Industry 4.0 – Implementation of an automated assembly line in a wooden modular house production plant: The case Leko Labs

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Abstract

Nowadays, housing building industry is getting used to off-site construction for its high-quality standards, short production time and minimal environment impact. Panelised construction, as one of the different type of off-site construction, is based on the approach to manufacture wood panels that constitute the skeleton of the house. Due to the customization and complexity of each housing project, existing manufacturing concepts, as automated production planning and control systems are not suitable for the facility production of panelised housing.

The aim of this paper is to design an automated manufacturing plant, suitable to assemble modular wooden panels, using the concept of Industry 4.0. In the first part, an accurate analysis of the different wooden panels has been made to highlight the critical parameters that affect the assembly process. After a standardization of the product, making it more suitable for the calculation of production time, every element of the panel and the assembly process have been analysed and optimized to achieve the best compromise between quality and suitability for an automatic assembly process. With all the product requirements defined, possible automated assembly solutions have been found out and analysed. Only the most reliable solution has been chosen, implemented and optimized in the 2D layout of the facility to check its suitability. Therefore, the final version of the automatic assembly line has been 3D designed and simulated in order to be shown in a manual panelised production facility operated by Leko Labs, a wooden modular housing builder in Luxembourg.

Keyword: Industry 4.0, Automatic Assembly, wooden panels

1. Introduction

The company Leko Labs produces wooden panels for panelised construction. Each panel consists of a combination of wooden slats with two types of insulation, distributed over a set of layers rotated by 90° each other. At this moment, the manufacturing assembly for these products is completely manual, managed by a couple of operators.

Automated processes are desirable because, in most cases, they decrease manual labour requirements and increase through-put, while also maintaining a high level of accuracy. Leko Labs must design and produce a wide range of different wall panels to accomplish the customization and complexity of each housing project. Each panel is customized according to various design parameters such as length, height, number and dimensions of slats, windows and doors. These design parameters affect the assembly process time and make the process in need of a high level of flexibility.

This project addresses their issue with the goal of designing an automated assembly line, by incorporating the idea of Industry 4.0, which would make possible the assembly of each different panel by meeting the annual target production requested by Leko Labs. This paper also concerns itself with the analysis and optimization of the product and the assembly process to make them ready for automation.

2. State of the Art in Modular Construction Industry

The most common panelised wooden construction like CLT (Cross Laminated Timber) or MHM (Massiv-Holz-Mauer) have a manufacturing process spread over different assembly stations. The frame of the panels and both insulations and vapor barriers are processed in different steps, that make the assembly process hard to be completely automatized. Moreover, factories usually have three subcomponent lines: floor, walls and roofs. For this reason, the production is generally carried out in very extensive semi-automated factories, where automated machineries are just used at some workstations. Since, these ones, are not inter-connected, the presence of operators is essential to manually load, unload and start the machines. Therefore, due to the specific design and assembly process of this kind of panels, the level of automation is relatively low in modular home manufacturers [1]. Flexibility is reduced, and significant customization of the product is difficult to be achieved.

3. Methodology

The objective of this project is to develop an automated assembly line, which will be implemented inside Leko's facility, can easily assemble each typology of Leko panel, in accordance with budget and production rate, above established. As shown in Figure 1, the methodology used to figure out a possible solution, consists on the following processes: (1) analysis of product and assembly process; (2) the data collected is used to figure out a possible solution of the problem; (3) validation of the proposal in accordance to the project requirements; (4) if the draft meets all the project requirements, the most suitable automated assembly line is figured out and ready to be shown to the company; (5) if the solution does not fit with the project requirements, optimization of the product and the assembly process is carried out, data collection is updated and the loop starts again.

4. Product and Assembly Process Analysis

4.1 Product Analysis

Deriving from technologies like CLT or MHM, Leko Labs, after years of research has developed its own technology based on assembly of crossing wooden slats thanks to a mechanism of triangular interlocking grooves [2].

