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Framework for Validation of Furniture Smartification Processes

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Abstract: The integration of hardware into furniture seeks to provide a better user experience and quality of life. For the smartified furniture to have the functionalities intended by the user, validations are required during the furniture smartification design and development processes. The authors propose a Smartification Quality Assurance System that is responsible for the validations of the furniture smartification process, ensuring that the hardware components used in smartification are compatible with the dimensions of the furniture and that the smartified furniture has the predefined functionalities. A validation framework is presented, whose purpose is to validate the intermediate steps of the furniture smartification process. A validation scenario of a furniture smartification process is also demonstrated. The applicability of the validation framework brings advantages to the furniture smartification process, such as: valid electronic hardware that can be used in the development of the smartification solution, the smartification problem is feasible, the solution and the furniture smartification prototype are valid both dimensionally and functionally. In this way the process of furniture smartification can occur continuously and uninterruptedly.

Keywords: Smartification, Quality Assurance System, Validation, Furniture Smartification Process.

1. INTRODUCTION

Technology is increasingly present and in abundance in everyday life. Currently, about 61% of people own at least one smart device (*Percentage of people who have a smart device*, 2019). The advantage of using smart devices is the functionalities and facilities they provide to users (Alter, 2020). Due to the high rate of use of smart devices, the integration of technologies into physical spaces has begun to develop, so that there are more and more functionalities that can assist the user (Wang *et al.*, 2004). Most physical spaces are made up of furniture, so taking advantage of the integration of electronic hardware in the furniture to acquire technological functions is an added value to make the physical space more efficient. From the integration of electronic hardware in furniture comes the term furniture smartification, which through sensors captures data and through actuators can improve the user experience, increasing comfort, productivity and minimizing the cost of operation.

1.1 Motivation and Objectives

During the process of furniture smartification several problems and constraints may arise which are divided into functional, e.g., hardware components not compatible with each other, sensors with incorrect data readings, improperly functioning actuators, and dimensional, e.g., hardware components system exceeding the dimensions of the available space for smartification on the furniture, wrong placement of sensors and actuators on the furniture.

The process of smartifying furniture consists of the following steps: identification of the need for smartification, creation of a list of electronic hardware to be used for solution development, development of the solution based on the need for smartification, development of the prototype based on the solution, and integration of the prototype into the furniture.

For the smartification process to run smoothly without functional and dimensional problems and setbacks, the steps need to be validated. The goal is to create a framework that indicates which and how the steps should be validated. Thus, during the process of furniture smartification, if the step is not valid, the step will require changes until it becomes valid. If the step is valid, the furniture smartification process can proceed to the next step.

1.2 Research Question and Hypothesis

According to the proposed objectives, the research method (Camarinha-Matos and Terminology, 2021) is composed of the Research Question "How can the furniture smartification process run smoothly in an optimized way?" and the respective Hypothesis "If there is a validation system that validates the functional, dimensional, and constraint requirements during the steps of the furniture smartification process, then the smartification process can be optimized from the source of the problem to the smartified furniture.".

1.3 Article Organization

The paper is organized in sections as follows: section 2 presents a literature search on existing concepts, technologies and similar projects, section 3 presents a contextualization of the furniture smartification process, the intervening systems and the scenario of need for validations, section 4 proposes the validation framework and architecture, section 5 presents the implementation and results of the validation framework, and section 6 presents the main conclusions and future work.

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2. STATE OF THE ART

So that the process of furniture smartification can be done seamlessly and optimally, research was conducted into existing concepts, technologies, and similar projects to obtain auxiliary knowledge for the development of the project.

2.1 Smartification and Smart Furniture

The term smartification arises from the integration of technology into existing products or spaces with the goal of making them more functional and efficient for the user (Bartolini *et al.*, 2012)(Luis-Ferreira, Sarraipa and Goncalves, 2019). The emergence of smartified products and spaces has been increasing as well as their demand (Berger *et al.*, 2019).

Smartification can be present in any type of space, such as a home, an office building, or even a smart city (Ottenburger and Ufer, 2019). Some of the advantages of having a smart space are increased efficiency, reduced operating costs, reduced use of resources such as electricity, water and gas, and reduced waste (Cyril Jose and Malekian, 2015).

