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Enhancing Engineer-To-Order Processes with Agile Project Management: Lessons from a Refurbishment Project

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Abstract

Changing customer requirements raised the bar for companies in terms of fulfilling individual demands and ensuring internal efficiency. This can be seen in a variety of business contexts such as Engineer-To-Order (ETO), characterized with high interaction with the customer and uniqueness of the products. The current paper suggests the use of agile project management to support customer-centric processes in ETO environments by addressing a case study involving a refurbishment project. The paper reports on how the project was planned, executed and closed, highlighting ETO processes intricacies and discussing how they are addressed. The case study brings empirical evidence of pursuing agile in managing ETO processes and uncovers some of the issues that ETO project stakeholders need to deal with. These issues include uncertainty and pricing, managing teams in complex environments, and dealing with cross-disciplinary projects. Ultimately, these findings will help decision-makers manage ETO processes more efficiently and continuously learn from ETO projects.

Keywords: Engineer-to-order; customization; agile project management; processes; refurbishment.

1. Introduction background literature

Increasing and changing customer requirements led to the expansion of firms' offerings [1]. This situation fostered the research seeking to deal with high product and process complexity induced by customization. Mass customization is among the overarching concepts embedding practices, methods and tools to ensure a balance between the benefits of pure personalization and those of mass production, i.e., meet individual customer requirements with near mass production efficiency [2]. In this movement, specific settings such as Engineer-To-Order (ETO) did not receive much attention [3].

Processes managed on an ETO basis allow for higher customization since customer order is received during the design phase. Generally, orders are different from each other and each order triggers a new project. In the literature, ETO is referred to using alternative terms such as project-based, one-of-kind and design-to-order [3]. The uniqueness and low-volume of products and services increases the complexity within the processes to create and deliver those products and services [4]. Authors such as Haug et al. [5] promoted the use of product configurators to tackle some of the issues related to specification complexity, quotation process time, and lack of customer interaction.

In a comprehensive review, ElMaraghy et al. [6] addressed several enablers that help to manage variety and reduce complexity within processes. Although the enablers are assumed to apply to mass customization context, many of them are also relevant to ETO processes. Examples of these include modularity and customer centricity. The basic idea behind modularity is to allow recombination of components to form new variants. A module allows for fulfilling a specific function of the entire product or service [6][7]. Customer-centricity suggests that customer needs should be considered not only in the design process but also in defining product development strategies [6]. Tseng and Piller [8] see customer centricity as

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achieving ultimate quality goals in terms of meeting exactly customer demands without increase in cost. Obviously, this vision is closely related to the mass customization movement.

In ETO environments, it is crucial to involve and interact with the customer throughout the development process to make sure the outcomes meet exactly his/her expectations, even if this results in higher costs [9]. This is closely related to the idea of blurred borders of the solution space within ETO context, unlike mass customization where the solution space is defined beforehand considering the trade-off between cost and customization [1]. Being customer-centric requires also to deal with changing customer requirements over time, this is typical in ETO contexts [10]. Due to these reasons, traditional plan-driven methods are not well suited to ETO context if they are used solely. Therefore, it is important to examine agile methods and explore their use in this context.

Agility from a production perspective involves responding to the fast-changing market and customer needs [11]. In this sense, the "challenge of agile manufacturing design is to put in place structures and systems supportive to the timely delivery of innovative products ahead of competitors" [12]. In a recent study, Medini [13] highlighted the need for agility improvement to overcome the relatively static nature of products and processes in mass customization setting. Similarly, Heraud et al. [14] developed a set of recommendations to improve agility in the production ramp-up process. Both works build on empirical studies, which is relevant to investigating agility. These studies concur on the fact that agile methods and agile project management benefits are not fully exploited in production domain. This aligns with the work of Sousa et al. [15] and Falcone et al. [16] which emphasize the role of agile project management practices in improving business process performance. Project Management Institute defines project management as the "application of knowledge, skills, tools and techniques to project activities to meet project requirements" [17]. Introducing agility involves mainly short cycles and iterations considering customer changing requirements for the delivery of the product or service [18].