As shown in figure 2, the structural element of Leko panel is made up by layers of wooden grooved slats, that are jointed together, in each intersection, by a combination of form fit (due to the spikes) and press fit (thanks to four self-tapping screws).

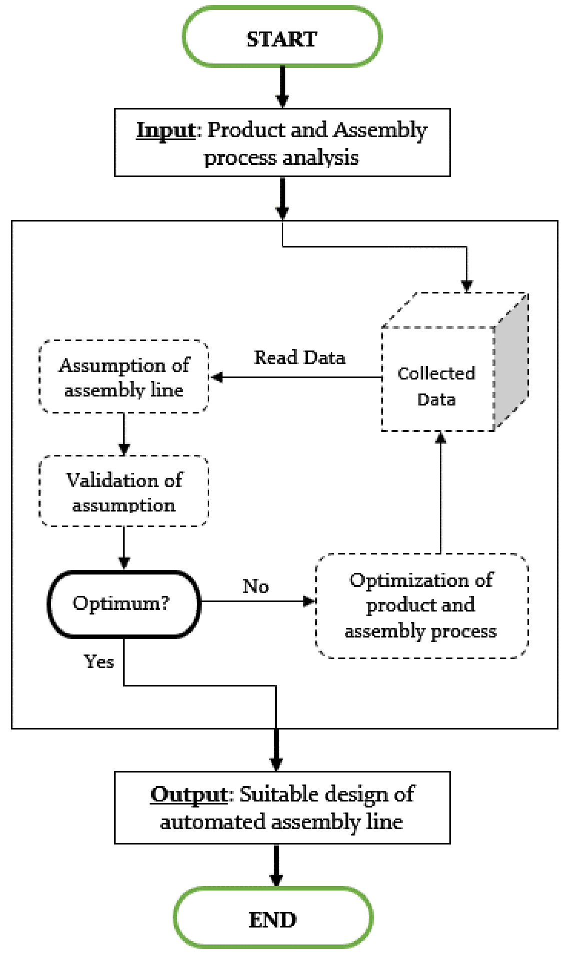

Figure 1 – Methodology

Figure 2 - Leko Panel, structural element

Each panel can be up to 6x3 meters of surface and can consist of 3-5-7-9-11 layers (from 105 mm to 377 mm thickness) depending on its application (internal or external wall, floor or roof). The odd layer number is due to keep the external and internal layer with the same orientation for structural reasons. Unlike CLT and MHM, where isolation role is internally made only by wood, each Leko panel layer is composed by both slats and insulation panel. After the finalisation of the structural element, vapour barriers are applied internally and externally to preserve the panel from the atmospheric agents. Therefore, an inner grid layer of non-machined wooden slats is applied internally to allow the installation of wires and pipes during the construction on site. Externally, on the other hand, thicker insulation panels are added to improve global thermal properties.

As shown in figure 3, each panel is composed essentially by five elements: *Slats, Inner Grid Slats, Vapour Barriers, Internal Insulations* and *External Insulations*.

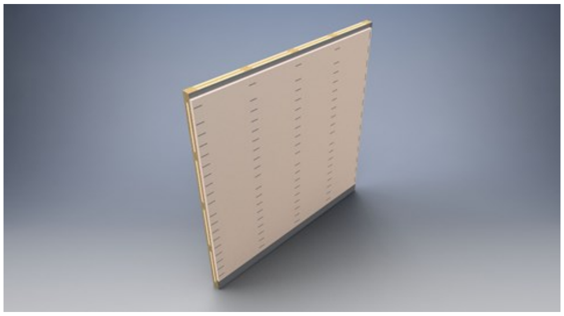

Figure 3 - Leko Panel CAD model, Complete assembly

4.2 Product Standardization

Due to the customization and complexity of each housing project, it is almost impossible to be in need to produce two very similar panels. Furthermore, inside one house project itself, the initial client project must be converted into wooden structure using Leko panel technology. This causes, even more probably, that two panels don't have similar shape and characteristics.

