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A Framework for Embedded Hardware on Furniture Smartification Design

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Abstract: Customers and manufacturers have never been as connected as in the present moment. When the Industry 4.0 introduced the possibility of having customizable products, the customer's needs evolved from the standardized requests to fully customized requests. Within the unavoidable evolution of Internet of Things (IoT) and Cyber-Physical Systems (CPS) in the households and the unquestionable demand for customization, an untapped niche exists in the customized smartification of furniture. Due to the absence of specialized support for the creation of unique smart furniture, a framework to guide in the development of embedded hardware on furniture design is proposed. The framework features stages that guide each process of product development during furniture smartification. It will be tested with two real life use cases that are expected to be developed with all the requirements fulfilled. The framework proposed in the paper turns the smartification of furniture simpler and more accessible to everyone. Additionally, it also features the possibility of using it in the smartification of other products that are not furniture.

Keywords: Smartification, Embedded Systems, Industry 4.0, Internet of Things (IoT), Cyber-Physical Systems (CPS)

1. INTRODUCTION

The rise of the Industry 4.0 and the periods of pandemic lived in the recent years made the customers hungry for customized products. The development of customized products deepened the need of a Social Manufacturing environment that allows the customer to have more power in the development decisions. With the increase in popularity of Internet of Things (IoT) and Cyber-Physical Systems (CPS), people started wanting their homes to become more intelligent, but there are still many ideas to be explored.

The average person can have innumerous ideas through the daily routine that could improve the abilities of the furniture around the house. Some ideas could involve energy saving, elderly supportive features, security, and comfort. One problem that may arise is that the average person may not have the time, money, or knowledge to design and implement such ideas. Some ideas may be modest; others can change the elderly by giving security, comfort or even independency like an automatic door that can facilitate access to people with reduced mobility; and others can revive furniture whose life cycle was ending. All the benefits just mentioned could be materialized if there was a way of anyone being able to see their smartification ideas come to life and at the same time being involved in the process.

The research question of the paper is - how can the development of embedded hardware solutions on furniture design be supported, to effectively solve users' needs? And the hypothesis proposed is - if a framework that can support the smartification process during the design and manufacturing phases of furniture is developed, then the prototyping and developing of a solution tailored to the users' needs is facilitated.

The paper is divided in six sections. The first and current section introduced the motivation and problem to solve. The second presents the state of the art of the concepts and tools needed for the creation of the framework. The third presents the scenario that the framework needs to support. The fourth proposes and details the framework, followed by an architecture specialized in furniture smartification. The fifth describes the web application created with the architecture from the previous section. The sixth and final section presents the results from the test executed to the framework and articulates the conclusions.

2. STATE OF THE ART

In this section the knowledge of concepts and study of existing frameworks is presented to support the development of the framework that will guide through the smartification process of developing embedded hardware solutions on furniture design.

2.1 Smartification

Smartification is a recent concept that can be defined as an improvement of existing products with the awarding of the abilities to be present, observe, analyze, and to act when needed. The old functions must be kept while turning the product more functional, efficient, and interactive (Luis-Ferreira, Sarraipa and Goncalves, 2019; Schuh *et al.*, 2019).

The smartification of a product can happen with the integration of embedded hardware on it. Embedded hardware derives from embedded systems, which is the aggregation of hardware,

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software, or other mechanical or electronic components to execute a specific task (Barr and Massa, 2006).

2.2 Product Development Frameworks Analysis

A study of existing frameworks for product development was performed with the analysis of three frameworks, namely S³ Product Development Framework, PFX (Prototyping for X) Product Development Framework, and Universal New Product Development and Upgradation Framework.