Against this background, current study suggests the use of agile project management to support customer-centric processes in ETO environments. To this end, the rest of this paper is structured as follows: Section 2 presents the research method, Section 3 reports on a case study involving a refurbishment project. Section 4 discusses main findings, Section 5 outlines some concluding remarks and research perspectives.

2. Research method

The current work builds on the idea that agility and agile project management exhibit a high potential to support customization, mainly in ETO context characterized by high uncertainty. Since agility relies heavily on learning from experience, a case study-based approach is adopted in order to learn from a real-life case [19]. To this end, a refurbishment project is considered, where the entire project is customer-centric. The project involves the redesign of a building floor to meet specific customer requirements. These requirements are only roughly described at the beginning of the project and they evolved throughout the implementation.

The author of the paper regularly discussed with the project team to contribute to the planning and monitoring of the project. Data was collected by the author regularly throughout the project. Used tools include short semi-structured interviews of 15 minutes on average (twice a day), along with observations (30 minutes on average per day). The entire project was conducted in 2023 and lasted less than one month.

3. Case study

3.1. Project initiation and planning

The case study involves the refurbishment of one of the two floors of a 9-year-old building. The floor in question consists of two areas that need to be merged to have more space and installing one office for professional use. For confidentiality concerns mainly raised by the project customers, no specific information will be disclosed about project stakeholders. Similarly, it was agreed not to disclose local currency, which will be referred to as UN (Unit) in the case study. This does not jeopardize the research objectives since the main aim of the case study is to provide a rough order of magnitude rather than focusing on costing aspects.

The project aims to create more space and install an office for professional use within a one-month period. The rough budget is 3 000 UN with a possible variance of -25% to $+50\%$.

The floor plan is shown in Figure 1. Dimensions, as well as some installed equipment, are omitted for readability. The areas that will be merged are referred to as Area 1 and Area 2. In the scheme, the parts (e.g., walls) that are going to be added are highlighted in green while the ones that are likely to be fully or partly removed are highlighted in orange.

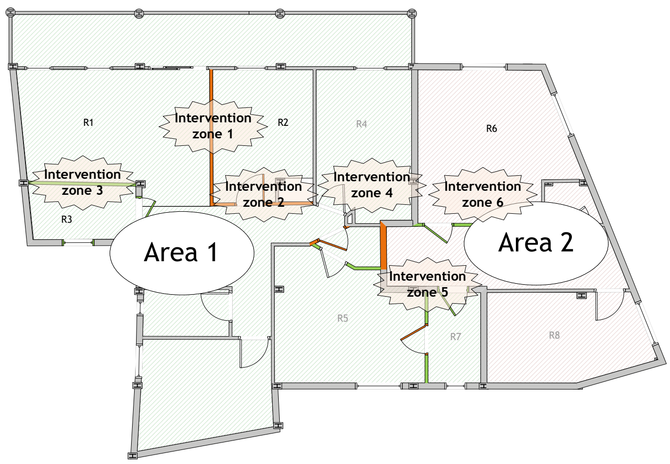

Figure 1. Refurbishment project intervention areas

The project team consists of a manager, one experienced bricklayer acting as supervisor, one electrician and two workers. The project manager coordinates project planning and monitoring including budgeting and scoping as well as managing suppliers. The project customers are the owners of the building.

The project team defined the scope of the work after examining the current layout of the floor and discussing it with the customers. In total, there are six zones of intervention within the project, as shown in Figure 1. Merging Area 2 into Area 1 will involve interventions in Zones 4, 5 and 6. Merging rooms R1 and R2 involves Zones 1 and 2. Adding one room R3 involves Zone 3. Removing scrap involves all six Zones. The work breakdown structure (WBS) is shown in Figure 2.

