Which Prototype to Augment? A Retrospective Case Study on Industrial and User Interface Design

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Abstract. Emerging augmented reality and tangible user interface techniques offer great opportunities towards delivering rich, interactive prototypes in product development. However, as most of these are evaluated outside the complexity of. Design practice, little is known about the impact of these prototypes on the resulting product or the process. As a part of a larger multiple-case study approach, this study attempts to explore cues to characterize and improve the design practice of information appliances by performing a retrospective case study. The development of a handheld digital oscilloscope was chosen as an exemplar, embodying complexity in both form giving, interaction and engineering aspects. Although some of the employed techniques have grown obsolete, reflection on this development project still forecasts interesting and useful issues that should be considered while developing new design support methods and techniques.

Keywords: Information Appliances, Industrial Design, Case Study, Design Support.

1 Introduction

Tangible Prototypes and scale models play an important role in the design of physical artifacts. In the field of Industrial Design, ergonomic, aesthetic, mechanic, and manufacturing aspects all need consideration and physical models are often used for exploration, verification, communication, and specification. As summarized in the following section, the combination of physical and virtual artifact models offers new opportunities. It could improve the outcome of the design process, creativity of the designer, and innovativeness of the product. Our focus is on so-called Augmented Prototyping technologies that include principles of projection or video mixing to establish a dynamic prototype at a relatively low cost. We have implemented a number of such systems. This collection has a use of Augmented Prototyping, although a robust evaluation and comparison of other prototyping means is lacking. The resulting systems also showcase the power of tangible computing as natural, embodied interaction. Of course, the use of physical mockups are not a necessary

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condition for success; for example Schrage [11] argues that the insistence of using full size clay models impeded American car manufacturers in maintaining their domestic market share in favor of foreign companies that switched to rapid/virtual prototyping techniques. This leads to our primary interest in question what these advanced prototyping technologies offer for current and future design practice.

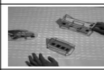
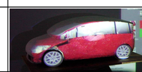
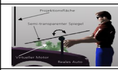
Category	**Geometric Modeling**	**Interactive Painting**	**Layout Design**	**Information Applicances**	**Automotive Design**	**Augmented Engineering**
Impression						
Functionality	General-purpose 3D modeling of surfaces.	2D painting on 3D surfaces.	Real-time simulations projected on floor plans.	Projection of screens on physical mockup, supporting interaction.	Projections on clay or foam models.	Visualization of engineering aspects in physical context.
Application fields	Sculpting/ detailing of shapes.	Exploration of styling curves, material/texture study.	Urban planning, interior architecture.	Usability testing.	Principle styling curves, component selection, material/color exploration.	Simulation of behavior, manufacturing aspects.

Fig. 1. Existing Augmented Prototyping Applications (adapted from [13])

1.1 Emerging Prototyping Technologies

The concept of Augmented Prototyping employs mixed reality technologies to combine virtual and physical prototypes. One of the objectives is to create product models with an embodied/tangible high level of engagement and with a shorter manufacturing time than high-fidelity physical prototypes. At present, a collection of Augmented Prototyping systems have been devised, which can be summarized in the following categories: Geometric Modelling, Interactive Painting, Layout design, Information Appliances, Automotive design, and Augmented Engineering. These are summarized in Figure 1, more details and references are specified in [13]. Of particular interest are the Information Appliances, which are difficult to evaluate with solely physical or virtual prototypes – augmentation to project the screen helps in assessing both physical and cognitive ergonomics. Furthermore, it enables easy rearrangement of keys or exploring interaction techniques (joysticks, touch screens).

From the field of tangible user interfaces, the disposal of physical sensors and actuators or “phidgets” [5] extend the capabilities to simulate and evaluate product interaction. Systems as Switcheroo [1], Calder [8] and [7] offer less cumbersome systems by using passive or active RF wireless communications. STCtools [10] and d.tools [6] offer platforms to model and evaluate interaction on physical mock-ups in the conceptual design stage. Both Kanai and Ayoama [12] present usability measurement methods to fine-tune operability by statistical analysis, which makes sense in detailing stages of design.