The S³ Product Development Framework (Miranda *et al.*, 2019) aims to develop sensing, smart and sustainable products. It consists of four stages that contain three types of activities: analysis; synthesis; and evaluation. The "Product Ideation" stage creates the idea considering what is asked by the customers and defining the scope of the project. The "Concept Design and Target Specifications" stage compiles a full specifications document with the solutions, functions, technical requirements and characteristics, product constraints, and the main structure with the parametric and geometric relations. The "Detailed Design" stage consists of detailing each engineering domain characteristic. The "Prototyping" stage is the development of the prototype and testing of the concept and functions proposed. For a better usage of time, the engineering domains execute their tasks at the same time. It also includes the instantiation of the model to a particular model by identifying the type of product and sequencing the activities.

The PFX Product Development Framework (Menold, Jablokow and Simpson, 2017) describes the process of prototyping with the use of three lenses that define three different concurrent prototypes. The Prototyping for Desirability (PFD) tries to grow the purchase-ability of the product and magnify the consumer value. The Prototyping for Feasibility (PFF) develops a prototype with all the necessary functions. The Prototyping for Viability (PFV) creates prototypes considering the reduction of time and money.

Each prototype is developed within a cycle of iterations that consists of a Frame, Build and Test phases. The Frame phase defines the context of the problem, the most important elements needed, and the goal that evaluates the outcome of the prototype. The Build phase will create a prototype considering the most valuable features for the customer (PFD), will decompose the functions and build an Analytic Hierarchy Process (AHP) matrix (Al-Harbi, 2001) before building the prototype (PFF), or decrease the critical parts, followed by the building of the prototype (PFV). The Test phase, similarly depending of the lens, will have a prototype evaluated by the customers with the strengths and weaknesses (PFD), a prototype to go through a functional test with root cause analysis of the failures (PFF), and a prototype for manufacturing cost estimation (PFV) with Computer-aided design (CAD) software. After the Test phase, there is the analysis that makes the decision of ending or not the iterations (Menold, Jablokow and Simpson, 2017).

On another note, the requirements needed for the development of a successful product are always important to define, and that is why the Universal New Product Development and Upgradation Framework (Dhargalkar, Shinde and Arora, 2015) introduces a list of the ideal attributes a product or service should have based on a study made with 215 participants for over three years. The framework proposes the focus on one or two attributes while considering the other attributes in general. Some examples are capacity, modularity, and comfort.

All the frameworks presented have important characteristics that make them unique. The S³ Product Development Framework has four well organized and easy to understand stages which contain three different activities that allow the preparation, execution, and evaluation of each stage. This makes it a solid and well-organized framework. It also has a specialization of the model to the type of product to develop, contributing for efficiency and quality. Although not including a specific stage for preparation before prototyping, the PFX Product Development Framework still contains preparation, execution, and evaluation of each prototype iteration. Its decision-making is faster since it consists of three specific prototypes being developed concurrently that include multiple iterations, decreasing time between decisions, reducing complexity, and increasing flexibility. One of its prototypes, the PFD, allows the customer to interact with it during the prototyping, decreasing the probability of customer dissatisfaction with the final product. The Universal New Product Development and Upgradation Framework also has a better customer satisfaction, because the product attributes are selected from a well-studied list of attributes wanted in products, increasing the chances of implementing attributes that may have been forgotten by the customer or were just not well defined. The characteristics just described are the most desired to be implemented in the framework to develop.

3. SCENARIO

The theme of smartification was required by a European project designated as INEDIT (*Inedit Project*, 2021), that aims to design products globally and produce locally in a Social Manufacturing (Shang *et al.*, 2013) environment that allows the development of a Circular Economy (Geissdoerfer *et al.*, 2017). Since the framework focuses on the design and prototyping of products, there are a lot of other stakeholders that may need to interact with the system. In this section, the scenario that the framework needs to support will be presented.

3.1 Stakeholders

The project starts from the Customer that requests the smartification of furniture through the User Interface System, which is the interface the Customer will use to communicate and make requests. The Prototyping System is the entity with the task of designing and creating the prototype while also providing a guide for the integration of the smart components with the furniture. The Quality Assurance System is occupied with the validations of the project, especially the management of tridimensional space for the combination of both smart and furniture components. The Runtime System is in charge of specifying runtime requisites that will be used for managing and analyzing the behavior of the smart product and updating its firmware or software. The Furniture Manufacturer will manufacture or modify the furniture to meet the requirements needed for the integration of the smart components. The

System Integrator integrates the furniture with the smart components to create the final product, the smart furniture. The framework is supposed to guide the Prototyping System while also being compatible with the interactions of the other stakeholders.