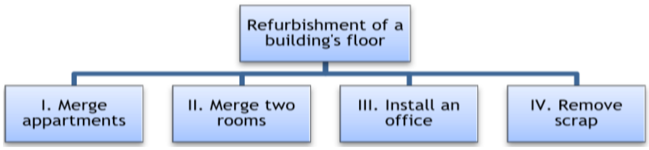

Fig. 2. Work Breakdown Structure

Starting from the WBS, the project team identified a more detailed list of activities to be executed in order to meet project objectives; the final list after updates is shown in Table 1. The full list of activities is shown for the sake of simplicity, although it was updated progressively throughout the execution of the project following agile methods. For instance, A5 and A14 were added to the scope of the project after around one week from the project start. This led to a change in the scope of intervention Zones 1 and 6 during the project.

Table 1. List of project activities

#	Description
A1	Demolish highlighted walls in Areas 1 and 2
A2	Close existing R7 door
A3	Open a new door for R7 in Area 2
A4	Plaster existing and new walls in the hall and R6
A5	Add a new wall for an additional room in Area 2
A6	Fill the stairs entrance
A7	Plaster horizontal beams in the hall
A8	Set marble in Area 2
A9	Set tiles in the hall in Area 2
A10	Replace and add baseboards in Area 2
A11	Destroy separating wall between R1 and R2
A12	Open a window from the R2 to the hall
A13	Build an additional small wall in R1
A14	Set marbles in R2
A15	Replace and add baseboards in R2
A16	Plaster new and existing walls in the R2
A17	Open an exit in the wall to R3
A18	Build an additional external wall for R3
A19	Plaster new and existing walls related to R3
A20	Set marbles in the office
A21	Replace and add baseboards in R3
A22	Remove scrap resulting from walls demolition
A23	Remove scrap resulting from demolition finalization
A24	Remove all scrap and tools from the working place
A25	Electricity works

In order to establish a rough estimate of the duration of the project, the team grouped similar activities resulting in the following categories: old walls demolition, new walls building, electricity installation, plastering and removing scrap. For each of these activities, duration as well as required resources (number and qualification) were estimated. This allowed calculating costs as per local daily wages. Total human resource cost amounts to 880 UN.

Required materials were determined considering the scope of the project and team experience, leading to a cost of supply amounting to 705 UN. Considering a management reserve of 500 UN, the project budget was fixed at 2 085 UN which is below the lower limit of the initial order of magnitude (2 250 UN).

As for the execution of the project, it was decided to proceed in an agile way following the SCRUM method [20]. The activities listed earlier, A1 to A24 form the overall backlog from which items are selected for each sprint. A25 referring to electricity work was not included in the sprints since the specific moments when this work should be done cannot be defined accurately from the beginning. Therefore, those moment were determined and planned separately as per the work progress, relying on the flexible electrician schedule. The electricity work is pulled by the other activities (A1 to 24) and is executed as soon as possible in order to prevent delays and bottlenecks.

Proceeding with short sprints is a bit challenging since the teamwork should result in an increment within a short period of time. From the customers' point of view, there should be a significant work achieved so that they perceive it and get reassured. This is challenging in a refurbishment project, in construction for instance, since much time can be spent in non-visible work to the customers, e.g., laying the foundations, complex finishing tasks. However, a benefit of short sprints is to be flexible with regard to any change in customer requirements as well as to be able to adapt the project scope and plan if needed.

Although sprints generally last no less than one week, it was decided to proceed with a 4 days sprint, given the project tight schedule and number of activities. This allows to adjust and refine the rough plan as the project moves forward, plus it helps accommodate customers' requirements on a more regular basis. The customers have no fixed budget neither completely defined preferences with regard to the refurbishment. Therefore, it is important to be in close ties with them to make sure they validate each piece of the work. The project team did not commit to a result-oriented contract but preferred to go with a cost-plus one.

3.2. Project controlling and monitoring

The project team met at the beginning of each sprint to choose the activities to be included in the sprint, any need for additional raw material was determined during this meeting, potential risks were also discussed such as delay and potential quality problems. Once the sprint is planned, the team holds daily scrums, each lasting an average of 10 minutes, with the aim of coordinating the work of the day, check if any equipment and material are required and make sure customer requirements are being met. A brief review of the work is conducted by the project manager at the end of each working day together with the bricklayer.

