Summary

The Value Stream Mapping (VSM) approach has originally been developed for the automotive industry for series production with limited variant number. Many case studies show the optimization of processes using the VSM methodology. The traditional VSM approach was extended to be used in single-part and small batch production with high diversity of products and variants in the manufacturing industry. The new approach was called Value Stream Engineering (VSE).

The case study presented in this paper was executed within the joint research project “build4future”, which is managed by the Fraunhofer Innovation Engineering Center (IEC) in Bolzano (Italy). The mentioned research project is composed of 12 small and medium sized enterprises (SMEs) situated in the province of Bolzano. The main target of the cooperation project is to optimize the process inside the enterprises as well as an integration of the value chain in building projects, targeting shorter lead times and lower costs without losing on quality and individuality.

To this goal the case study aims on evaluating a standardized methodology for analysing and redesigning processes in the construction industry by means of a supply chain analysis for window installation. This standardized methodology consists of an adapted VSE approach to the needs of the construction sector. For the case study a project scenario has been chosen consisting of a hotel with an overall building cost of around 3 Million Euros and with 120 windows to be installed. The current processes for the glass supply, the window manufacturing and the installation on site were mapped using the VSE methodology. In addition, lead times of different processes were registered. As a result, interfaces between the supplier, the manufacturer and the installation on site were studied in detail identifying sources of waste in the construction supply chain.

In traditional construction projects wrong materials on site are the main concerns of project supply, causing losses in construction quality or large material stocks creating high fixed costs. Therefore, in the case study based on the current state analysis, an innovative methodology for an efficient supply, manufacturing and installation of windows on site will be presented. The concept developed in the case study is different from the prototypical applications of “Lean Thinking”
concepts in construction up to now, because it is worked out in an integrated manner. This means that the coordination on site is integrated in the internal process optimizations of the involved companies.

As a result, a standardized methodology is shown, which serves as a best practice for analysing and optimizing every process in the construction industry using the VSE approach. Furthermore, four guidelines are presented, which should allow to design and align the supply, manufacturing and installation of different crafts to the building site.

1. Introduction

The South Tyrolean building sector is well known for its innovative and high quality standard. It is one of the key industries for the local economy. However the building industry is composed of small and medium sized companies that struggle the price competition in a globalized market. Therefore the research project “build4future”, which is currently managed by the Fraunhofer Innovation Engineering Center (IEC), was launched to build up a platform, composed of twelve companies from different businesses in the construction industry. The target is to develop an industrialized, integrated and intelligent approach in planning and construction method to help each project member sustaining and strengthening its market position.

“Build4future” is organized as a cooperation project between South Tyrolean construction companies and research institutes like Fraunhofer IEC, the Free University of Bolzano, TIS innovation park and the KlimaHaus Agency. Facing problems of different sectors in the same industry by different research partners allows an integrated view of the whole process.

In South Tyrol labour costs are relatively high and enterprises do not have a strong negotiation power to reduce them. So, the only way to influence costs is to work on reducing waste in processes. Traditionally, construction companies focus on their core competences and only a few years ago they started to consider redesigning process flows to reduce waste [1]. The main goal of the project “build4future” is to optimize the value chain in construction in order to get lower costs and shorter lead times without losing on quality. Hence, the existing processes of the partner companies were analysed using the Value Stream Engineering (VSE) approach. On the basis of the current processes, the applicability of lean concepts derived from other industries, for example the automotive industry, were considered and their adaptability on the construction business were studied. In addition, process models were developed to make these concepts applicable to wider project scenarios. The case study validates some of these concepts on basis of a supply chain analysis for window installation.