3.2 Scenario Description

The scenario that the framework needs to support consists of the smartification of furniture asked by a customer. The Prototyping System needs to define and design the solution, create a prototype, and create specifications to help manufacture.

The Customer inserts the problem in the User Interface System to be processed and sent to the Prototyping System. In case of existing a similar smartification project, the user can suggest the project, reaping the benefits of project reutilization. Following after, the Prototyping System is required to interpret the problem and present a solution to the Customer, so that it can be confirmed and moved forward. The Customer checks the solution and decides if it can be implemented or if it needs more readjustments.

Succeeding the approval of the customer, the Prototyping System defines technical specifications for the solution with the optional help of the Runtime System since it can add pre-requisites for the runtime of the final product. The technical specifications describe the way the solution will be implemented, and the materials used. Afterwards, the Quality Assurance System proceeds to evaluate the specifications. Some objectives of the Quality Assurance System are verifying if the electronic components fit in the furniture and confirming the requisites are achievable.

When the specifications are validated, the Prototyping System develops the prototype. The prototype is also validated by the Quality Assurance System to assure it is correctly functioning with the requisites defined in the previous stage, and is shown to the Customer through the User Interface System, to receive feedback and the final approval.

Immediately upon validation and with the green light from the Customer, the Prototyping System creates specifications that will help the production of the final product. Finally, the Furniture Manufacturer manufactures or modifies the furniture according to the specifications and the System Integrator creates the final product by assembling the furniture with the hardware.

4. FRAMEWORK AND ARCHITECTURE

In this section, the framework proposed will be explained in detail and subsequently the architecture adjusted for the scenario will be presented.

4.1 Smartification Framework

During the creation of the Smartification Framework, it was concluded that it was not only going to support the development of embedded hardware solutions on furniture design as proposed in the hypothesis, but it was also going to be broader in a way that could be used in any project of smartification. The Figure 1 illustrates the Smartification Framework.

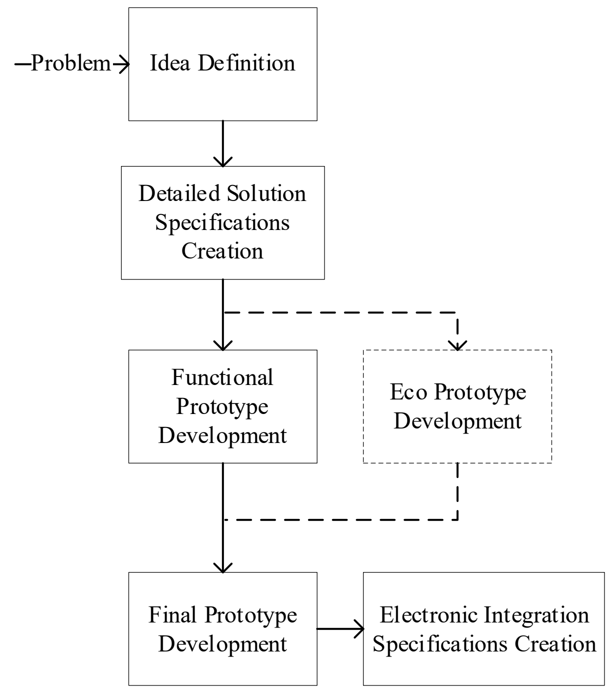

Figure 1 – Smartification Framework.