Smart furniture through the use of sensors, microcontrollers and actuators aims to provide comfort by satisfying the user's stated and unstated needs, improving the user's quality of life (Vaida *et al.*, 2014). Smart furniture can be found in the residential area, for example in lamps that detect the brightness needed based on the user's needs, in healthcare, for example in smart medicine cabinets with the ability to identify and locate medications, in education, for example in adaptable chairs and desks to improve user ergonomics (Krejcar *et al.*, 2019).

2.2 Examples of Dimensional Matching Algorithms and Applications

To verify dimensional compatibilities between a piece of furniture and the hardware components needed in the smartification process, research was conducted on algorithms and applications with similar functions and characteristics.

2.2.1 Smart Packing using Genetic Algorithm

The Smart Packing Genetic Algorithm (Khairuddin *et al.*, 2020) is used for packaging optimization. Using the dimensions of the boxes and the container, the algorithm arranges the geometry of the boxes in the container. The algorithm is based on a chromosome consisting of plots of starting positions, heights, widths, and lengths of boxes. Through a cycle of mutations of the chromosome, i.e., changing the starting position and alternating the remaining dimensions per box, the boxes will move as close together as possible until they occupy the smallest possible volume. The Smart Packing Genetic Algorithm could have features and be considered for the development of an algorithm for checking dimensional compatibility between a piece of furniture and hardware components.

2.2.2 3D Bin Packing Application

The 3D Bin Packing (*3D Bin Packing*, 2011) application is intended for packing 3D objects of different dimensions inside another 3D object with larger dimensions. The report obtained from the packing application presents in detail information such as: dimensions, number of objects packed, space occupied, weight, and the step-by-step accommodation of the smaller 3D objects in relation to the larger one. The 3D Bin Packing application presents a final report that can be considered for an output generated by the dimensional compatibility checking algorithm.

2.2.3 Bindrake Application

The Bindrake (Onur Gümüş, 2014) allows packing different 3D objects inside a larger 3D container, set preconditions for the different objects, such as: not allowing the object to rotate, set whether the object should be placed on top, on the bottom, or whether it cannot have anything on top or underneath. In case the sum of the volumes of the 3D objects exceeds the volume of the container, or if the dimensions of the objects exceed the dimensions of the container, the application does not allow packing. At the end, a 3D geometric representation is displayed inside the container. The Bindrake application can be an asset to the dimensional compatibility checking algorithm, as far as the preconditions, constraints, and 3D geometric representation model that the application presents.

2.3 State of Art Review

Through research, the concept of smartification was defined, and it was concluded that smartification can exist in different types of spaces, including furniture. There are some ideas of smartified furniture however there are few implementations.

For the integration of hardware components in a piece of furniture it is necessary to perform some validations, the most obvious is the validation of dimensional compatibility. The applications and algorithms obtained during the research reveal advantages and functionalities that can be used to develop a dimensional compatibility validation algorithm.

3. SCENARIO

For the proposed According to the objectives of the European project designated as INEDIT (*INEDIT - European Commission*, 2019), the proposal for the creation of the validation framework was made. To better understand the need for the validation framework, the intervening systems that will help in the furniture smartification process are presented, as well as a contextualization of the process. For the furniture smartification process to occur in a liner and uninterrupted way, a QAS that will support the validation framework was created. To better understand the actions of the systems during the validation phases, the interactions between the QAS and the other intervening systems are explained.

3.1 Furniture Smartification and Operating Systems

The smartification process consists of the following steps: explanation and identification of the furniture smartification problem, creation of a list of hardware components, development of the furniture smartification solution, development of the furniture smartification prototype, integration of the prototype into the furniture, maintenance, and firmware update to the smartified furniture. Each step of the furniture smartification process has one or more responsible parties for its execution (Figure 1).

The responsible systems are:

User - Starts the furniture smartification process by explaining the problem or the need for certain functionalities in the furniture, generating a description of the smartification problem, and has the option to suggest a proposed solution for the presented problem. The User also intervenes in the validation of the proposed solution of furniture smartification.

User Interface System (UIS) - System that allows communication with the User to expose the problem or need for furniture smartification. The system also allows the functionality to demonstrate the furniture smartification solution to the User, so that the user can validate the furniture smartification solution.