2. The Value Stream Engineering Approach

“The construction industry still continues to under-perform, generally due to a continued lack of design and construction process integration, a lack of focus on quality and customer value, poor contractual relationships and a general lack of understanding as to why poor performance continuous or how improvements might be achieved” [2]. Thus, a methodology has to be provided, which visualizes in detail the different processes occurring during a construction project. The Value Stream Mapping (VSM) approach as described by Rother and Shook in [3] has not been diffused in the construction industry. In fact, few case studies exist, which only show the optimization of sub-processes introducing Lean Production methods to construction. The interaction between different stakeholders is analysed only superficially without a systematical approach. This leads to the consideration that the VSM methodology introduced by Rother and Shook is not suitable for studying processes with high diversity of product typologies and variants, like in the construction industry. Therefore, the Fraunhofer Institute for Industrial Engineering (IAO) developed a further evolved and adapted version of VSM, which is called Value Stream Engineering (VSE). This methodology allows to design work-processes with embedded Make-to-Order Process chains. “VSE contains a toolkit with design options, process templates and methods for design of a firm specific industrial engineering approach in enterprises with customer driven work processes” [4]. This methodology describes the process in a holistic way, which means that it starts with the order
from the customer and finishes with the delivery of the final product or service to the customer. So, all participants in the planning, production and logistic process are included. Furthermore, the process chain is represented by a flow graph starting at the customer order and ending at the delivery to the customer. In conclusion, interfaces to downstream or upstream process stages can be depicted in detail, identifying sources of traditional problems in construction supply chains.

In this case study, an adaptation of the VSE approach to the construction industry will be presented.

3. Process analysis

Based on a problem analysis carried out within the project “build4future” in traditional construction projects wrong materials on site causing losses in construction quality, or big material inventories creating high fixed costs, emerged as main concerns of project supply. Therefore, in this case study, the optimization of management and control during construction execution will be described in detail. The supply chain is composed of a tier one supplier and a tier two supplier. The tier one supplier delivers his products to a building site for assembly. In the following paragraphs the current state of this window installation supply chain will be studied. The supply chain of the window manufacturer was analysed because of its significant participation in total building costs. Production and installation of windows constitutes around 10% of total building costs [5].

The analysis starts with the tier 2 glass pane supplier continuous with the tier 1 window manufacturer and finalizes with the installation of the windows on site. After a brief description of each company, the suppliers’ processes are analysed using the VSE approach and a connected lead time analysis is worked out. Due to confidentiality reasons the names of the considered companies are not shown.

3.1 Process analysis of the glass pane supplier

The company produces multifunctional insulating glasses. More in detail, it doesn’t fabricate the glass by itself but it purchases prefabricated glass panes. The core business of the enterprise is in the building sector. There, it acts in a business to business supply chain, where the customers are window manufacturers, carpenters, facade constructors and interior furniture manufacturers (joiners).

The VSE-map is shown in Appendix A. First of all, the information flow, which is shown with thin lines, is explained:

- The window manufacturer sends a customer order which is acquired in the order processing centre.
- Afterwards, the order is forwarded to the job scheduling department, which plans the used machines and the time necessary to produce the requested order numbers. Moreover, it determines a list for tailored glass panes which should have the task to minimize the offcuts. This means that from one raw glass pane different production orders from different customers are tailored. In a next step, the job scheduling department forwards a production order to the production planning department which splits the assignment in sub-orders and arranges the time scheduling for elaborating the capacity planning. Finally, the production planning department sends a purchase requisition to the purchasing department which organizes the needed materials.

In the following paragraph the material flow is explained:

- The glass panes are delivered directly to the glass inventory which is installed into every automatic cutting cell. Due to the great handling effort a quality control before the storage is not done. The production process is triggered by the enterprise resource planning (ERP) system. The first process stage of the company consists of cutting the glass panes. Next, the tailored glass panes are commissioned and stored in an intermediate buffer. This intermediate storage is needed because the tailored pieces have to be rearranged/ resorted according to the different customer orders (Fig. 1).
- In a next step, the tailored and sorted glass panes are transported manually to the insulation glass line. Within the insulation glass line, firstly, the glass panes are seamed, secondly they are washed and afterwards an automatic quality control by a so called quality
Contemporarily to the previous process steps the glass pane frame is prepared. To ensure a sufficient cover of glass pane frames the company uses an intermediate buffer with the size of one shift. After this process stage the glass panes pass through a second automatic quality controller. In the last stage of the insulation glass line, an automatic sealing takes place and after this stage one employee moves the insulated glass panes from the production line to so called A-rack charge carrier. The finished glass panes require a drying time of 1 working shift. In conclusion, the A-rack charge carriers are then commissioned and stored in the warehouse for shipping to the customer.