The framework starts with the Idea Definition. This stage initializes by researching a solution for the problem defined by the Customer. The solution is then defined using the knowledge obtained in the research. To structure and organize the solution, an Idea Specifications document is created with the explanation of the problem, solution, and requirements. The requirements are collected from the customer problem description and may be gathered from the Universal New Product Development and Upgradation Framework attributes list. The Idea Specifications document is verified by the Customer to ensure it is in harmony with the customer's perspective. In case the Customer does not agree with the document, it is recreated by rewriting the solution and requirements. Prior to the next stage, the following activities can be organized and scheduled using the research done on the solution or by researching for more similar projects. This technique is designated as specialization and can decrease both time and money, which will improve the overall performance of the project.

The second stage is the Detailed Solution Specifications Creation. This stage lies on the creation of the Detailed Solution Specifications document that must include the specifications needed to start prototyping. The document should contain technical specifications like hardware and software to be used and a more precise description of the solution. There is also the need of containing a first version of the instructions for electronic integration with the product or at least a reference to the positions of the hardware in the final product. It can also contain electronic diagrams and functionalities flowcharts. Afterwards, a Quality Assurance System should evaluate the specifications, and optionally, the customer may also verify them.

The next task is the Functional Prototype Development. The functional prototype intends to implement the functionalities by order of importance and key features by order of favoritism of the customer.

The Functional Prototype Development stage starts with the definition of context, need, and goal. The context delineates the purpose and constraints of the prototype, the need defines the primary requirements of the implementation, and the goal establishes the objectives that will be used in the evaluation of the prototype. During the definition of need and goal, an AHP matrix can be used to help organize by order of importance the main functionalities, and key features for the customer. The prototype is built with the features and requirements determined. When built, its functionalities are tested and evaluated. The prototypes that do not achieve the required functionalities are iterated and the origins of the issues can be investigated through root cause analysis. The prototypes that have the pre-determined functionalities successfully achieved are evaluated by the Customer. The feedback from the Customer is used to decide if the prototype is iterated or concluded.

Concurrently to the functional prototype, a prototype with the least possible economic and environmental impact can also be developed. This prototype is depicted in the framework as the optional Eco Prototype Development stage. The Eco Prototype Development stage also has the definition of context, need and goal, but the need and goal correspond to the reduction of non-critical parts and the use of materials with less environmental impact. The prototype is built within these foundations and afterwards its manufacturing cost and environment impact are estimated. If the results meet the goals defined, the prototype can be concluded or can still be iterated to define greater goals.

After the creation of the standalone functional prototype (or both functional and eco prototypes), the final prototyping stage starts. The Final Prototype Development stage consists of building a final prototype that gathers all the knowledge from the previous ones. It also starts by the definition of context, need and goal. In this case, the need and goal correspond to the requisites defined in the Detailed Solution Specifications document and the alterations from the previous prototypes. The final prototype is built and then verified by the customer that can accept and finish the prototyping or decide to alter something.

Finally, the Electronic Integration Specifications Creation stage has the objective of creating the Electronic Integration Specifications document with technical specifications, such as the hardware and an electronic diagram. It should also include instructions for the electronic integration of the components in the product. These instructions can be based on the first version on the Detailed Solution Specifications file or can be created from origin. At the end of this stage the framework ends, since the designing and prototyping phases of smartification are concluded.

4.2 Scenario Architecture

Although, the Smartification Framework can support any type of smartification, the application scenario focuses on furniture smartification as the main case study. For that reason, this section will detail the changes made in the Smartification Framework within the furniture smartification scenario. The architecture is represented in Figure 2.

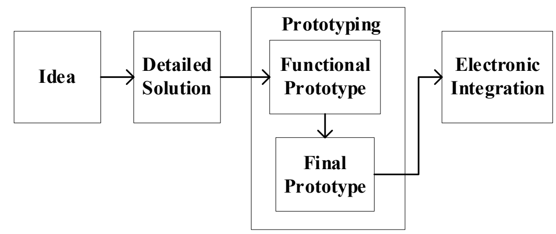

Figure 2 – Architecture.

As depicted in the scenario (section 3.2), the Customer has the option of suggesting an already finished project or asking for the creation of a new idea. To implement these two possible options within the framework, it was decided that when a project is suggested, the Prototyping System reviews and validates if the Idea Specifications document is compatible with the Customer's problem. The Idea Specifications documents that are not compatible with the problem receive some readjustments or are completely redone. The ones that are compatible, skip the first steps right into the Idea Specifications Customer verification.