Prototyping System (PS) - System that creates the list of hardware components based on the usage need and is responsible for developing the solution and prototype for furniture smartification. Participates in the process of integrating the prototype into the furniture.

Quality Assurance System (QAS) - System that validates: the furniture smartification problem, the list of hardware components, the solution, and the furniture smartification prototype. Participates in the process of integrating the prototype into the furniture.

Furniture Manufacturer (FM) - Responsible for the technical information of the furniture and the integration of the prototype into the furniture.

Runtime System - Collects and analyzes the data generated by the smartified furniture and is responsible for maintenance and firmware updates to the smartified furniture.

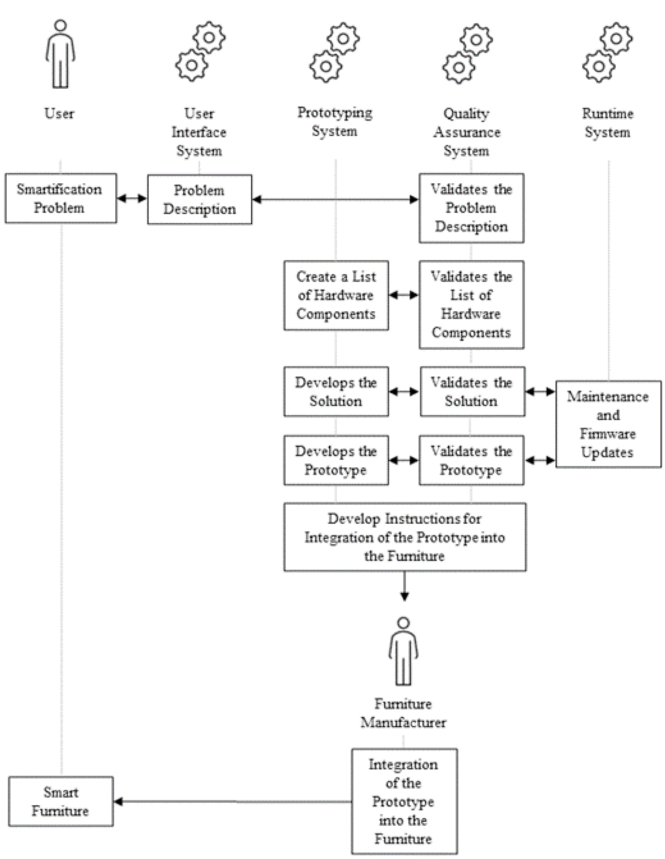

Figure 1. Operating Systems and Main Function

3.2 Hardware List Validation Interactions

The list of hardware components is created by the Prototyping System, based on the need to use the electronic hardware. The list of hardware components is inserted in a database shared with the QAS.

The sharing of the list of hardware components between the systems is based on the need to validate the technical date of each hardware component. If the list of hardware components is valid, the list of hardware components can be used for the development of smartification solutions.

3.3 Smartification Problem Description Validation Interactions

The User exposes his problem or need for smartification to the UIS. The UIS generates a smartification problem description and puts it into a shared database with the QAS.

The problem description is shared because the QAS needs to study and verify whether the problem description is feasible and therefore valid. In case the description is valid, the solution can be developed.

3.4 Furniture Smartification Solution Validation Interactions

Based on the list of valid hardware components and the description of the smartification problem, the PS develops a furniture smartification solution. The technical information of the solution is placed in the database shared with the QAS.

Using the solution's technical information, it is necessary to validate that the hardware components are compatible with each other and have the intended functionality. It is also necessary to verify that the available space in the cabinet is dimensionally compatible with the hardware components defined in the solution. If the solution is valid, you can proceed to the prototype phase.

3.5 Furniture Smartification Prototype Validation Interactions

Using the furniture smartification solution as a reference, the PS develops the furniture smartification prototype and places the operating instructions in the database shared with the QAS.

Based on the working instructions of the prototype, there is a need for validation of the predefined functionalities in the furniture smartification solution. If the prototype is valid, the PS together with the QAS will help the FM to integrate the smartification prototype into the furniture.