Other categories from Figure 1 that are relevant in this discussion are Interactive painting and layout design; both illustrate the naturalness of the interaction, while complicated simulations can be included. For example the Urp system projected calculated shadows, reflections, and wind turbulence on a urban design plan; when buildings were moved, the virtual simulations were updated in real-time. For industrial design engineering, one could extend such simulations to for example mould flow simulations or finite element analysis.

1.2 Multiple Case Study Approach

Although the technologies described in the previous section offer appealing solutions, there is a lack of knowledge on how such advanced prototyping technologies are assessed in practice. Most studies evaluate systems with small groups of people, solely relying on students, and cannot reflect on the overall impact such means has on the design process. The usefulness of such techniques in a design or engineering setting is of a different order than testing internal validity of a tool. Amongst others, Gill et al [4] involves professional design teams, but only for specific activities, which is difficult to judge in complex product realization.

We chose the method of multiple case studies to produce a deep and accurate account of all prototyping and modeling activities [14]. Our approach harbors two types of case studies (“pre”and “post”). In the “pre” phase, three different product realization processes are empirically followed (see following section). These represent a range of industrial design engineering domains, which were considered to be susceptible to support by interactive augmented prototyping [13]. The chosen design domains are: 1) Information Appliances, 2) Automotive, and 3) Furniture. At present, the three “pre”case studies are being finalized. This specific article reports on the case study on Information Appliances, focused on the development of a handheld oscilloscope sold by a large measurement maker in the United States. However, due to the fact that not all conclusions could be finalized, the main contribution of this article is to indicate the complexity of such product development processes and the variety of prototypes. After a short description on the case study approach, we will report on the project characteristics and its implicit complexity. The type of product also yields specific bottlenecks, which are described in section 4. Section 5 contains preliminary conclusion and a specification of future work.

2 Retrospective Case Approach

The research questions formulated in the introduction section are stated as “how” and “why”, suggesting investigations of exploratory, descriptive or explanatory nature. In particular, the instrument of case studies seems to be applicable. As described by Yin [15], a crucial aspect of case study is the combination of the multiple sources of evidence (triangulation). Observations, artifact models, documentation, interviews are all be consulted to establish causal relationships. This provides a means for internal validation. Furthermore, the case study requires a case study protocol: a public document that acts as an agreement on what will be studied between investigator and the subject/company of interest. This section will discuss the details of this specific study.

2.1 Case Selection

Our criteria for case selection were: i) The domain should be identifiable with industrial design engineering products and processes, ii) the domains can be accessed by the researcher in terms of time, resources and openness, iii) the selection of cases should cover a diverse range of products. In meeting the second criterium, finding a representative case in the field of information appliances proved to be difficult, as most developing products are shielded from competitors and external observers are not allowed. As a matter of fact, the only remaining option was to select a product development process that had finalized. In the context of the product design portfolio of the particular manufacturer, we specifically selected the first comprehensive handheld digital oscilloscope – offering both color and black and white LCD displays -as a representative and well-documented example. The resulting product (which is still on the market today) has increased the reputation of the company's brand while the development included a number of design and engineering challenges. As this product development process happened between 1996 and 1999, the developed case study protocol had to be adapted to cater for an historic analysis. The second author acted as the main guide to this process, he was involved in various aspects of the product development as industrial designer. He re-established contact with other former team members/stakeholders and provided access to archived material.

2.2 Sources of Evidence

Information sources for this study comprised of the following: 1) The existing product, 2) interviews with several people of the original design team, including the lead user interface designer and industrial designer, 3) Archived documentation: product specifications (both UI and electrical engineering), several versions of the product development schedule and related resource planning, and 4)Several product and services commercial material with references to this particular product development process. In a period of three months, these data were studied and meetings were planned with former stakeholders. The findings of the study will be presented for verification to all key stakeholders (in principle, the lead industrial and interaction designers). Furthermore, the bottlenecks will be validated by an external expert committee, which will consider the multiple cases in order to harmonize and differentiate bottlenecks and further cues for Interactive Augmented Prototyping. The strategy and procedure of this component has been specified in [14].

2.3 Case Study Components

As Yin specifies, common components of case studies are: 1.) a study's questions (typically 'how' and 'why' questions), 2) its propositions, if any, 3) its units of analysis (measures), 4) the logic thinking the data to the propositions, and 5) criteria for interpreting the findings [15]. The case specific questions, closely associated with anticipated results and data collection methods are presented in the Table 1.