At the end of the sprint, a short review meeting of the work is conducted by the team based on which activities status is updated to "done" if they are completed or kept in the overall backlog if not. This meeting is followed by a short debrief on what went well and what should be improved, acting as a sprint retrospective. This helped to highlighted several points such as the need for setting order in the workplace and for preparing raw material one day before use. Another point was raised about irregular consumption rate. The actions taken regarding these issues are detailed in section 3.3.

In total, 6 sprints were conducted resulting in an overall project duration of 21 days instead of 16 days. The activities conducted in each sprint are shown in Figure 3 (see Table 1 for full names). Naturally, the team decided to start with demolishing identified walls (sprint 1) in order to clean the space and move to building (sprint 2) and plastering (sprint 3). At the beginning of sprint 4 and given some frustration of the customers who want to see *light at the end of the tunnel*, it was decided to finalize and clean Area 1 as much as possible, before moving to Area 2. Therefore, in sprint 5 there are again some plastering activities, followed by paving in sprint 6.

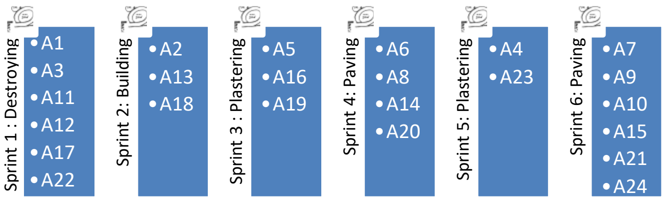

Fig. 3. Conducted sprints throughout the project

3.3. Continuous improvement

Regarding the issues identified in the retrospectives, the following measures were taken. It was seen that some of work tools were left in the floor while walls are being demolished, some other tools were left in relatively hidden locations (see Figure 4). This led to wasted time in searching for the tools and in some cases losing some of them under the scrap.

Fig. 4. Tools arrangement

The project manager decided to proceed with a small 5S project. 5S is a Japanese method well suited for organizing workplaces as well as processes [21]. The application of the method is summarized as follows:

- *Sort*: it was seen that some of the tools are not used such as a defective hummer and screwdrivers. Therefore, the team grouped them and put them aside from the workplace.
- *Set in order*: following project manager's suggestion, the team installed a unique moving workbench in the middle of the room where the work is conducted. This allows the tools to be visible and far enough from the walls where most of the work is conducted.
- *Shine*: the project manager asked the team to make sure that the tools are left at the end of the day on the workbench as well as to remove all scrap that is not related to bricks or cement.
- *Standardize*: the project manager asked the team to keep up with this routine whenever they change the work place. No visuals were created since the work place is not very well suited mainly due to dust and the condition of the walls.
- *Sustain*: no formal training was conducted, however informal discussions were held to emphasize the benefits of such approach, which were recognized by the team.

The need for preparing the materials one day in advance comes from the noticed waiting time of the bricklayer in the mornings, in order for the workers to prepare the material. This was mentioned in an issue register during the second sprint by the project manager. Then, starting from the third sprint, the work was organized in a way to prepare the material at the end of day *n-1* for the work of day *n*. Lastly, close coordination with the material supplier was highlighted as a means to overcome the irregular consumption rate and the lack of storage space. The reactivity of the supplier was paramount at this point.

The project outcomes are exemplified in Figure 5 with some photos taken from the workplace after project closure. As mentioned earlier customer requirements were evolving, for instance at the beginning of sprint 3 customers wanted to add one room in Area 2, resulting in additional material consumption as well as increased time required for building (A5) and plastering (see Area highlighted with blue ellipse in Figure 5). Similarly, after seeing how the new arrangement looks like by end of sprint 2, the customers decided to add some marbles in the newly created counter in R2 (see the area highlighted with yellow ellipse in Figure 5).