4. VALIDATION FRAMEWORK

The proposed validation framework presents a set of validations at different stages during the furniture smartification process. The architecture of the validation framework presents in detail the steps needed to perform the validations during the smartification process.

4.1 Framework Design

The validation framework consists of two asynchronous processes (Figure 2).

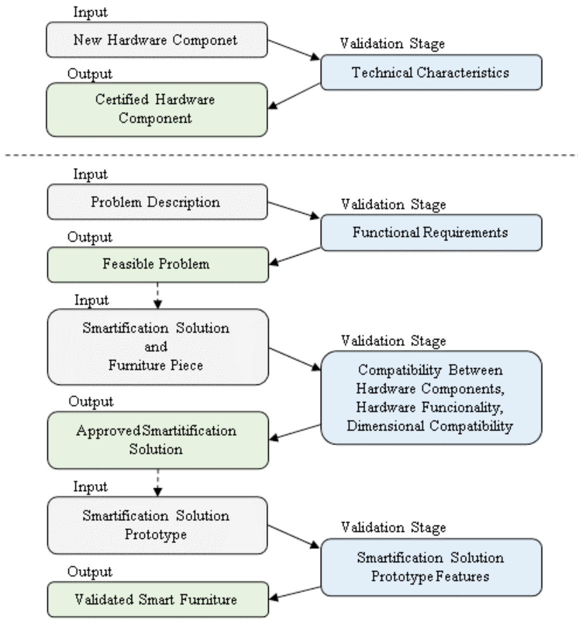

Figure 2. Validation Framework

The first focuses on the validation of the technical characteristics of new hardware components and the other focuses on the validation of the functional requirements of the problem description, the validation of compatibility between hardware components, of the functionalities of each hardware component and dimensional compatibility between hardware components and finally the validation of the functionalities of the smartification solution prototype.

Each validation step is associated with an input and output, that is, to make a validation it is necessary to receive an input and after the validation is completed, an output is returned. Thus, through a set of validations ordered during the furniture smartification process, the valid smartified furniture is obtained.

4.2 Architecture

The presented architecture is based on the implementation of the scenario-centric validation framework described and consists of two asynchronous processes. The architecture uses a graphical user interface (GUI) that is connected to a database that contains the necessary information so that validations can be performed.

The first process (Figure 3) in the architecture is the validation of new hardware components. The process starts by entering the id of the new component into the GUI and where all the information about the hardware component is displayed. With the previous information two validations are made: if the technical date is correct and if the hardware component is appropriate for the predestined function.

If any of the previous validations are not valid, through the GUI the validation state of the hardware component is changed to invalid and the reasons for not being valid described, so that they can be modified and submitted to a new validation. If both validations are valid, the validation state is changed to valid.

The goal of the first process is to obtain a certified hardware component to be used in the development of smart furniture.

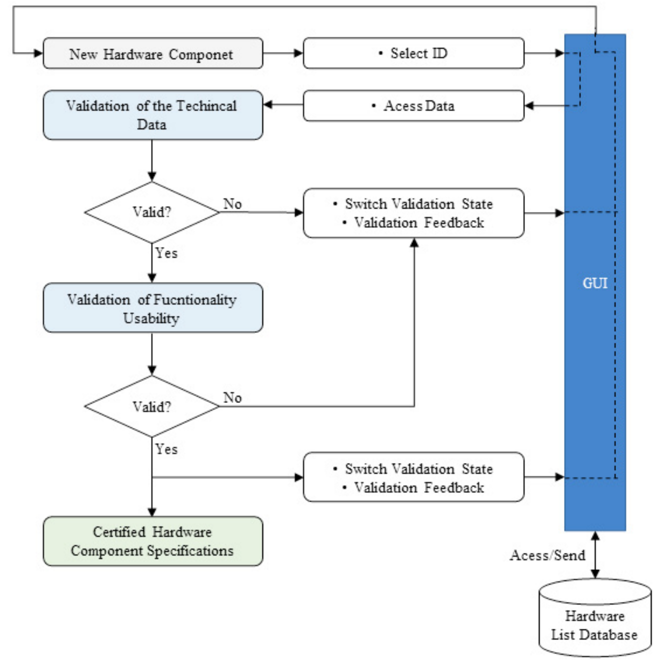

Figure 3. First Architecture Process

In the second process (Figure 4) the remaining validations take place to obtain the valid smart furniture. The first validation focuses on the functional requirements of a smartification problem, by entering the smartification problem ID into the GUI the smartification problem description is returned and with the smartification problem description an evaluation is made whether the smartification problem is feasible.