Since each panel may have or not windows or doors, also panels with the same number of layers and same surface may have a different number of elements (slats and insulations) and number of intersections (number of screws to be put in place), that make even more difficult the possible estimation of the assembly time. Therefore, critical parameters, that affect the product can be summarize as follow:

- *Number of elements (slats, internal and external insulations);*
- *Number of layers;*
- *Number of intersections (screws to be applied).*

Unfortunately, surface could not be considered as one of the critical parameters that affects the assembly process, since there is not a direct relation between panel surface and cycle time. Therefore, it has been found out the need to identify a reference product that could be used for the validation of the automated assembly line. A possible reference product has been identified in a panel with the following characteristics (figure 4):

- *Dimensions: 3 m x 3 m;*
- *N° Layers: 3 layers (can easily be converted into more layer's version thanks to the same surface);*
- *Distance between slats: 0,6 m;*
- *N° Intersections: 50 intersections (200 screws).*

Figure 4 - Leko Reference Panel, 7 Layers example

4.3 Assembly Process Analysis

The next step, after the product analysis, consists on going through the assembly process in order to finalise some possible suitable automated assembly lines. Each panel is a combination of layers with slats and internal insulation covered on both sides with vapour barriers, inner grid layers and external insulations. According to the manual production requirements, the assembly process can be summarized as follow:

1. *Positioning of the first layer of slats (n° 5 wooden slats) on the assembly table considering the right distance of 600 mm between each other;*
2. *Putting in place of the second layer of slats (n° 5 wooden slats) rotated by 90° and fixing of each slat using the grooved system and 4 screws for each intersection;*
3. *Handling and fixation of the internal insulations for the 2nd layer between each slat by nails;*
4. *Continuing in the same way for the 3rd layer restarting from point 2;*
5. *Vapour barrier is applied and fixed by nails on the 3rd layer;*
6. *External insulation panels are handled and fixed by nails on the vapour barrier;*
7. *Overturning of panel;*

8. *Handling and fixation by nails of 1st layer internal insulation panels;*
9. *Vapour barrier is applied and fixed by nails on the 1st layer;*
10. *Handling and fixation of the Inner Grid Layer on the internal side of the panel. Each Inner Grid slat is fixed by one screw in every point of contact with the 1st layer slats.*

4.4 Assembly Line Assumptions and Process Optimizations

Once product and assembly process have been analysed in detail, the project enters in the phase where possible layout solutions are figured out. After an evaluation of all the suitable automated technologies (*gantry crane, gantry robot* and *industrial robots*), a solution with the use of industrial robots (*figure 5*) has been evaluated as the most affordable and suitable for the following reasons:

- *Floor Footprint:* since the Leko's facility has limited space availability, Industrial robots can provide the lowest footprint compared to Gantry Crane and Gantry Robots thanks to their missing of external structure;
- *Price:* usually price of Industrial Robots is lower than other solution thanks to their mass production;
- *Delivery Time:* Industrial Robots supplier, usually, have products ready to be shipped in warehouse. This significantly reduces the time of delivery after the purchase;
- *Maintenance and Customer Service:* since the product is compact and at the state of the art, less maintenance will be needed during the robot life and easily managed by the supplier.

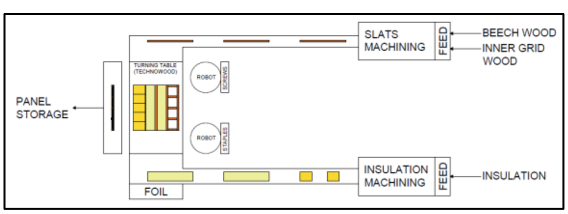

Figure 5 - Two Industrial robots and turning table solution

Thanks to the evaluation of the cycle time of this solution, it has been pointed out that the production rate was not sufficient to meet the requirement of the project.