In Figure 2 the lead time analysis was performed based on the VSE-map. The glass pane supplier works with two shifts, therefore one time interval corresponds to one shift (Fig. 2). Firstly, at the proposal process stage the sales division gets a request for proposal and in collaboration with experts an offer is forwarded to the customer. Secondly, in the process called “Customer” the insulation glasses are produced and delivered to the client. This process has a delivery time range of 1 to 8 labour days. In Fig. 2 it is evident the small amount of value adding time of 0.5 days (Cutting, Insulation), and the large amount of time consumed by the order processing centre (50% of the delivery time).

The identified types of waste can be described as follows:

- **Long lead time in the order processing centre**: the lead time of the order processing centre amounts at 4 days, which corresponds to 50% of total lead time. This because every order passes through the order processing centre, causing queues, even if a technically feasibility is not necessary.
- **High work in process and long searching times**: The intermediate buffer used for rearranging the tailored glass panes (charge carrier) contains an average duration of one shift. In other words, the buffer is used not only for sorting the tailored glass panes, but as an intermediate storage too.
- **Production is pushed**: The glass pane supplier processes large batches of items and moves them from the cutting cells to the insulation glass line. Moreover, the bending line for glass pane frames produces an amount required for one shift in advance regardless of the actual pace of work in the insulation glass line.
3.2 Process analysis of the window manufacturer

The company manufactures primarily wooden and aluminium windows. In addition, it supplies and installs front doors, roller shutters, window shutters and fly-screens. The company has 25 sales consultants in the north and in the middle of Italy and 15 assembly operators, to install the products on the construction site.

The VSE-map is shown in appendix B and the description is divided in 4 sub-processes.

Proposal stage process: The customer of the window manufacturer is usually an architect or the owner of the planned building, who generates a request for proposal (RFP) to the sales department. The sales people record this RFP, using a configurator, and forward it to the sales management department which controls the price and the technical feasibility. If the sales management approves the RFP, the vendor generates an offer and forwards it to the client.

Project-contract award process: If the customer approves the offer, the vendor forwards the conceptual plan to the job scheduling department. Afterwards, a non-definitive production order is forwarded to the production planning department. In this department, the resource planning and the production sequence planning is done in a backward analysis. The production planning department fixes a target completion date and books the needed production time in the ERP-system. Furthermore, the production planning department organizes the supply chain. Consumable supplies, like aluminium profiles or iron fittings are stored in the stock receipt of the window manufacturer. “On-demand” supplies like front doors are delivered directly to the commissioning zone of the window manufacturer. Glass deliveries are not stored in the stock receipt though, whereas they are delivered directly to production, i.e. to the assembling line.

Window subframe manufacturing and installation: When the shell construction of the building is completed the contact person of the construction site (the architect, the construction supervisor or the owner) contacts the vendor by a phone call. Then, the vendor goes to the construction site and takes the detailed measures of the structural opening, which means the allocated space for windows, roller shutters or front doors (Fig. 4). With this information, the job scheduling department configures the computer aided manufacturing (CAM) data to steer the machinery park. It is only now that the window subframes can be produced. At the same time the job scheduling department places an order at the assembly schedule department for the installation of the subframes on the building site. Furthermore, the assembly schedule department places an order at the installation team for mounting the subframes on the building site (Fig. 3).

When the window subframes have been installed the vendor goes to the construction site and takes the exact measures of the installed subframes. Now, the vendor scheduling for the computer aided manufacturing (CAM) forwards the exact measures to the job data to steer the machinery for producing the final windows.