If the smartification problem is not feasible, the validation status of the smartification problem is changed to invalid and the reason why the problem is invalid is described, so that later the smartification problem can be modified. If the smartification problem is valid, the validation status is changed to valid, and the process continues.

By entering the smartification solution ID into the GUI, access to the list and datasheets of the hardware components used in the development of the smartification solution is returned, as well as information regarding the piece of furniture. Using the above data, the existence of compatibility between the hardware components is checked, and whether the hardware components are the most suitable for the purpose.
If the hardware components are invalid, the status of the smartification solution is changed to invalid and the reasons are explained, so that the smartification solution can be corrected. If they are valid, then dimensional validation takes place, where it is verified that the hardware components are dimensionally compatible with the piece of furniture.

To verify dimensional compatibility, by accessing the 3D files of the piece of furniture and the hardware components used, fastening systems, connections, and layout conditions, and with the support of the 3D Modeling Software, the previous information is entered, and layout solutions will be generated.

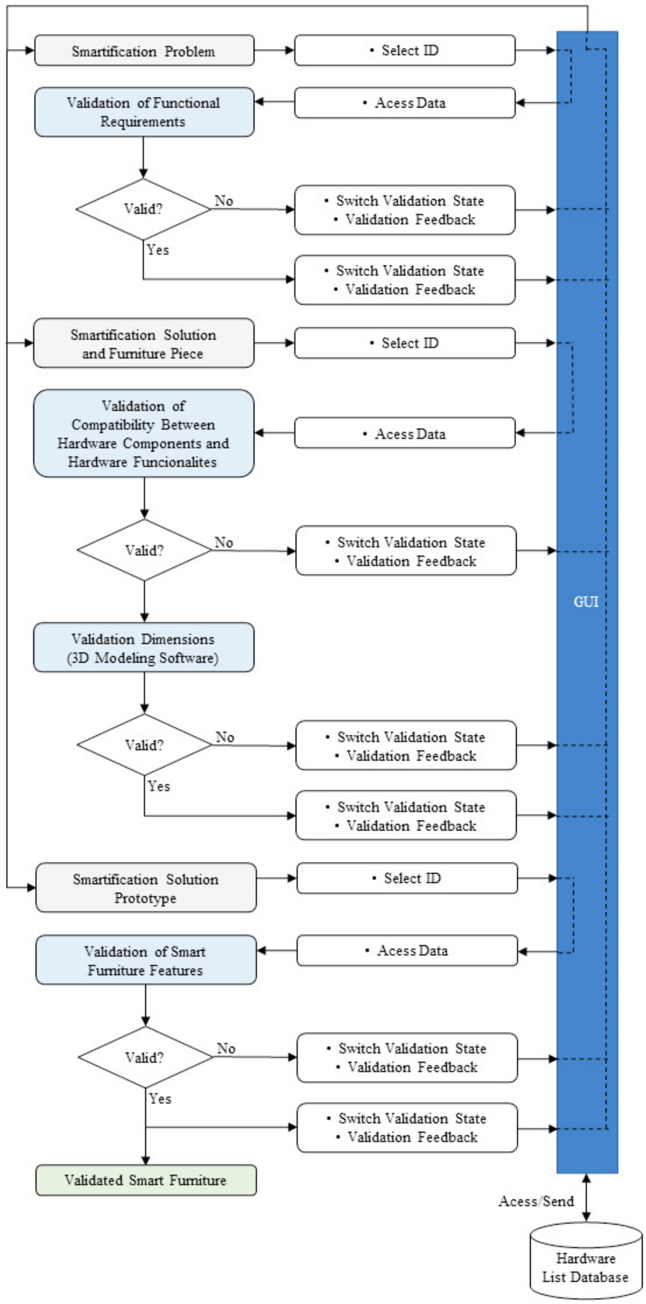

Figure 4. Second Architecture Process

If no layout solutions are generated, the validation status of the smartification solution is changed to invalid and described in the reasons why. If layout solutions exist, the validation state is changed to valid, and the process continues.

