Augmented Object Development using 3D Technology

An Object Redesign Process in the Ubicomp Domain

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*Abstract— **The construction of augmented object´s prototypes is a difficult process because most of the time these prototypes contain several sensors embedded in real life objects. In this paper, we present our experience using 3D technologies (scanning and printing) to generate prototypes of augmented objects which allow an early evaluation of them. Three different objects with embedded sensing and actuating capabilities were designed and developed. We discuss several pros and cons of applying this technology when developing augmented objects. Our results show that the use of 3D technologies enhances the quality of the final prototypes and allows a better concept validation and evaluation.***

Keywords- 3D printing; fast prototyping; augmented objects; ubiquitous computing; HCI; usability; mixed reality.

I. INTRODUCTION

An augmented object is defined as a common object, which has been provided with additional functionalities through integrated computing or software systems [1]. This definition biases people to build an augmented object from an existing one by adding other capabilities. In contrast, Waiser [2] describes Ubicomp as invisible computers in different sizes, situated to specific tasks.

Augmented Objects are normally developed to be incorporated in the Ubicomp domain. Therefore, they should be as seamless as possible depending on the goal of the objects, i.e., the capabilities added to the object. If the object to be augmented is selected from the natural context of use and additional capabilities are added, those capabilities should change it as little as possible. To do so the external look and functionalities of the object must be studied in order to add the capabilities without changing it.

In this project, we propose a strategy to develop augmented objects using 3D technologies, i.e., using a 3D scanning of the original object, redesigning it and printing a 3D version of such object with the least visible changes.

We also evaluate the proposed strategy by building versions of objects with embedded capabilities changing the object only slightly and almost imperceptibly to users.

Our main goal is to provide a strategy to allow the construction of new versions of objects as if the embedded capabilities were already there in the original design.

In a previous work, a process for the development of augmented objects (called AODeP) [3] was proposed and was later validated and improved [1].

However, the construction process was not fully addressed. This project defines some guidelines that can be followed at that stage.

Using augmented object as non-traditional interfaces for software systems can be difficult, especially when designers are reluctant to undergo a learning process. Our approach deals with that problem by designing familiar interfaces for the target users that resemble and function like the already known objects.

We add new functionalities to an object requiring the least cognitive effort possible from the user. Our approach intent to understand the object and its capabilities to assure that the new capabilities engage well with the original ones.

According to Hollinworth and Hwang [4], avoiding an increase in cognitive effort is achieved through the construction of physical objects that resemble or behave in a familiar way and context of the final user.

Implementing interfaces with familiar designs, and that provides more comfortable environments, results in better acceptance from final users. It also helps to reduce the cognitive effort and the time spent by the user to adapt to the device or system [5].

Furthermore, the use of 3D printing to make prototypes and construct real size devices in order to evaluate aesthetics, space distribution and functionality may also reduce the cost of production of the prototypes [6]. However, the use of low cost 3D printers could affect the possibility to print large objects.

Sophistication and appearance need to be addressed when creating augmented objects [7]. It is no longer enough to attach some sensors on an artifact and name it an augmented object. It is necessary to redesign the objects and really embed the new characteristics.

We use Human Computer Interaction (HCI) techniques to enhance the objects capabilities and evaluate them. HCI involves the study and design of interactions between people and computers through joint work of computer science and behavioral sciences. The main goal of HCI is to improve the interactions to create more usable interfaces [8][9].

The rest of the paper is organized as follows: Section II shows some related work. Section III explains the construction process when embedding the new capabilities in objects. Section IV shows three examples of developed augmented objects. Section V discusses our findings. Finally, Section VI shows some conclusions.

II. RELATED WORK

Augmented objects are also known as smart objects [10] or sentient artifacts [11]. Sánchez, Ranasinghe, Patkai and Mcfarlane [10] call smart object to a product which is capable of incorporating itself into both physical and information environments. Meanwhile, Kawsar, Fujinami and Nakajima [11] refer to sentient artifact to everyday life objects augmented with sensors to provide value added services.

Many augmented objects examples are present in the literature. However, most of these examples were all developed without following a formal design and development process and there is no special attention given to hiding the sensors or actuators.