Window manufacturing and installation: The windows are produced in the plant of the window manufacturer according to the booked date of the production planning department, which is explained in the project-award contract process stage. The production start is set by the ERP-system of the window manufacturer. The window production process is done in a flow line. In the last manufacturing step, which is called “Glass Pane Assembly” the glass panes are installed in the casement (Fig. 4). The glass panes are delivered on A-rack charge carriers directly to the final assembling line. The manufactured windows are packed to special...
charge carriers and sorted according to the different building sites. This is done in the commissioning zone of the manufacturing plant. Finally, the windows are transported from the production site to an intermediate stock.

For the final installation at the building site, the site manager contacts the assembly scheduling department which places a pick order in the intermediate stock, where the windows are stored. Furthermore, it places a supply assignment to a local freight company to transport the windows to the installation site. Finally the assembly schedule department places an order to the installation team for assembling the windows on the building site. The value stream map is shown in Attachment B.

Lead time analysis (Fig. 5): As explained before, the case study consists of a hotel with an overall building cost of around 3.0 M€ composed of 120 windows and one front door (external door). The proposal process stage has an average duration of six days. The manufacturing and installation process stage of window subframes has an average duration of 15 days. When the window subframes are produced, the site manager takes the measures for the window production and for the ordering of external doors. Only at this time, the ordering of external doors and the manufacturing of windows can commence. This process stage is called “Purchase and production windows” and it has an average lead time of 48 days.

External doors are delivered directly to the commissioning zone of the window manufacturer where they are commissioned with other products, like windows etc., for the delivery to the intermediate stock. The window production is booked by the ERP-system in a backward analysis with the aim to have the produced windows and the supplied external doors at the same time in the commissioning zone. The windows are produced in one batch which allows a production lead time of four days. External doors are outsourced and have a lead time of seven weeks. Therefore the supply process of external doors is the pacemaker for the entire process. The commissioning of windows, external doors or roller shutters has a lead time of four days. Sometimes, a defective glass pane is found only when the windows are commissioned. Therefore, the window manufacturer considers a time buffer of four days, which corresponds to the average reordering time of glass pane supplies. In this case, the quality of glass supplies influences directly the lead time of the entire process. The final process stage “Window installation” takes place with a lead time of 18 days.

The identified types of waste are described as follows.

a) Production is not connected to construction: Manufacturing is triggered by the ERP-system, and therefore the order penetration point (OPP) is placed too early. This means that the trigger point for a customer order is set too early and so a just in time (JIT) deliver to the construction site is not possible.

b) Insufficient quality from glass supplier process stages: The glass supplier company produces and delivers with an error rate ranging from 0.5% to 2%. Therefore, the window manufacturer has to consider a time buffer of four days in the commissioning zone. This means that the reorder time for the replacement of a glass pane has to be considered. It extends the window lead time.

c) Large handling effort of glass panes: The glass supplier delivers the panes in a sequence according to their dimensions, from small to large. Therefore, the window manufacturer has to rearrange the glass pane order within the final assembly process. This leads to high searching
and handling efforts, which represent waste activities. More than 50% of the work needed for the glass installation is spent for searching and sorting [5].

3.3 Process analysis on the construction site

When the shell of the hotel-building was completed, the window subframes were installed. In the next process stage the wall plastering was done and afterwards the windows were installed on the basis of the subframes (Fig. 4). In this case, the painting of the internal and the external walls was done after the window installation. The site manager of the window manufacturer acts like a project manager in the traditional definition. Normally, he visits the construction site up to four times. The first time, he takes the measures of the allocated spaces for windows, roller shutters and front doors. The second time, when the roller shutters or the window subframes are delivered to the construction site the site manager instructs the window installer about technical details. The third time when the window subframes have been installed, the vendor visits the construction site and takes the detailed measures of the installed subframes. As mentioned before, the detailed measures are forwarded to the job scheduling department for preparing the machinery park. The fourth and last time, when the windows are installed, the site manager visits the construction site for the acceptance inspection with the owner.