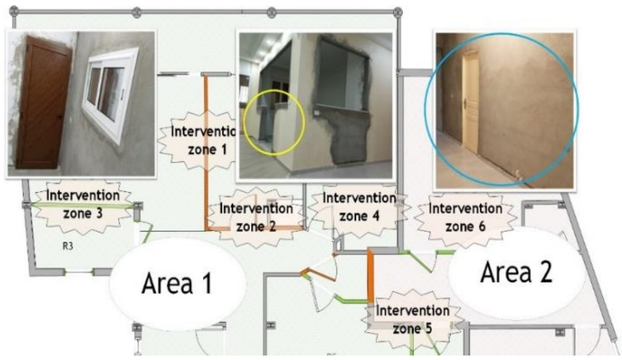

Fig. 5. Exemplified project outcomes

3.4. Earned value analysis

Changes in the scope of the project led to changes in the project timeline as well as the budget. This is reflected by the earned value estimates, obtained at the end of the retrospective meetings of sprint 3, 4 and 5, referred to as Earned value S3, 4 and 5, respectively (see Figure 6). This can be mainly seen in the slope of the actual cost curve which increased during sprint 3 with the newly added room (A5). It is noteworthy that earned value estimates for a given sprint k allows assessing the situation from sprint k onwards. Therefore, earned value curve spanning from the project start to sprint k should not be taken into consideration.

Cost increases were heightened in sprint 4 because of another change. In fact, it was seen that the floor of the extension hall should be paved entirely. First, many of the old tiles were damaged during the work; second, there were no available tiles in the market with the same characteristics as the old still intact ones. Another relatively significant increase in cost can be seen in sprint 5 due to the rising customer need for marble plates to be installed (A14).

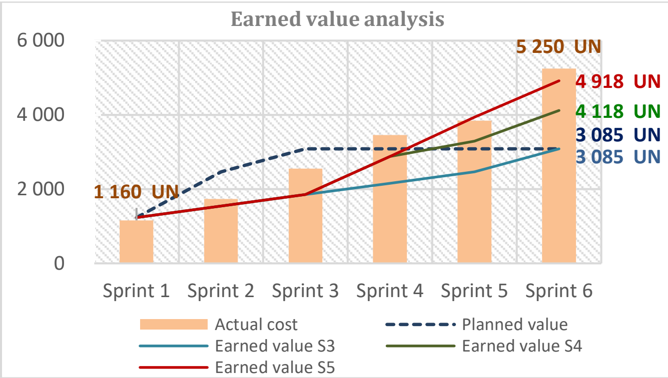

Fig. 6. Earned value analysis results at different sprints of the project

Changes in customer requirements as well as estimation errors mainly in terms of time, led to an increase in the budget by 67%, the final project cost amounts to 5 250 UN. In Figure 6, the planned value is the one defined at the very beginning of the project (Budget at Completion of 3 085 UN and 16 days duration). The increase in project cost is however accompanied with an increase in the overall value created while accommodating changes in customers' requirements. For instance, an additional room in Area 2 was not planned at the beginning nor were marbles to be installed in Area 1. The increase in earned value can be seen in the three curves in red, green and blue. These were performed at different moments of the project, at the end of sprints 3, 4 and 5. The values on the right-hand side of the figure, 3 085 UN, 4 118 UN, and 4 918 UN represent the Estimate at Completion (EAC) obtained at the end of sprints 3, 4 and 5, respectively. Unsurprisingly, EAC was more accurate with the latest update of earned value done at the end of sprint 5 (4 918 UN), however calculated earned value and adjusting EAC since the third sprint allowed to ensure the customer was fine with the new budget (+34%) considering the changes in the project scope.

3.5. Project closure

At the end of the project, the team held a meeting with one of the customers to make sure the final increment is aligned with their expectations. The project team also gave some recommendations to the customers about the next steps (painting, plastering, etc.). The project documents including lessons learned, earned value calculation, invoices, etc. were gathered and organized. These documents were also helpful to fine-tune the analysis and write this paper.

4. Discussion

In many ETO projects involving a high level of customization, a "north star" is generally defined for guiding the project, however the target state is often partially defined. The case study presented in this paper perfectly illustrates this situation, although it represents a small-scale project.

