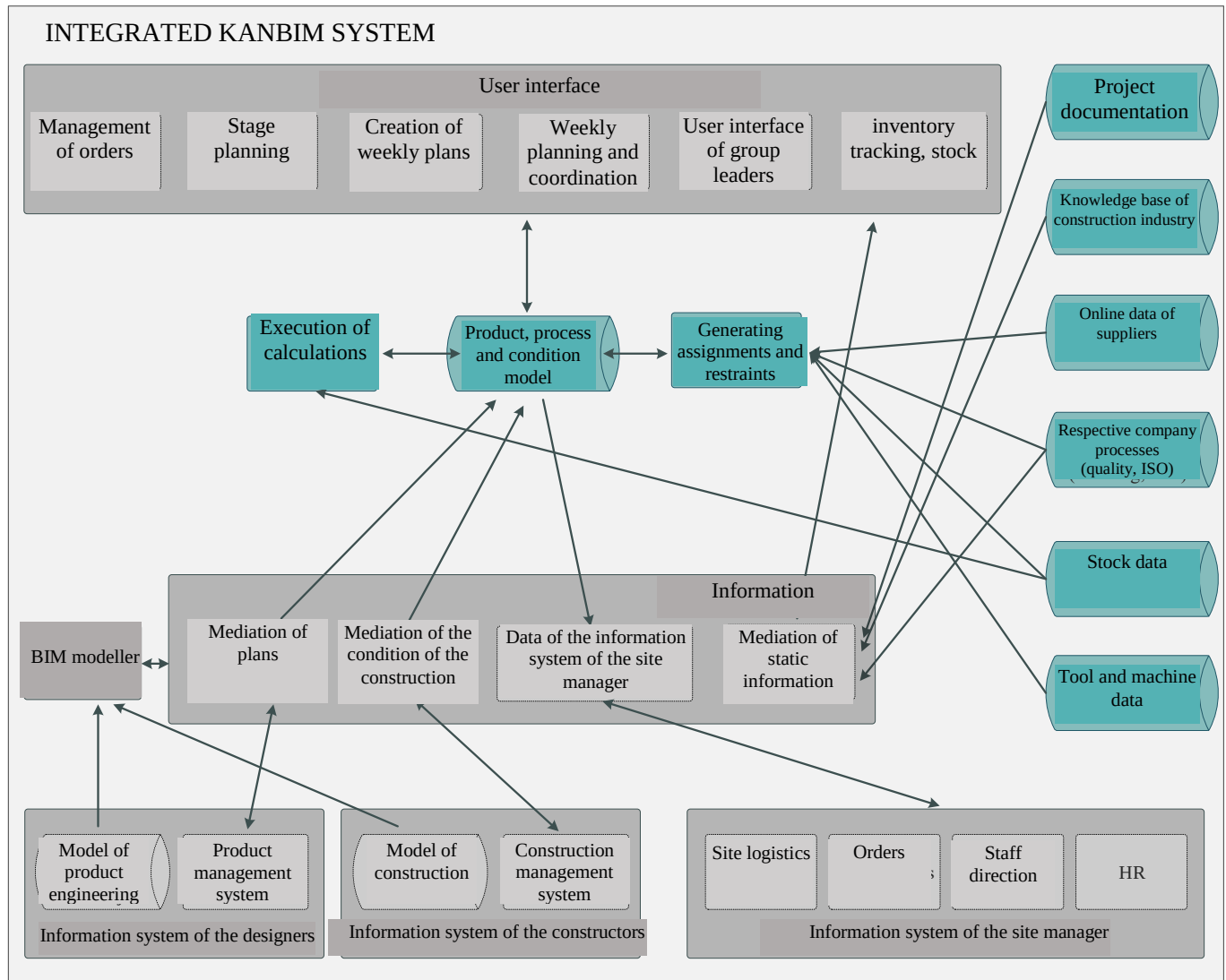


Figure 6.: The theoretical model of the integrated KanBIM system covering the complete system of company networks