Since the appearance of new prototyping and modeling techniques for creating custom devices, HCI researchers have been developing new forms of using this technology to improve the user experience. Due to the development of these technologies, the design processes of hardware components can now focus not only on the internal electronic components of the device but also on the external components: functionality and aesthetics [12][13]. Another sought characteristic among the researchers of these kinds of techniques is the affordability and accessibility of the components that can be obtained through custom construction.

Groups like Microsoft Research have been studying and experimenting with several physical prototyping techniques, combining different methods of generating structures like 3D printing and laser-cut wooden components [14]. These techniques provide great opportunities to integrate the design of the inner parts of a device, e.g., circuits or sensors with the design of the outer part of it, like shape, buttons and colors.

The applications and advantages of custom component fabrication go beyond customer satisfaction or market driven design. It also benefits areas like education [15] because students can build and prove their designs in a real context.

Some research groups have also been focusing in the inner parts or functionality of smart objects and tangible and more intuitive interfaces. However, authors use an approach that does not incorporate sensors. Instead of that they use conductive and capacitive interactions as a way to provide low cost prototypes with interaction capabilities [16].

Wiethoff et al.[17] propose a method to quickly prototype tangible user interfaces without having a complete design or process of construction. This is achieved by making cardboard structures for the external parts and using conductive ink to design the tangible surface of the objects.

Some research is also being made on 3D scanning quality and the influence of diverse factors, e.g., surface color, glossiness, ambient light, resolution in the scanning process and results quality [18][19].

3D Scanning and printing has been used to potentiate the transformation design practices. Stanislav and Chyon [20] demonstrated that 3D scanning and printing process enables a rediscovery of the artifacts when crafting. Authors also project the possibility of this technique used in redesign process by designers.

III. CONSTRUCTION PROCESS

The construction process detailed in this section is an in-depth description of one of the steps proposed by Guerrero, Ochoa and Horta [3], in what they called Augmented Object Development Process (AODeP).

AODeP is a method that ensures that all stages in developing augmented objects are addressed focused on the problem to solve and from an engineering perspective.

AODeP was addressed in other studies [1] and some improvements were proposed however no details on the step five were presented. AODeP proposes six main stages to develop an augmented object:

1. Problem definition
2. Context of use definition
3. Requirement definition
4. Selection of the object
5. Development
6. Testing with users

This paper addresses the fifth step of AODeP process. The development of an augmented object, assuming that a problem has been identified and requirements have been gathered; this is the next stage of the process.

Several guidelines are available to conduct a prototype development in HCI literature. However, not many people address the problem of how to augment an object. If an object has been selected for augmentation the idea is to embed the sensors or actuators in it, while changing as little as possible its external looks and of course the original functionality of such object.

We propose a Physical to Digital to Physical (P2D2P) process. Using a 3D Scanner the original object can be digitalized to be redesigned in order to make sure the new components fit the interior while changing the external looks and functionality the least possible. Once the object is redesigned, a 3D print process is used to obtain the new version of the object with the actual size of the original object with the new components.

In this project, we use a NextEngine 3D Scanner HD to obtain the digitalized model. It is necessary to do at least two 360° scans to get a clear model of the original object. The software we used was NextEngine ScanStudioHD. This method creates a virtual representation of the surface geometry. If there are components inside of the original object, such components should be also scanned in order to leave the required space for them in the new version of the object. Once the object is scanned, we export it in OBJ format and import it using Blender 3D computer graphics software [21].