3 Handheld Oscilloscope Design and Realization Processes

The client in this case was a large electronic measurement and diagnostics devices manufacturer. Its brand has a reputation for portability, ruggedness, safety, ease of use and rigid standards of quality. The company in question already had a handheld digital multi-meter with some oscilloscope functions. By demand of the customer base, a dedicated oscilloscope seemed a logical extension of the existing product range. The handheld oscilloscope is intended to be used by service personnel to perform all types of diagnostics in the field. The whole project can be characterized as a typical human-centered design project; it featured usability engineering techniques like concept testing (in focus groups), paper prototyping, and virtual prototyping evaluation on PCs with physical mockups attached. [9]. Most of these evaluations were facilitated by external UI evaluation experts and took place in the United States, as the prospective users were considered to be more outspoken and less trained (i.e. more faultfinding) than Europeans.

Table 1. Pre Case study analysis structure

Case study question (and related propositions)	*Result*	*Data collection methods*
When in the design process are concept utterances generated and used? (P1)	Timeline with design representations	Interviews, planning inspection, pictures of prototypes, design services presentations..
What are the characteristics of these concept utterances? (P2, P5)	List of characteristics	Structured interviews of stakeholders, confrontations with visual materials, product inspection
Which product modeling aspects play a role in these utterances? (P1, P4)	List of aspects per prototype	Structured interviews,
What topics are dealt with as group activities? Who are involved? (P3)	Addition to the timeline of topics: product modeling aspects and who is involved.	Planning documents, interviews
Which bottlenecks occurred during concept uttering?	Collection of bottlenecks, tied to list of concept utterances and timeline/activities. Classification of bottlenecks (impact on overall process)	Product inspection, interviews with stakeholders, process reflections.

Table 2. Product development timeline

Design phase	*Start date*	*Activities*	*Prevalent Design representations*
Market study	March 1996	Exploration market opportunity	-design sketches -rough foam models -interface on paper
Definition	July 1997	Validation of initial concept: technology, market and user research	-3d renderings - foam models - paper test model
Conceptualization	March 1998	Creation of design concepts and design specifications.	- machined sight model - 3d cad surface model - interaction simulation on laptop with ‘ foilkeys’ on front (connected to laptop) - state transition charts for specifying interaction.
Detailing	April 1999	Implementing all relevant aspects of software/hardware.	-Stereolithography model -Casted models -Software alpha release tested with users

The development project timeline is depicted in Table 2. It was based on the structured development method that defined milestones, to deliverables and responsibilities.

The design of the handheld digital oscilloscope included accessories, packaging, and documentation. In particular, new measurement probes were developed in a modular fashion (fitting a multitude of interchangeable tips). Furthermore, the official black and white display was extended by a color version. This mainly affected graphical design, although the size of the screen was increased a few millimeters, which required changes in the key layout. After this project, other alterations of the oscilloscope were developed to suit specific tasks, e.g. power quality measurement and servicing MRI/CT scanners.

3.1 Stakeholders

The development team of this product represented a large number of disciplines. The stakeholders and their most significant information exchange paths are shown in Figure 2. This includes Industrial Design (ID), User Interface Design (UID), Product Planning (product marketing), core technology research and development (technology Innovation), Sales, Mechanical Engineering (ME), Software Engineering (SE), Electrical Engineering (EE), Factory Engineering (FE), and packaging. Not depicted in the figure are project planning and prospective clients. Most stakeholders were employees and had experience with project-based organizations.