To support the development of new projects, the hardware from all projects is shared in a common hardware list. In the beginning of the Detailed Solution Specifications Creation stage, the scenario includes the addition of necessary hardware to this hardware list. This hardware is only usable after being validated by the Quality Assurance System. During the creation of the Detailed Solution Specifications, the Runtime System can help the Prototyping System defining the runtime specifications.

The prototyping stages are similar to the original prototyping stages in the framework. The eco prototype is not included since it is optional and vaguely defined to have a practical implementation. The Customer prototype verification is done through a video demonstration. The final prototype is additionally validated by the Quality Assurance System. And the Customer validation of the final prototype includes the possibility of asking for reconfigurations, such as changing the color of a component.

To end, the Electronic Integration occurs as expected in the framework, but it only ends when the System Integrator successfully completes the integration of the electronic components with the furniture.

5. SCENARIO IMPLEMENTATION

The architecture presented was used to create a web application that guides the Prototyping System through all stages of furniture smartification and automates the interactions with the other systems. The web application starts with a login page for the authentication of the Prototyping System. When logged in, the project can be selected and in its main page, presented in Figure 3, there are buttons correspondent to each stage

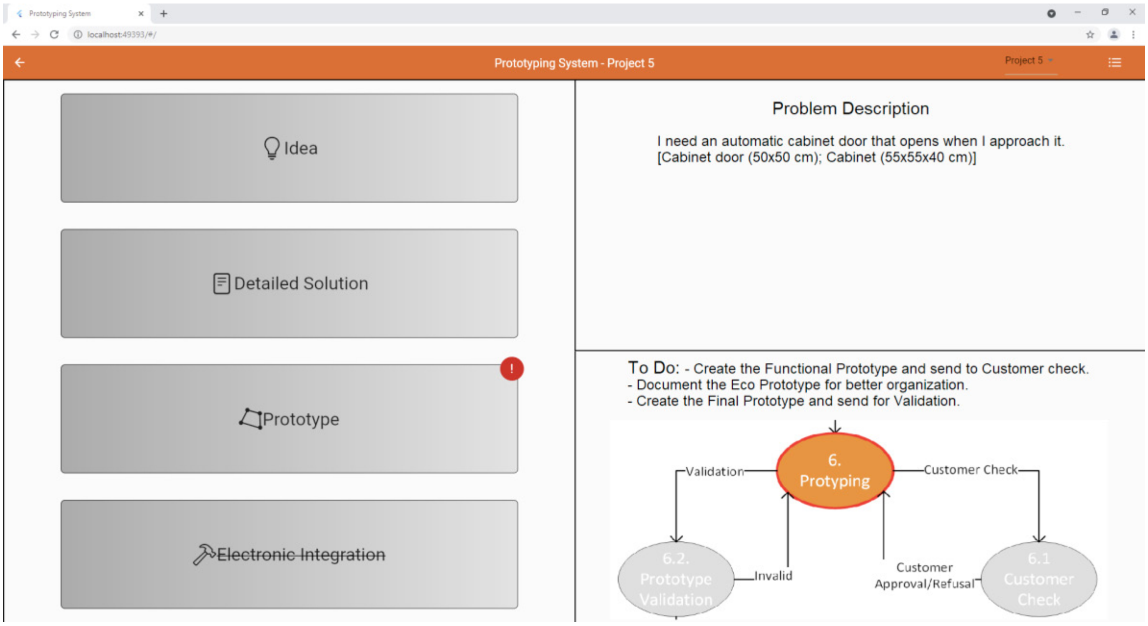

Figure 3 – Web Application Main Page.