In the following paragraph the installation on site is explained in detail: 1) the windows are delivered on special charge carriers to the construction site; 2) the provisionally covering in synthetic material is removed from the structural opening; 3) the window subframe is cleaned with a brush; 4) a sealing gasket is plastered on the frame; 5) a silicone stripe is plastered onto the subframe; 6) the frame is mounted based on the subframe and the single side hung casement is latched into the frame (Fig. 6). In conclusion, the window has to be adjusted and a silicon stripe has to be plastered into the fugue between the frame jamb and the wall inside and outside the building. After 5 to 6 months a final setting-up of the installed windows has to be done by the window installation team.

The identified types of waste are:

a) **Wasting quality assurance in the construction process**: The masonry process (upstream process stage) delivers insufficient accuracy in the wall construction – structural opening. The disadvantage of a subframe system is that small dimensional tolerances of the structural opening are allowed. If the sales agent does not take the measures (2 times) on site, the window subframes or even in the worst case the windows have to be reworked on the construction site.

b) **High amount of work due to low quality of upstream companies**: The insulation and the plastering process are not carried out according to the specifications. This means that the finishing coat is spread over the window subframe. Moreover, the insulation cover is plastered over the window subframe. The window installation team has to clean up the subframe which corresponds to non-value adding activities.

c) **Weak coordination of window installation – high work in process**: The site managers have the authority to decide when the windows should be mounted on the construction site, trying to push the window installation. Therefore, the windows are often installed too early, which causes damages deriving from other companies.
4. Approaches for process optimization

On the basis of the previous analysis optimization approaches are discussed. Every optimization corresponds to a problem listed in the previous section.

4.1 Optimizations for the glass pane supplier

a) **Optimization of the information flow:** The glass pane supplier works with two different categories of customers. One customer group orders products with special requirements, whereas the other one orders standardized products, where a technical feasibility is not necessary. The window manufacturer has concluded a master agreement with the glass pane supplier. Therefore, the order from this type of customers can enter directly in the job scheduling department bypassing the order processing centre (Appendix C). So, the average lead time of glass pane supply will be reduced from 8 to 4 days (Fig. 10).

b) **Reduce work in process:** In the current state, after cutting/tailoring of glass panes an intermediate storage is used. The main objective of this buffer should be rearranging/resorting the tailored glass panes according to the different customer orders. The average lead time of this buffer consists of 1 shift. The reason of this high work in process is that the buffer consists of two different parts. One part is composed of semi full charge carriers, whereas the second part contains charge carriers with complete customer orders. In this case, the flow is disconnected by the intermediate buffer. In order to reach a continuous production flow, only the buffer for sorting the tailored glass panes is needed.

c) **Link production with construction:** According to the authors Rother and Shook production must be planned just at one point of the value stream. Moreover, in the future state the pacemaker should be driven by the external customer orders [3]. This guideline was adapted in the development of the future state, where the trigger from the construction site enters directly into the first process step which stands for tailoring the glass panes.

To achieve a pulled production from the construction site, the insulating glass frame production system should be optimized. The bending, threatening and preparing process has to be integrated into one production cell. In the current state the ERP-system triggers the tailoring process and the bending process. Otherwise in the future state, only one trigger starts the production line.

To reach a production flow, in the future state the cutting cell triggers directly the bending production system by sending a scheduled assignment. More in detail, the cutting cell delivers information about which customer order is completed first, according to the cutting list. Therefore a just in time delivery of insulating glass frames to the insulation glass line is possible.

In conclusion, the cutting cell stands for the pacemaker process. As shown in Appendix C glass pane production is triggered directly from the building site. This allows eliminating demand amplifications upstream the value chain.