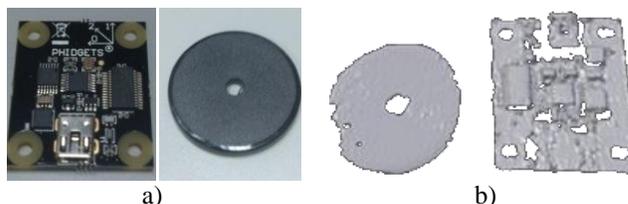| a) | b) |

Figure 1.   a) Pictures of the sensors to be embed in the augmented object. b) Low quality 3D models of the sensors.
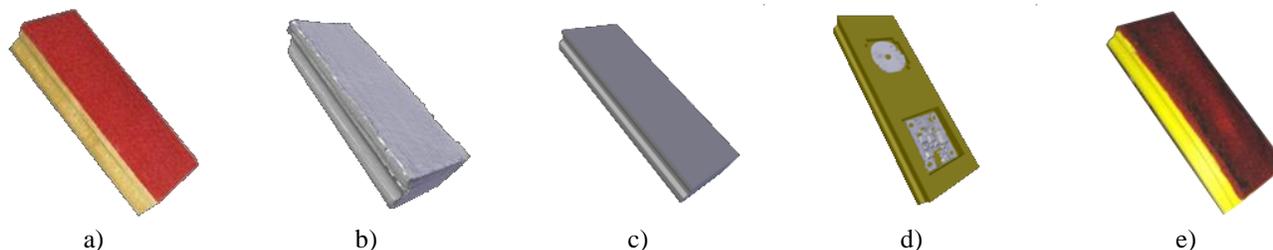
Figure 2.   a) Photo of the original object, b) Digitalized model of the original object, c) Simplified model, d) Redisigned model, e) Printed object

Using this tool we create a simplified model in order to avoid manifold edges, flipped normals or face overlapping. With the new simplified model of the object, the redesign process starts. This process needs to be addressed individually for each object since the object characteristics and the new components are specific to a given problem. For instance, we want to fit a RFID emitter and an accelerometer, both from the Phidgets kit [22], into a board eraser. Figures 1.a and 1.b show the sensors that we want to embed into the eraser. Figure 1.c shows the scanned digital representation of the sensors that would be used to measure and leave the required space inside the new object.

Once the object has been redesigned and the space for the new characteristics has been added, the replication (printing) process begins. The new model is exported in a STereoLithography (STL) format.

To process the STL file we used Replicator G [23] for Windows. Replicator G is the software that drives many computer numerical controlled machines. The model exported from the redesign process is positioned, scaled or rotated as needed to accommodate it in the print bed.

The Flashforge Creator printer is used to print the new object. It uses open source controlling software and ABS plastic filaments. It also provides an accuracy of 0.0025mm on Z and 0.011 on XY axis. The cost for using the printer is US$0.003 per printed inch of filament.

Figure 2 shows the whole process followed:
1. Digitalize the object using the 3D scanner.
2. Simplify the model reducing vertex count and avoiding problems in the model.
3. Redesign the model to fit new and old components.
4. Print and polish the final version of the new object.

Figure 2.a shows the original object to be digitalized, 2.b is the digitalized model without any modification, 2.c shows the simplified model from the digitalized one, 2.d is the redesigned model and finally, Figure 2.d shows the printed object.

IV.   EXAMPLES

This section presents three examples of augmented objects we built using our P2D2P process. We redesign the objects in order to incorporate sensors and actuators to the environment changing few physical aspects of the real objects and context. All the prototypes presented in this section have a software component. However, we will briefly discuss it in this paper since our main goal is to describe the physical redesign of the objects.

A. First augmented object: An automatic post-it note

Email service has been developing for the past 40 years. In the past few years many companies, especially phone builders, have been developing nontraditional interfaces for email services and special notification systems to let people know they have received an important email. It does not matter if the mail is used for personal or business reasons there are always some emails that are more important than others and of course there is also spam mail.

We built an augmented object to notify a user when they have an unread important mail in their inbox. The metaphor that we decided to use was a post-it note, because normally, when you missed an important message, this kind of note is used to let you know about it.

The context of use selected was an office setting and the post-it note is displayed on top of the monitor of the computer, it could be on the keyboard or anywhere else.

The developed system consists of two software parts. One part is a Web page for configuration and the other a daemon that samples the inbox of the configured email account and determines if there is an important unread mail, if so, it sends a signal that displays the post-it note.

The case for this augmented object was printed in order to fit the needed components and so that it would disturb the least possible the context of the post-it. If an unread important mail is detected, a signal is sent and the servo contained in the case shows the post-it, otherwise it hides the note. Since we used general purpose components as sensors, the size of the prototypes are bigger than they would be if more specialized sensors were used.

The physical components of the post-it note are: (1) a servo motor, (2) a servo controller, (3) USB cables and power cable, (4) the note, (5) case and (6) case cover. Figure 3 shows the prototype set in angle to visualize the case and components.