Source: Respective edit

An important element of the integrated KanBIM system is that the stockpiling system is integrated into the software; in the previous practice the system did not take stock data into account, so it had to be separately monitored by the participants of the projects. I created a

model for the integration of stock data and ordering processes, as the above figure illustrates. Integration and data management could be facilitated by the creation of standardized product categories. An important foundation of the above model is the software-based integration of the partners, in other words, the suppliers could receive the information that is relevant for them much more easily, if they would have an access in the integrated informatical system. Beyond the integration of suppliers, their rating has to be continuously updated, and the outcomes of the rating should be integrated into the planning process; the development index should also contain the rating of the supplier (SACKS et al., 2010). In order to provide opportunity for the constant review of certain suppliers, the orders, their reception, and their fulfilment need to be continuously monitored and registered in the integrated system. If the registration of the temporal quantitative and qualitative fulfilment rate of the certain orders is integrated into the system, the reliability of suppliers becomes predictable in the course of each weekly planning, and this reliability can also be included in the development index.

According to the applications that are implemented in construction industry in international practices, it is apparent that image recognition has adequate application possibilities in various construction industry environments too. One of the significant fields of application for image recognition softwares could be the monitoring of raw material stock that is stored at the construction site (SZTRAPKOVICS - PATAKI, 2017). Image recognition systems can also be used for the estimation of the stock of bulk materials. There are already some pilot projects for the estimation of the volume of bulk materials at construction sites (SZTRAPKOVICS - PATAKI, 2018). As a result of the above facts, the subject of my investigation was the estimation of the volume of bulk materials by the use of image recognition tools. My objective was to develop a solution that is simple, accurate, practical, and economic at the same time, since with these qualities there is a chance for its widespread application. In the course of my experimental project, I pursued to determine the volume of gravel and sand. The difference between the value calculated by the help of image recognition and the weighed value in case of sand was 6.7%, while in case of gravel 9.4%. Calculating with 95% reliability, in case of sand in 81.8% of the measurements, and in case of gravel in 62.5% of the measurements, the system remained between the predefined minimum and maximum values. It is apparent that the amount of raw material supplies

located at the construction site can be estimated by the use of image recognition systems with sufficient accuracy.

4. CONCLUSIONS AND SUGGESTIONS

In this chapter I summarize the main objectives and hypotheses of my research, as well as the major conclusions related to these. The basic statement of my dissertation according to international specialized literature and to my own research: Besides the processes of construction industry, the implementation of lean management that was very successfully applied in processing industry is also possible in the logistics of construction industry; its use results in significant increase of efficiency concerning each member of the supply chain of construction industry, while at the same time facilitating pull principle material supply

I test the pertinence of my basic hypothesis with the previously established objectives, and with the secondary hypotheses based on them.

C1. Comparison of the processes of construction- and processing industry according to their level of development; identification of the reasons of efficiency-related differences, and the analysis of the effects of different industrial characteristics upon work processes.

The first step of my research was to identify the fields of divergence between construction industry and processing industry. In the course of my research I basically established that the most significant cause of the divergence is the project-based nature of construction industry. In my dissertation I sorted out the concordances and differences between the two industry sectors, thus I accomplished this goal.

C2. Allocating construction industry logistics as a field of profession, identifying its characteristics, collecting the main objectives and functions of the profession, and the definition of construction industry logistics according to these informations.

Following the detailed investigation of construction industry and processing industry, I focused my research on the logistics of construction industry. At first, I have investigated the supply chain of construction industry, considering the characteristics that depend on the location of the construction. Following this, I examined the organisational manifestations of the logistics of construction industry. According to my research, the definition of construction industry logistics can be established as follows: management, organisation, planning, and verification of material flow at the construction site, including its joint logistic processes, within certain temporal, local, financial limitations.

C3. Classification and analysis of the case studies and specialized literature that describe the application of certain tools of lean management in the field of construction industry and following the evaluation of the outcomes, determining, which tools could be applied efficiently in the logistics of construction industry.