Also a layout with two assembly tables in parallel, to divide the process in two steps and then to reduce the cycle time, was not sufficient to satisfy the expectation of the company.

Thanks to an accurate analysis of the cycle time, it has been pointed out that the most critical actions during the assembly process are the screwing process and the rollover of the panel for the putting in place of the 1st layer of insulation, internal vapour barrier and inner grid layer. Since screwing process was considered more related to the technology instead of the assembly process, the only action, which considerably affects the cycle time possible to optimize, was the rollover of the panel.

Therefore, the solution was figured out into the design of a special assembly table (*figure 6*), that could allow the assembly of all the different kind of Leko panels without the overturning of the panel, constraining the first layer by a clamping system to achieve an optimum level of quality of the product.

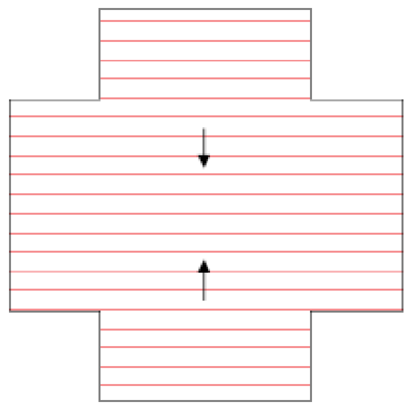

Figure 6 - New design of assembly table

5. Proposed Solution

5.1 Design and Validation of Final Assembly Line

Thanks to the assembly process optimization described before, a new layout solution (*figure 7*) has been designed.

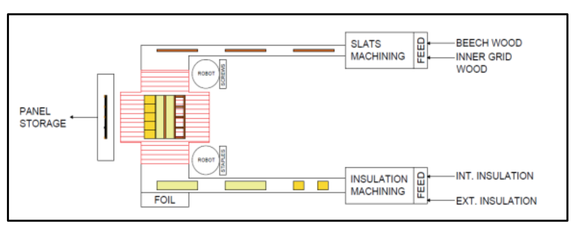

Figure 7 - Layout modification with new assembly table

As shown in figure 7, the new solution is basically a modification of the layout in figure 5, with the new concept of assembly table, able to both assemble

Landscape and Portrait panels. Thanks to this modification, cycle time of Internal and Portrait panels have been reduced, with the benefit of increasing annual productivity. Also, thanks to the elimination of the panel capsizing, it can significantly reduce the risk for the process and operators, due to the previous hazardous handling.

Also, a solution with another table and two more industrial robots in parallel is possible to improve further (almost double) the productivity (*figure 8*).

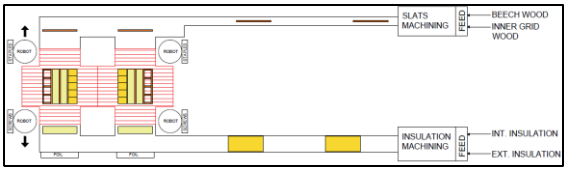

Figure 8 - Layout modification, Parallel Assembly Process

Thanks to this configuration, two parallel and different assembly processes can be performed with a double productivity, respect the previous solution. The two tables shall work at a different height (table on the right at lower height), in order to allow the unload of the finished panel from the right table, moving the panel under the left table with a conveyor system. In addition, the new two robots (on the left) must be applied on a rack, to be able to move in the direction shown in the figure. In fact, it is required to have enough space for the unloading of Landscape Panels (vertical orientation on the assembly table). Since two assembly tables need to be fed, probably just one conveyor for each element will be not enough to fulfil the cycle time previous estimated. For this reason, most probably, a feed system with two conveyors at different height will be requested by the process. In this way, the lower conveyor can bring elements to the first assembly table and the second one to the second table. This aspect will have to be significantly analysed, also with the supplier of the two cutting machineries.