We incorporate an HCI technique in order to validate the experience of use for this prototype. We conducted a Diary Study by asking selected participants to keep a diary of usage over 8 days.

The importance of this study was that the non-intrusive design of the object allowed the participants to keep using the original object as if a regular post-it note was there. The purpose of the notification is achieved when the participant observes the post-it note and realizes he/she got an important unread mail. The main complaint of the participants in the study was that the prototype was wired and that makes it intrusive to the environment.
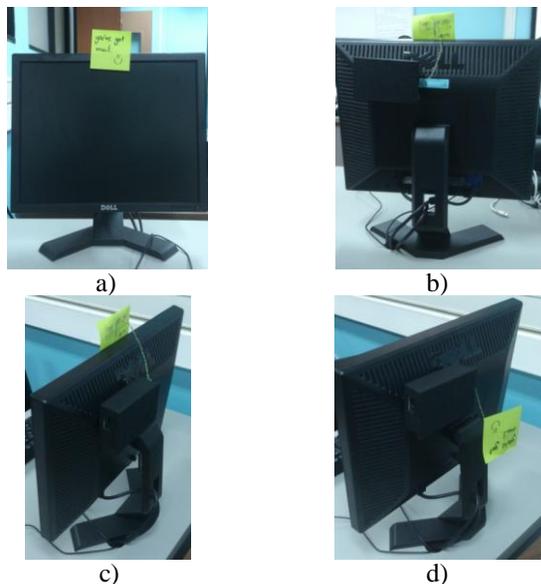
Figure 3.   a) Front picture of the post-it displayed, b) Back picture of the post-it hidden. c) Angle picture of the case and post-it displayed, d) Angle picture of the post-it hidden.

We intent to perform one more iteration with the prototype to create a wireless version. Of course we were not able to redesign the full monitor; so, we developed this prototype trying to have a non-intrusive post-it note without affecting the monitor's functionality.

B. Second augmented object: A whiteboard eraser

One of the biggest problems that ubiquitous computing tries to solve is the automation of environments through what is called ambient intelligence. For instance, we designed an augmented whiteboard eraser to automate a classroom. This device is an example of overcoming the problematic of solid objects when trying to embed sensors or actuators.

Normally, when prototyping the developers attach the sensors on the outside of the objects but this may make them difficult to use, or can change the physical appearance of the object. We found this problem when trying to use a whiteboard eraser for recognition of the professor's presence in a classroom and to know if the whiteboard is being used. The context of use of this prototype is a university setting.

Common whiteboard erasers have two parts: a base and a plush. The base is normally made of wood or some kind of styrofoam and these materials are not pliable enough to insert sensors. On the other hand, the modification of the plush could jeopardize the functionality of the eraser. Therefore a redesign is needed to embed the sensors.

The physical components added to the augmented eraser were: (1) a Radio-frequency identification (RFID) transmitter; (2) a 3 axis sensor; (3) a plastic base; and (4) the plush. Figure 4 shows the original eraser and the printed version. There are no external differences although the printed version contains the sensors. An RFID receiver is on the classroom entrance and on the marker holder on the whiteboard.
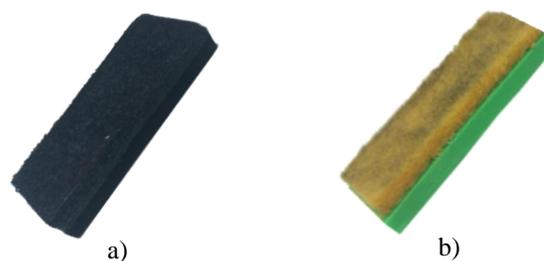

Figure 4.   a) Picture of the physical eraser to be augmented. b) Augmented Object developed using a 3D printer.

Depending on the eraser position the classroom changes settings, e.g., turning the lights on or off.

To evaluate the structure and functionality of the eraser we gave it to five faculty members of the School of Computer Science and Informatics at University of Costa Rica. They just used it as a common eraser and did not know anything about the object or the research goals. Users held it and used it in a common environment and were not able to find any difference between the regular eraser and the augmented one.