I created two hypotheses in relation with this objective. H1 hypothesis is as follows: *Despite the significantly different characteristics of construction industry and processing industry, the lean methodologies that are successfully used in processing industry, could be effectively adapted in construction industry too, considering certain limitations and particularities.* Upon the overview of international specialized literature, my research confirm that lean management can be successfully applied in the logistics of construction industry. According to international specialized literature, and my respective research, **I consider my first hypothesis as confirmed.**

Regarding my third objective, I established another hypothesis, since besides the use of lean toolset, the reduction of logistics-related environmental impacts also have an increasing importance. H2 hypothesis is as follows: *The initiation of lean management into construction industry can reduce the environmental impacts of construction projects in a significant extent.* In my research, in parallel with investigation of the applicability of lean in the logistics of construction industry, I have also sorted out the possibilities that could reduce environmental impact by the initiation of lean toolset. In case of some lean tools I also investigated special methodological modifications that focus on environment protection, as well as their practical applicability in the logistics of construction industry. The specific environmental impact of construction industry is much larger than the one caused by processing industry, and it is apparent that the initiation of lean management is also able to reduce “green deficit” beyond normal deficits; according to this I can establish that **I also consider my second hypothesis as confirmed.**

C4. Overview of project-planning methodologies and their available software support, analysis of their practical applicability through case studies, allocation of development directions.

In my dissertation I introduce Last Planner System, which is a project planning methodology developed in parallel with the application of lean in construction industry. International case

studies confirm that the application of lean tools can exploit the adequate savings potentials, if Last Planner System is also initiated. The most recent research already consider the initiation of Last Planner System as a fundamental part of lean construction industry. According to the case studies presented in the course of my research it is apparent that the application of Last Planner System with appropriate software support can significantly reduce deficit, while the number of delayed executions observed in construction projects also decreases.

C5. Overview of the current situation of domestic construction industry, on the one hand in regards of major economic processes, on the other hand from the aspect of the current development state of the supply chain; by the help of the outcomes of the survey, deciding whether domestic construction companies are fit for the initiation of lean-based material supply methods at present.

Following the examination of international research, I investigated the possible implementation of international observations and best practices into domestic industry sectors, and I established the following hypothesis regarding this: *H3. A comprehensive industrial survey of domestic construction industry sector and the execution of the projects of practical initiation helps to confirm that the industry sector needs development in several areas, both on industrial (supply chain) level, and on the level of the development of factory processes before the introduction of pull principle material supply.* In order to confirm the above hypothesis, between 2014 and 2018 I conducted a questionnaire survey among the larger companies of domestic construction industry. My research revealed that because of the layered structure of the projects and the highly concentrated nature of the domestic market, the questions concerning material supply are only relevant to a quite small number of companies. I was able to comprehensively survey 15 companies, in two cases I was only able to conduct partial professional interviews, however, I have to add that because of the above mentioned reasons, there are only 19 companies in Hungary that substantially provide material supply for larger projects too, thus the initiation of pull principle material supply could have any relevance for them; therefore the survey can be considered as representative. According to the interviews, I defined 5 necessary conditions for the initiation of pull principle material supply, 4 of which are not fulfilled in case of domestic construction companies. Following the survey, in 2018 and 2019 I initiated Last Planner System and pull

principle material supply at two domestic enterprises. In the course of the initiation it became clear that the integration of these methodologies cannot be executed completely, due to the current development level of informatical systems and the characteristics of the supply chain. According to the above observations **my third hypothesis is confirmed.**

C5. Overview of the current situation of domestic construction industry, on the one hand in regards of major economic processes, on the other hand from the aspect of the current development state of the supply chain; by the help of the outcomes of the survey, deciding whether domestic construction companies are fit for the initiation of lean-based material supply methods at present.