Thanks to the copy-paste of the new extension of the layout, this configuration can provide a wide flexibility during the implementation. In fact, this solution, which produce a very higher production than the requirement, can be implemented inside the facility, also after the implementation of the Layout in figure, almost without any issue for the production. Moreover, since this will be a new technology of product and assembly process, a possibility to check the reliability of the system can be obtained with a lower starting investment.

5.2 Implementation of Final Assembly Line in the 2D Layout Facility

After the selection of the most suitable configuration in accordance with Leko's team, the following step has been to implement, in the Leko facility layout, the technology previously evaluated, out of building constraints. The factory layout has been first designed using the CAD software Autodesk AutoCad 2018 and then implemented and optimized, as shown in figure 9.

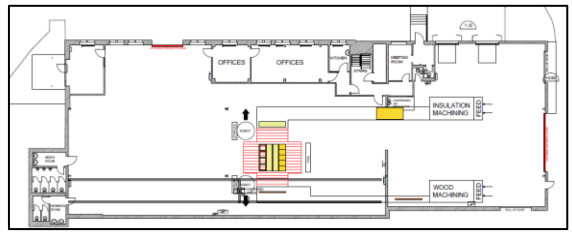

Figure 9 - Final Layout, 2D facility implementation

As can be seen in the drawing, the implemented Layout differs for the original one in figure 7 for some aspects:

- The position of slat and insulation conveyors has been switched to benefit a better optimization of the space;
- The length of the conveyors has been necessary of a reduction to leave enough space in factory for the possible update of the layout and for supply chain and logistics reasons. In accordance with Leko Labs, the right part of the factory (where the two machines are located) will be used for storage of incoming raw materials and the left part for the outgoing finished products;
- The applying of the vapour barriers will be managed manually by a couple of operators, since the particularity of the required process does not fit with possible automated process;
- In accordance with Leko, the two walls located in the middle of the factory, shall be removed (or at least remodelled) to allow the crossing of the two conveyors.

5.3 3D Design and Simulation of Final Assembly Line

Once the layout has been optimized inside the Leko's factory, a 3D design has been performed using the CAD software Autodesk Inventor Professional 2018. So far, the analysis has been more focused on the concept of layout and cycle time. At this point, instead, also some assumptions and rough concepts (for example of the gripper to apply on the two robots), have been required. The two robots, due to the different material to be handled, must have a different concept of gripper.

The gripper, applied to the robot in charge to clamp wooden slats, shall be able to clamp, thanks to a pneumatic or hydraulic system, each slat and at the same time, thanks to a screwing station applied on the same gripper, able to tighten four screws per each intersection. A very rough concept has been 3D modelled, to show the concept to the possible supplier in the future phases of this project.

On the other hand, the "insulation" robot shall be able to handle and to put in place insulation panels. Due to a not very rigid body, insulation material is not suitable to be clamped by a standard mechanical or pneumatic gripper or vacuum system. For this reason, after some market research, a technology based on a needle system, developed by a German company (Schmalz) has been chosen for the application. In addition to this needle system, the gripper applied mounted on the insulation robot, shall be able to nail both internal and external insulations. Therefore, a rough concept has been implemented in the 3D model.

Thanks to these assumptions, the 3D design of the final suitable automated assembly line has been, thus, finalized as shown in figure 10.

At the same time, a simulation made also with the CAD software Inventor Professionals 2018 has been made to be shown to Leko, suppliers and possible client how the final solution shall work.