One important result of the interviews was that none of the interviewed persons were able to distinguish that there were sensors or anything different about the eraser. One issue that was derived from the questioning of the faculty members was that the erasers are commonly disposable so we should provide exchangeable plushes if we want to continue to use the base and sensors.
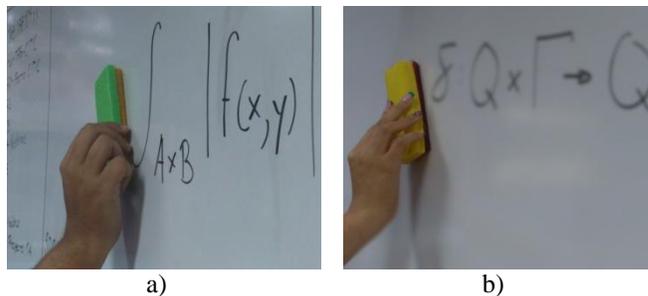

Figure 5.   a) Small printed eraser used in context. b) Big printed eraser used in classroom.

Figure 5 shows the use of the printed version of the eraser. We used two different models to consider external complexity. Figure 5.a shows a rectangular eraser, and figure 5.b shows a more complex 8 shaped eraser.

C. Third augmented object: A real size classic doodler

With the emergence of interactive video beams such as eBeam products [24], most of the interaction is being done by software and clicking in some places of the projection area. In this study, we used a Classic Doodler metaphor [25] to create a real size classic doodler that would allow the user of the interactive video beam to erase a part of the projected scene by using a little slider placed on the marker holder of the whiteboard used to project.

Figure 6.   Front Picture of the printed doodler.

Figure 7.   Picture of the Doodler slider in context

The only hardware component needed to build this prototype was the slider (Figures 6 and 7). In order to embed the slider in the marker holder we printed the holder to provide the space needed for the slider sensor. It is important to mention that this augmented whiteboard requires a connection to a computer. This connection is used in order to interact with the projector software that allows the user to write on the board. Instead of having to interact with a computer, having to erase with the mouse, or create a new blank document to be projected on the screen, the user can simply use the slider at the bottom of the board to erase all the contents of the board.

This object gives extra functionality that does not interfere with any of the other functionalities that the board already has. Finally, this augmented object does not add much cognitive effort in order to use it because of the simplicity of the device.

Figure 8.a shows a projected image with annotations using the Epson BrightLink projector software and the 8.b shows the object being used to erase the comments.
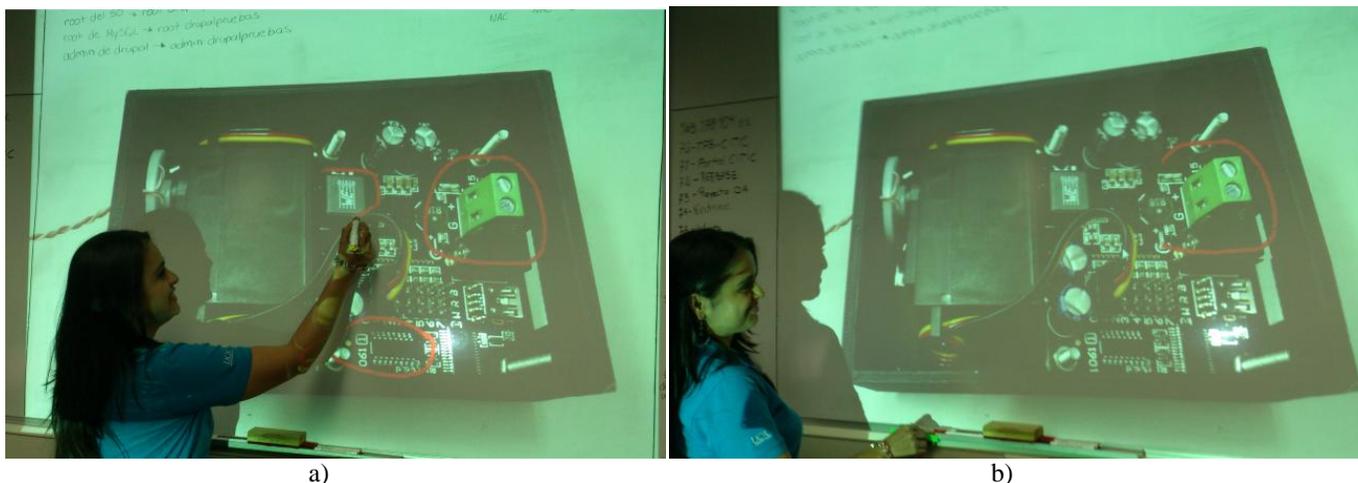
V.   DISCUSSION