4.2 Optimizations for the window manufacturer

a) **Link production with construction:**

At the moment, the window manufacturer books the production start by the ERP system. More in detail, the production end of window manufacturing is set at the same time as the delivery of front doors or roller shutters. Thus with the aim that outsourced product groups can be commissioned with manufactured windows without unnecessary storages. Therefore, in the current state the supply of front doors sets the pace for the entire system. On the other hand, in the future state the supply of front doors is disconnected from the window manufacturing, because Production on Demand (POD) components are delivered directly to the site. In this way, the commissioning is moved from the factory to the construction site. So, the supply of POD-components and the manufacturing of windows can be steered in an independent way (Fig. 7). This allows to trigger the production in the first process step, and the material can pass from the pacemaker
process downstream in a continuous flow. As a result, in the future state production will be triggered according to the construction progress. More in detail, in the future state two different production triggers are considered. The first interface stands for smaller building projects, where the building crafts are not synchronized with each other. In this case the production is triggered as before. The second production trigger is set by so called Weekly Last Planner Meetings with the aim to align the production start with the construction progress. In this case the production order is acquired in the same way as before, where the site manager forwards the technically information to the order processing center which controls the technically feasibility and organizes the supply chain of needed material or components. The difference in this case is that the production is not triggered by the ERP system but from the construction progress on site (Fig. 8).

b) Introducing charge carriers which allow a loading JIS (Just-in-Sequence):

In the future state, the glass pane supplier delivers the requested glass panes according to the production succession of the window manufacturer. The window manufacturer organizes the production sequence according to an optimized installation on site. The existing charge carriers don’t allow a loading in JIS due to structure problems and therefore the glass pane supplier developed a prototypically charge carrier (Fig. 9).

4.2.1 Optimized lead time analysis

In the case of the window manufacturer, the commissioning zone and the intermediate stock could be eliminated. In the future state the task of the production planning department was replaced by the triggering point derived from the construction site. After receiving the measures of the installed window subframes the job scheduling department prepares the machinery data CAD/CAM for the production facility and organizes the supply of POD components (i.e. glass pane supply). The manufactured windows are transported directly from the manufacturing facility to the construction site. As mentioned before, the window manufacturer works particularly in the north and in the middle of Italy, and therefore one day was considered for the transportation. In conclusion, three calendar weeks could be reached for the production and installation of windows (Fig. 10).

4.3 Optimizations on the construction site

a) Design of a reliable construction progress: First of all, the building has to be subdivided into construction phases with separate processes. In Fig. 11 the Pitch-Lane defines the labour content in every construction phase for every involved company. In the manufacturing industry this is called “Pitching”. In this context one Pitch means the work content for one craft per week in a specified Pitch-Lane (construction phase).
The foreman on the building site was replaced by weekly “Last Planner” meetings. In these meetings the foreman of the window installation team, the manager of logistics and installation and the foreman of the masonry should participate. Every three weeks a so called look-ahead plan is elaborated, where the work content of the window manufacturer and the glass pane supplier will be defined. In this context, “Pitch” means the work content for one craft per week in a specified construction phase. So, as shown in Fig. 11 a lean thinking methodology which is called “One-Set-Flow” can be introduced. During the first week, in Pitch-Lane A, the glass supplier delivers an amount of 30 glass panes. Next, during the second week the window manufacturer produces 30 windows with the glass supply of the first week. Simultaneously, the glass supplier can produce glass panes for Pitch Lane B. During the third week the window manufacturer installs the windows on site produced for construction phase A.

This methodology should be repeated for every construction phases (A, B, C, D). “One-Set-Flow” means in this case, that the total delivery of 120 windows is subdivided in 4 construction phases each composed of 30 windows. So, one set of 30 windows flows from the glass supplier to the construction site.

b) Continuous quality assurance: As mentioned before, during the weekly “Last Planner Meetings” the foremen of every participating craft discusses problems in the current week and at the same time an update of the weekly working plans is done. So, these meetings have a dual function: 1) by updating the weekly working schedules a reliable construction progress is reached. 2) at the same time a quality control is done. More in detail, if the upstream companies don’t fulfil their work according to the specifications, during the weekly “Last Planner Meetings” rework assignments are given to the concerned crafts. In other words, the window manufacturer is allowed to access the site, until when the building project is ready for the installation of subframes or for mounting the finished windows.