The last validation refers to the smartification solution prototype, which by entering the smartification solution prototype ID in the GUI is given access to the detailed information of the smartification solution prototype and the demonstration video, making the validation if all features are implemented and working correctly.

If there are inconsistencies, the status of the smartification solution prototype is changed to invalid, and the reasons are described. If everything is up to standard, the validation status is changed to valid. Following the smartification validation process by performing all the above validations, the smartified furniture is now validated.

5. IMPLEMENTATION AND RESULTS

The implementation of the framework was based on a validation system where functional, dimensional, and constraint requirements can be validated so that the furniture smartification process can be optimized.

For the implementation, a database was designed to receive the necessary parameters for validations to be performed during the furniture smartification process. To facilitate the validation process, a graphical interface was developed to be used by the QAS. When starting the graphical interface, the QAS logs in and receives notifications about the type and quantity of validations it has pending. The main menu displays the four possible validation types: hardware component list; problem description; smartification solutions; and smartification prototype. In the list of hardware components validation option, the QAS can query all hardware components or only the unvalidated ones. To update the validation status of a hardware component, the QAS enters the hardware component id and has access to the hardware component's datasheet, as well as the status update field and validation feedback.

In the problem description validation option, the QAS can query all problem descriptions or only the unvalidated ones. To update the validation status of the problem description, QAS enters the id of the problem description, modifies the status and validation feedback field.

In the smartification solution validation option, the QAS can view either the smartified solutions or only the unvalidated ones. To update the validation status of the solution, the QAS enters the id and will have access to the following options: list of hardware components used in the smartification solution; description of the smartification solution; algorithm for checking the volumetric and dimensional compatibility between the space available in the cabinet and the hardware components used; algorithm for checking the possibility of embedded wiring in the cabinet and the algorithm that generates 3D geometric schematics of the hardware components' layout in relation to the cabinet. After validating, QAS needs to change the state and validation feedback field.

In the smartification prototype validation option, the QAS can see all prototypes or those not validated. To update the validation status, the QAS enters the prototype id, and has access to the demonstration video, the prototype description, and the status change and validation feedback fields.

The implementation of the validation framework was applied to two real furniture smartification cases. The first smartification case consists of a kitchen cabinet that opens automatically when it detects motion nearby and after a while without detecting motion closes. The second smartification case consists of a kitchen cabinet that when the door is opened, the interior is illuminated, and when the door is closed the interior illumination turns off.

By applying the validation framework in the first case, the use of hardware components with the desired functionalities and dimensions was possible, such as an ultrasonic sensor for motion detection, a linear actuator with the correct dimensions in maximum and minimum stroke, among others. The verification that the linear actuator had to be in a specific position to work correctly and that the ultrasonic sensor had to be outside the cabinet, in a static place that would not interfere with the sensor measurements was also possible.

In the second case, with the application of the framework, it was possible to ensure that all hardware components would take up as little space as possible inside the cabinet through the geometric layouts, and that the brightness sensor would be in a specific place so that the measurements would be the most accurate.

During both cases of furniture smartification, through the application of the framework, problems and setbacks were detected and solved with the objective of the smartified furniture having the intended functionalities.

6. CONCLUSIONS AND FUTURE WORK

Through the scenario the importance of validations regarding hardware components, scenario description, solution and prototype for furniture smartification was realized. With the need for a validation system a validation framework and architecture were created that presents in detail the whole process to perform the individual validations.

To verify the importance of the validation framework in the process of furniture smartification validation, the implementation was done through a database and a GUI that helps the QAS. Furthermore, the framework was designed to support the adaptability and interoperability of each validation component with different processes and algorithms, enabling the customization necessary to distinct smartification projects. The implementation was tested in real furniture smartification cases and problems and constraints were encountered during the smartification process, which were corrected, and the result was a smartified piece of furniture with the intended functionalities.

Future work will be to improve the graphical user interface for a better user experience and to develop the algorithm for geometric layouts between the piece of furniture and the hardware components so that it can assume 3D models instead of similar regular straight geometric shapes.

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