In this project, we found that 3D printed prototypes can not only be built to allow embedded sensors but also to enhance their capabilities. For instance, if the sensor to be embedded is a vibration sensor the case could be built to hold the sensor in a better way to enhance its functionality. This characteristic is present in the design of our email notifier. It was built so that the inner workings of the device are not visible to the user except the user sees what should be seen, which is the post-it itself. This ensures that the cognitive load for using the object is low (the physical circuits are hidden).

Another example of a redesigned object was the whiteboard eraser. In this prototype, we performed an interview, and no faculty member was able to distinguish that the sensors that were placed inside the redesigned object. In this way, the principle for ubiquitous computing was achieved: to embed the systems in a way that they are invisible to the users.

We found that printed prototypes can hide the new components to avoid cognitive load for the final users. Printed prototypes also avoid affecting the physical appearance of the object.

In our email notifier prototype, the augmented post-it was an actuator but we occlude it behind the monitor. Therefore, the physical appearance of the monitor remains intact except when the note is displayed.

The most valuable use of 3D printing models for rapid prototyping of augmented objects is the possibility of an internal redesign. As we told before an extensive evaluation of the object that would be redesigned is required. However, once the evaluation is performed the redesign process can help to introduce new devices to increase the object capabilities.

Our eraser validates the fact that, if a solid object is selected to be augmented, an internal redesign would allow the use of sensors without changing the physical appearance and the functionality of the object. However, the use of low cost 3D printers restricts the printing size.

a)   b)

Figure 8.   a) Interactive projector being used to draw some circles over an image, b) Doodler used to erase the previously drawn circles

The quality of the redesigned object can also be affected by the size of the sensors or actuators. With the whiteboard eraser the model was divided and printed in several parts. As an example, the printing time for each of the objects presented in this paper was approximately two and a half hours.

In our research lab, we have been developing prototypes for the past few years without using a 3D printer. We found that a printed prototype is better in terms of cost and quality. Without considering the cost of the 3D printer itself, i.e., considering only the filament and the design and printing time.

The cost for creating 3D printed prototypes is very low, especially if we can use free and open source software design tools. The cost of each of the prototypes presented in this article did not reach US$10 on total printed material cost. The sensors and actuators reach over US$250 (US$90 for the servo controller, US$12 the servo, US$6 for the RFID reader, US$2 the RFID and US$140 the main board controller). These prices correspond to the multipurpose sensors. Specific sensors can be cheaper.

We have found that 3D printing might not be the best option for small models or models that need some very precise parts, because of the coarseness and the quality of the printed object. It can be advantageous when dealing with cases or protective structures. Printing more precise models or devices, or even certain parts of a device that might need more finesse can be very counterproductive due to the lack of precision it provides.

Modeling an object following the process described in Section 3 could be facilitated by using a 3D scanner to digitalize the objects. It is interesting to mention that this 3D redesign process could be incorporated to the development process described in AODeP methodology.

VI. CONCLUSIONS AND FUTURE WORK

The use of 3D printing models can improve the quality of the prototypes and allows a better and quicker evaluation of them. When the prototypes involve an actuator that cannot be easily incorporated into the object, it is useful to create a case to hide the components and reduce as much as possible the cognitive load for the user.

It is important to try not to modify the physical and aesthetic characteristics of the objects when augmenting them. This will help keep the principle of the ubiquitous computing: to make the computer invisible.

The examples presented in this paper show the use of 3D printing in prototyping. However, it is not enough to generate a systematic process of augmented object prototyping. As future work, we will design and create more printed objects and will try to generalize the creation step of the augmented object development process.

Based on the evidence presented in this paper we also present a crucial improvement to AODeP methodology by incorporating the redesign of the augmented objects with a finer level of detail.

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