5. Generalization and Standardization

In this paragraph, first of all, design rules for efficient customer oriented value chains will be described. In a second step, the identified process template developed for a better coordination of the involved companies will be presented.

The suggested design rules are:

a) **Let the customer order flow**: Identify the pacemaker process in the current state and separate it from other processes. Moreover, set the first manufacturing step as the pacemaker process. In the future state, the external customer order should trigger directly the pacemaker process. Upon this point, the production order should flow in a continuous way.

b) **Connect the order penetration point with the construction site**: In the automotive industry the Order Penetration Point (OPP) means a process stage where customer neutral production assignments transition to customer related production orders. In the case of the window manufacturer, the OPP was set too early in the current state and therefore a stock for finished goods is used. In the future state, the construction site should trigger directly the production of upstream suppliers.

c) **Connect value chain participants avoiding intermediate stocks or buffers**: In the current state, two different control loops exist for the window supply chain. One supply loop is set from the site to the window manufacturer and the second one from the window manufacturer to the glass pane supplier.
Otherwise in the future state, the delivery of glass panes and the manufacturing of windows are triggered directly by the construction site. In this case not only the production of windows is connected with the site but also the production and delivery of glass panes. Therefore, if delays occur on the building site, product buffers don’t arise in the intermediate processes.

d) **Control a process chain in one place:** The whole process, from glass supply, to window manufacturing to the installation on site is controlled in one point. This is done in the weekly last planner meetings, where the Plan Percent Complete (PPC) value is measured. So, production orders can be released to upstream companies according to the real construction progress on site using just one control point.

The mapping of a holistic construction process has to be highly flexible and adaptable in terms of product and process as construction firms are not able to operate on basis of a fixed target process because of the changing customer requirements from one project to the next [7]. Therefore, for every construction project the ideal coordination process is different. Using the VSE approach a customized integration of different lean process templates should help to develop an ideal coordination process with a minimum of effort. In the case study a process template for optimizing management and control during construction execution was developed, where concepts from Lean Production and concepts from Lean Construction, like the “Last Planner System” were used (Fig. 12).

**Build to Order (BTO):** The producer builds products entirely to confirmed order rather than to forecast [8]. This should eliminate the demand amplification, registering the data back upstream the value chain. In the case of the glass supplier and the window manufacturer production starts until when the construction site is ready for installation.

**Just in time (JIT):** As shown in Fig. 8 production is pulled from the building site, allowing so to eliminate intermediate stocks. To synchronize the glass supply with window manufacturing and installation, “Pitches” have to be defined. As a result a continuous flow from the glass supply to the installation on site can be reached.

**One set flow:** Producing and moving a small and consistent batch of items at a time through a series of production steps as continuously as possible. In the case of the window supply chain a batch of 30 window panes is moved from the glass supplier to the window manufacturer, which moves than 30 windows to the site. This allows reducing drastically the lead time because a parallelization of the glass supply, the window manufacturing and the installation on site is possible.
6. Conclusion and Outlook

The concept developed in this case study is a new approach, which adapts well known concepts from the automotive industries to the construction industry. In the case study, three different processes of the window supply chain were analysed with the VSE methodology where an adaptation to the construction industry was done. Processes like the acquisition of new orders (service processes) or the measuring for the final window production (production trigger) were added to the VSE toolkit. Furthermore, process lead times of the current states were registered. On the basis of the current state analysis optimizations were identified and applied within the case study. The coordination on site was integrated in the internal work processes of the involved companies. As a result, the identified concepts were standardized. A process template including the mentioned optimizations was developed which can be used by other companies in the construction industry. Moreover, four guidelines for an efficient customer oriented value chain usable for every construction supply chain were discussed.

It can be concluded that the VSE methodology can be adapted for analysing and optimizing construction processes. To match the supply chain with the building site, the construction process and the mentioned “Last Planner” Meetings need to be studied in detail. This sets the goal for the future research activities within the “build4future” project framework.

7. References


Appendix A Value Stream Map Current State glass pane supplier