The largest opportunity for the increase of efficiency in the logistics of construction industry is provided by the application of lean principle material supply methodologies. I can establish that at present the supply chains of construction industry operate on the basis of traditional push principles. According to specialized literature as well as to my respective research, I established that the efficient application of “just in sequence” in construction industry is not possible, while the use of “just in time” can result in significant savings. In case of two domestic companies, pull principle material supply was initiated, which resulted in a significant decrease in the amount of stored supplies. However, for a more efficient application of “just in time”, the supply chain of construction industry needs to be reconsidered, thus on the basis of my research I created the “just in time” capable model of the supply chain, whose application can reduce the risks caused by the low levels of stock while transportation costs do not increase significantly. According to international observations and my investigated domestic examples it is apparent that by the initiation of “just in time” and Kanban, raw material stocks, commodity losses and operational costs significantly decrease, however, the examples also made it apparent that the existence of up-to-date project plans is a fundamental condition for the successful application of “just in time”, while practical applications revealed that in order to keep project plans up-to-date, adequate software support is necessary. An increasing number of functions supporting Last Planner System started to appear in the software basis written for construction projects; these software typically included stock management functions too, however the joint application of these functions as an integrated system was not executed yet. In the course of my research I investigated the possibility of the integration of these two functions, in order to facilitate

automatic stock management in connection with the execution of the certain work processes, I confirmed the outcomes of this methodology with the outcomes of a Danish research, and then I created the informational model of the integrated system.

C6. Initiation of lean-based material supply methodologies in the logistics of domestic construction industry, overview of previous case studies, and according to the observations of domestic initiation, revealing the application possibilities of these tools at the level of the supply chain.

The verification of stock levels is also necessary even if material supply is linked to project planning, due to the significant variance resulting from the characteristics of the industrial sector. My last hypothesis is: *Stock management and ordering, as well as material usage measurement functions could be efficiently integrated into the project-planning methodologies applied in lean construction industry and its supporting software basis, thus facilitating real-time stock management. Temporal stock controls can be executed automatically by the use of intelligent tools, according to the guidelines of Industry 4.0. The implementation of pull principle system facilitates the use of “just in time” philosophy, thus significantly reducing the amount of stock kept at the construction premises.* I have created the informational model of the integrated system, which could increase the efficiency of the necessary administration processes for pull principle material supply. In my dissertation I introduce the modern image recognition software that facilitate the adequate estimation of stock levels without manual measurements, these methodologies are also already applied in construction industry in a pilot-like manner. I have executed the measurement of the volume of bulk materials by the aid of image recognition software, according to manual measurements and the weighing related to stock return transports I can establish that the volume of bulk materials stored at the construction premises can be determined with adequate accuracy by the help of image recognition software. In my research I emphasize that by the use of drones these systems could be even more adaptive, which is an important aspect in case of construction industry that operates on project principles. In conclusion, according to the created model, practical examples and technological innovations **I confirmed my fourth hypothesis.**

5. NEW AND NOVEL OUTCOMES OF THE DISSERTATION

The investigation of the applicability of lean management in construction industry was not conducted in Hungary yet, so my research can be considered as a domestic novelty. International researches mostly investigated the initiation of lean management into the direct processes of construction industry, concentrating less on the logistic aspect of construction industry. In my research I investigated the initiation possibilities of lean management into the logistics of construction industry, which basically is a new direction in this subject. A new outcome is the allocation of the logistic development level of domestic construction companies, and also the establishment of the conditions for the initiation of pull principle material supply, and the allocation of the possible results of the initiation through six practical projects; and the survey-based assessment of the already fulfilled conditions at domestic construction companies. The new and novel results of my dissertation are as follows:

E1: I executed the allocation of construction industry logistics according to specialized literature and my respective research, analysed the supply chains of construction industry, and established the definition of construction industry logistics. I assessed the development level of the logistics of domestic construction industry, determined the 5 conditions for the execution of pull principle material supply, and by the help of interviews I sorted out, which of the above conditions are fulfilled in case of domestic construction companies.

E2: I investigated how the observed environmental impacts of construction projects could be reduced by the use of lean tools in the course of the logistics of construction industry. On the basis of practical examples of application I further developed the methodology of green approach value flow in the logistic processes of construction industry.