The page also shows the problem description and a map with the state of the project that gives a tip of what the Prototyping System needs to do at that moment. One of the button options is the hardware list that is universal to all projects, and in this page the hardware can be added, deleted, or observed along with the characteristics and validation state (the validation state indicates if the hardware was validated by the Quality Assurance System). The other option on the main menu is the Idea, that allows the revision of any version of the Idea Specifications document and the creation of newer versions. All the specifications documents are presented as a page with each specification and saved in the JSON format. There is also a button for the Detailed Solution, that is identical to the Idea page, but with the Detailed Solution Specifications and with a table to add the hardware from the hardware list to the project. The next button is the Prototyping that includes a page for the concurrent prototypes and the Final Prototype. This page shows the description and video of the prototypes, the option of seeing any prototype version, or the choice of creating new prototype versions. Finally, the main page has a button for the Electronic Integration that leads to a page almost like the Idea, but with the Electronic Integration Specifications and a button to end the project.

6. RESULTS EVALUATION AND CONCLUDING REMARKS

To test the framework in the scenario of furniture smartification and to validate the hypothesis proposed in the paper, two real life case studies of smartification were implemented with the use of the web application developed and the guidelines from the framework adjusted to the scenario architecture. One project was the creation of an automatic cabinet door for a kitchen. This door opens automatically when sensing the presence of the users and includes various modes that are controlled through voice commands. The other was the insertion of smart lighting in a kitchen cabinet, which allows the user of the cabinet to use voice commands to ask for specific product zones in the cabinet and, consequently, those zones become illuminated.

Both projects had successful results, since all requirements defined in the Detailed Solution Specifications document were fulfilled. The Smartification framework supported these implementations in various aspects. The use of iterative prototyping helped developing the prototypes, considering some materials were not accessible right away. The approach of constant feedback from the Customer enabled more product customization and effectiveness in delivering what was pretended. The creation of a Detailed Solution Specifications aided the prototype development, since it contained the hardware and electrical diagrams, and was also useful during the testing of the prototype due to every requirement being already identified and described in the document.

Although meeting the requirements, the prototypes were not implemented as final products at the time of publishing of the paper, since the kitchen where the smartification will be applied is still in construction. This means the Electronic Integration Specification were not properly tested. Both prototypes can be visualized in Figure 4. The cabinet in the automatic cabinet door case study is represented by a yellow card box, and the LEDs illuminating each type of product in the embedded smart lighting case study are represented by one led and a draw of the product in a paper.

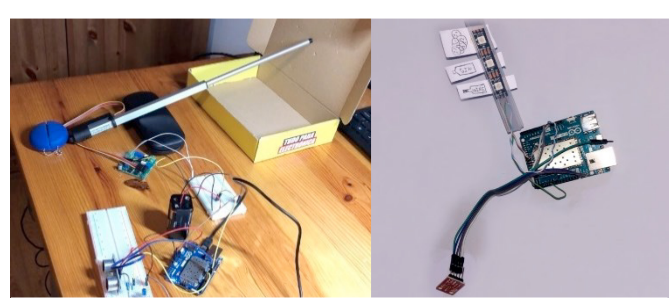

Figure 4 – The Case Studies Prototypes, Automatic Cabinet Door at the Left and Embedded Smart Lighting at the Right.

The Smartification Framework was proven to support the smartification of furniture and promises to guide in any smartification project. The accomplishment of finishing both projects with the use of the framework, confirms that the Smartification Framework can support the smartification process during the design and manufacturing phases of furniture, facilitating the prototyping and developing of a solution tailored to the users' needs, as the hypothesis proposed. The Smartification framework mixed the features from the frameworks described in section 2.2 and applied them to the topic of smartification. The result was a framework that uses each feature to its advantage, just as it was described above for the case studies.

To ensure it can guide more types of smartification projects, it is advisable to do further testing with the framework. The Eco Prototype could also be more refined, mainly in the topic of environment impact estimation, that was not too explicit. Nonetheless, the Smartification Framework is directed towards the customer satisfaction and is possible to be used in a Social Manufacturing environment where products are designed globally and are produced locally. This framework is one more step into the future where manufacturing is even more customizable, smartification is available to everyone, and the environment always comes first.

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