The general objectives of the refurbishment project are clear but specific work content cannot be defined in detail from the beginning. The definition of "done" is therefore quite difficult for the entire project. This explains why, at the beginning, the project team did not commit to a result-oriented contract with the customers. They preferred to proceed with a rather simple cost-plus pricing based on the realized work. This allows them to mitigate the risk for the project team of cost overruns due to uncertainty during initial planning (leading to errors in estimates) as well as changing customer requirements throughout the project. Traditional plan-driven methods are not suitable for these high uncertainty contexts. For example, accommodating one more requirement of the customer in the middle of the project would have been too difficult with a cascade-based plan. In contrast, agile methods exhibit a high potential to deal with the changing requirements and lack of information at the early stages of the project. In the presented case study, the work was broken down into activities and conducted through several sprints. The content of each sprint is defined based on the rough project plan, on the previous sprints, and on input from the project stakeholders (customer, team, suppliers). This situation is very similar to several manufacturing cases. For example, an equipment provider working with a customer to design and manufacture a cleaning robot will also be confronted to pricing problems due to structural and behavioral complexity of the robot as a system. In this case, breaking down the robot into sub-systems and proceeding with iterations to develop and test prototypes could be very helpful.

Going agile is likely to help manage teams in complex environments and mitigate work pressure among them (resulting from uncertainty and changing requirements). In the presented case study and throughout the project, each of the team members provided feedback and contributed to decision making during daily scrum meetings and beyond. The project manager is goal-oriented; he was available to support the team in order to deliver quality work in a short time without micro managing activities. The "how" to do work was completely defined by the team who consulted with the project manager when needed. Interpersonal skills of the project manager probably helped create the good work climate where the team feels more comfortable and more productive. This can be seen throughout various stages of team development. For example, at the beginning of the work some of the team members were curious about project manager's style of leadership, and some other argued about their own work style. In this context, the project manager was an active listener and managed to smoothly communicate about how to work together as an agile team. This helped move quickly with setting some ground rules, such as trust, active listening, commitment, and friendliness. This helped to efficiently perform the work in a favorable atmosphere. By the end of the project, several convivial moments were held together among the project team members. In this sense, going agile and having a good understanding and interpersonal skills help deal with the project complexity. The reported practices and management style are undoubtedly relevant to several ETO contexts. Take as an example the cleaning robot design and manufacturing which involves various and large teams. Active listening, trust, friendliness, and commitment are of great value for overcoming pressure induced by system and working environment complexity (e.g., design constraints, number of suppliers).

Many of the ETO projects are complex due to their large scope involving several disciplines. Cross-disciplinary and agile teams are key for conducting these projects. A major challenge at this point is the synchronization of the work from the various teams considering dependency in their tasks. In the case study, it was important to coordinate construction activities with the electricity installation activities. Construction activities result in a rather smooth workflow. However, it was not possible to exactly know when the electrician needs to intervene. For instance, some of the electricity work should be done at specific moments during the plastering process. The relatively flexible schedule of the electrician was very helpful at this point. Considering the cleaning robot example, the synchronization of the work is obviously more challenging as it involves several teams with much more interrelated tasks. One means to address complex manufacturing projects is breaking down large teams into small cross-functional teams leading to higher agility. Developed system architecture provides a reasonable basis for defining the work breakdown structure and therefore functional teams. Similarly, system engineering and management skills are of much interest in such ETO contexts.

5. Conclusions and perspectives

The current study brings some evidence of the usefulness of agile project management to support ETO processes considering a refurbishment project. It also uncovers some of the issues that project stakeholders need to deal with, such as uncertainty and pricing in ETO context, managing teams in complex environments, and dealing with cross-disciplinary projects. In this sense, the paper brings a complementary perspective to the research works exploring the potential of project management and agile project management in areas such as production [22]. One way to deal with the relatively limited scope of the addressed case study is to reexamine the findings in the context of more complex ETO projects in the manufacturing domain. Recent research in this area such as the work of Brandl et al. [22] provides a good starting point.

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