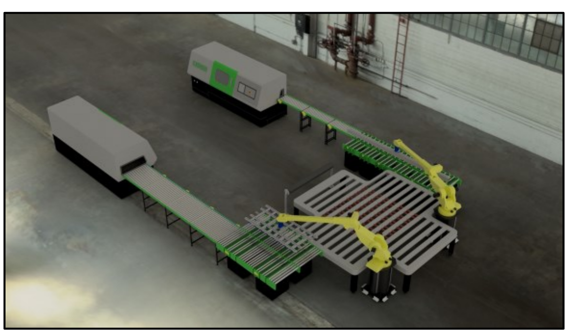

Figure 10 - 3D CAD Design of the final assembly line

6. Conclusions and Future work

6.1 Conclusions

An automated assembly line for wooden modular construction industry has been designed and virtually implemented during this project. This was possible only thanks to a very accurate analysis of products and the manufacturing process and subsequent optimization of both. Because of the non-direct correlation between the project productivity requirement (surface [m2]) and product critical parameters (n° of elements, n° of layers and n° of intersections), a reference panel has been created with the scope to be used into the evaluation of the cycle time and production rate of the proposed layout solutions. Different automated technologies have been analysed and evaluated in order to choose the most suitable one considering feasibility, reliability and economic aspects. Once the most suitable configuration has been figured out thanks to an accurate assessment, CAD software have been used both for a virtual implementation in the factory (to check its real feasibility) and to make video simulations (to show supplier and possible clients).

The following conclusions about the proposed automated assembly line can be drawn from this work:

- Primary objective of automation and Industry 4.0 (improvement of productivity, quality and safety) has been achieved by the outcome of this paper. The project requirement of 150 000 m2 of surface panels has been fulfilled thanks to the possible extension of the assembly line. The quality of the panels will be widely higher than manual production, thanks to specific grippers and assembly table. Safety of the process has been absolutely increased thanks to the abolition of the overturning of the panel, that in the manual production is usually done by an overhead crane or a fork lift;
- The possible extension of the assembly line makes easier the transition for Leko Labs from a manual production to an automated one, especially in term of initial investment. This is double important for a start-up company like Leko Labs, that is currently starting the first manual production of panels. Furthermore, since the assembly line will be an innovation in the modular construction industry (thanks to the Leko panel technology), dividing into two steps the whole implementation, suppliers can improve the overall reliability of their solution for the second step implementation;
- The final assembly line, with double assembly table, once implemented, will give to Leko Labs a very high level of flexibility of production. One project can be managed by two different

assembly stations (allocating a different kind of panel for each tables) or, eventually, also two different housing projects can be managed. In this way benefit in terms of project delivery can be easily achieved.

6.2 Future Work

Due to time constraints, this paper, just, has covered the part of the project until the 3D design and virtual implementation in the Leko's factory of the most suitable automated assembly line.

The next steps of this project will have to be the following:

- With the outcome of this research, Leko Labs can, now, start to contact possible supplier for checking the feasibility of assumptions pointed out in this paper. Some suitable suppliers have been already found out during the Internship;
- The feasibility of the use of Industrial Robots needs to be accurately verified with the selected suppliers. In fact, due to the distance from robot's base to assembly table and to the technology to implement in the grippers, maybe a technology like gantry crane could be more appropriate;
- In this work, cycle time has been calculated thanks to the standardization of the panels in terms of surface (3x3 m) but still considering the same percentage of panel typology, requested by the first Leko's housing project. This method has been very useful to get results as much close as possible the reality. Unfortunately, since the range of Leko panel covers also different dimensions and versions with door or windows, the obtained production rate can be a bit different than the reality. The solution (to be used in the future when CAD database of the first project will be ready) will be to import all the critical parameters of each panel (surface, n° of elements, n° of layer and n° of intersections) into an XML database and evaluated for each panel the necessary cycle time with the same approach explained in this paper. In this way a more accurate productivity can be processed and estimate;
- Another important aspect, to be considered in the future, is the design of each panel, mainly concerning the assembly on site. Currently, to allow a very easy assembly on site, design of some panel is not suitable for an automated production and need to be modified. Also, possible further optimization (for example number of screw in each intersection) can be figured out to more decrease cycle time and then increase productivity;
- As final step, an important and effective coordination will be required with RPD International (supplier for cutting machineries and supply chain). Only in this way the final implementation will be successful.

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