E3: According to the observations concerning the initiation of pull principle material supply at domestic enterprises, I investigated the possibilities concerning its application in the supply chains of construction industry, and its expected effects upon work processes. On the basis of my research I created the “just in time” capable model of the supply chain, whose application can reduce the risks caused by the low levels of stock while the significant increase of transportation costs can also be avoided. In my dissertation I established the methodology of the application of “just in time” in construction industry, the methodologies

for the material supply of different types of products, as well as the integration of these methodologies into Last Planner System.

E4: I have created the model of integrated KanBIM system, whose essence is that beyond the support of project planning and material management the system also integrates these functions, which facilitates real-time stock management with significantly less resource requirement.

E5: I investigated the applicability of image recognition software in the course of the measurement of the volume of bulk materials stored at the construction premises. According to my practical investigations I can establish that image recognition software are able to assess the volume of bulk materials with adequate accuracy.

6. PRACTICAL EXPLOITABILITY OF THE RESULTS

I conducted my research and created my dissertation with dual purpose. On the theoretical side, I created a research basis for the application of lean management in construction industry and especially in its logistic processes. I have collected and published the major international results and observations in Hungary, and by their further improvement, specifically focusing on the logistics of construction industry, I developed the model that facilitates pull principle material supply. My research, my publications and my dissertation also contribute to the widespread execution of the domestic research that is necessary for the initiation of lean management in construction industry, thus to the establishment of the so called “lean construction industry”. My results and my publication constitute a foundation for the initiation of further domestic research, and one of my future objectives is to establish the Hungarian member organisation of Lean Construction Institute, thus joining into international bloodstream. One of the main objectives of the research was the development and modernisation of academic materials, in the course of my research I already integrated several elements into the curriculum of the subjects that I teach. An important objective is that further outcomes of my research would be adapted in academic education curricula, thus the students would have the opportunity to discover the most recent international methodologies, as well as the practical and research outcomes.

Regarding practical application, my objective was to assess the development level of domestic construction enterprises, with special focus on the aspects concerning logistics and the supply chain. The objective of my survey was to highlight the areas that domestic construction enterprises need to develop in the future, on the one hand to facilitate the initiation of lean management in the logistics of construction industry, on the other hand to facilitate the initiation of pull principle methods in the supply chains of construction industry too. According to the outcomes of my survey, it is apparent for the construction enterprises, which areas need further development. By the development of these areas, by the initiation of software solutions and process models that are already successfully applied in international practice, domestic construction companies can significantly increase their efficiency. Domestic construction enterprises did not know about the possibility of the application of lean management in construction industry. In the course of my research I initiated certain lean management tools at two domestic enterprises, and upon highlighting

the areas of necessary further development, domestic companies also have the opportunity to set their foot on the path of improvement. As both my survey, and practical observations confirm, there are significant development opportunities in domestic construction industry, which can lead to the increase of efficiency. Construction industry is a highly relevant part of national economy, thus the improvement of the competitiveness of domestic construction industry enterprises is a special interest of Hungary, in order to make them able to compete with their foreign rival companies. In the course of my research I confirmed that image recognition systems can be efficiently used in the logistics of construction industry.

An important element of my dissertation is the development of the supply chains of construction industry, and the initiation of pull principle material supply in construction industry too. The network- and informatical models that I created in the course of my research, facilitate the development of the supply chain of construction industry. A key issue for the efficiency of the industrial sector that the effectiveness of the value chain would significantly improve, become more competitive, and apply the methodologies that are successfully adapted in processing industry, decades ago. Due to its locational characteristics, Hungary possess an important position in the logistic network of the European Union, that is why our country have the chance to become the main centre of the supply chains of construction industry.

7. PUBLICATIONS WRITTEN IN THE SUBJECT OF THE DISSERTATION

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Registry number:

DEENK/225/2020.PL

Subject:

PhD Publikációs Lista

Candidate: Balázs Sztrapkovics

Neptun ID: RAM843

Doctoral School: Károly Ihrig Doctoral School of Management and Business

MTMT ID: 10050780

List of publications related to the dissertation

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The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of Web of Science, Scopus and Journal Citation Report (Impact Factor) databases.

09 July, 2020