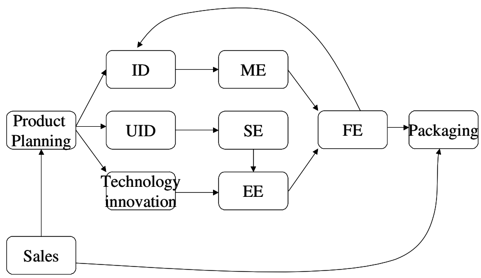


Fig. 2. Flow among internal stakeholders during the development process

The followed development method defined clear boundaries and interfaces between these groups. The product-planning representative steered both the design and technical development. For the technical innovation, this included the development of new sampling and processing chips (ASICs, DSPs), graphical processing units and related custom-made components. For the Interface Design the focus was on the product housing and the button layout. Past products had rather conservative form factors, which were considered to be outdated by the product planning. For User Interface Designers, the main responsibility was to develop a function requirements and a function hierarchy that would best fit the tasks of electronics diagnostics in the field. The development progressed in three parallel tracks with little interaction, delivering the physical design to the Mechanical Engineers, the User Interface Design to the Software Engineers, and the specialized components to the electronics engineers. The end result was then forwarded to the factory engineers who were responsible for the shop floor planning, manufacturing preparation and so on. Some additional information flows can be identified, namely the dimensional data to the packaging department, the involvement of the sales department in both marketing and packaging aspects, and the consultation of the Factory Engineers by the Industrial Designers to test the manufacturability of particular designs. Unfortunately, our case study has not yet evaluated this development process. In its complexity and diversity of disciplines, one could assume to find a number of conflicts of interest among the groups, or particular cultural aspects that influence the decision making process. Such aspects are worthwhile to investigate, as advanced prototyping systems could visualize or bridge those gaps and to find consensus or to acknowledge a certain degree of pluralism.

3.2 Design Challenges

In our initial interviews with the industrial and user interface design representatives, the following topics were considered to be large challenges in the development of this particular product.

- Fitness to task; The task analysis and related navigation structure and mental maps have been given a lot of attention by the user interface designers.
- Making a complex tool accessible to lower educated users. Simple and flat navigation structure was essential for the success of this product
- Screen layout; the limited resolution was a primary concern from start. Font design and graphical layout of presenting measurement data took a considerable amount of time, as extreme conditions (large numbers or information) had to be considered. The introduction of the color version ignited a (unavoidable) repetition of this effort.
- Grasping, ergonomics; as the handheld microscope has a considerable weight (2 kilograms) and size (26x17x6 cm) while the usage context can be quite harsh, the ease of grasping and holding the device for longer periods of time is important. Extra straps and holders were devised to cater for such requirements.
- Button layout; careful placement and size of the keys was crucial. As the digital oscilloscope has more advanced functions than analogue ones (e.g. storing and recalling measurement data, filters and triggering), the keys cannot be directly copied from analogue counterparts. Furthermore, there were technical constraints in locating soft keys as close to the display as possible.
- Probes; the use of the oscilloscope is not limited to operating the console (keys). Picking and touching the intended signals is of crucial, being able to shift between tips and clamps when necessary. Safety regulations also introduced extra complexities, as outdoor measurement of high voltages/frequencies requires physical barriers.

Although this study is unfinished, the design challenges show resemblance to other handheld appliances.

3.3 Characteristics of the Employed Prototypes

Based on planning documents and interviews, we could recreate the following overview of physical models shown in Table 3. We have disregarded all specific prototypes geared towards electronics engineering. In the use, we differentiated between exploration (diverging), verification (evaluation), communication, and specification objectives, as proposed by Geuer [3]. Based on project planning and memory recollection, the amount of prototypes and the duration that it took to develop and use them was estimated. In further discussions, we tried to differentiate the impact that these prototypes had on the development of the handheld oscilloscope. It is interesting to relate the impact to its use, explorative and verifying types of prototypes seem to have a larger significance on the project than specification models. However, this strongly depends on the definition of "impact", something that we will revisit extensively in the cross case analysis (not in this paper). Based on the judgment of the second author, coverage of aspects and fidelity level for each of these prototypes has been estimated; this is depicted in the Appendix.

Table 3. Prototype characteristics

Type	*Use*	#	*Duration (lead+lifetime)*	*Impact on project*
Sketch prototype (foam)	Exploration of dimensions and overall shape.	10	2 weeks	Large
User interaction prototype (PC-based simulation with physical keys on mockup)	Verification and specification of User Interface.	1	2 months	Little
User experience prototype (milled)	Specification and communication of shape details and surface tuning	1	2 months	Little
Mechanical prototype (SLA)	Exploration of inside construction	3	3 months	Medium
Test prototype (PU vacuum casting)	Specification of shell parts.	1x20	2 months	Little
FOOT/SOOT (first/second out of tool)	Exploration in tolerancing and material finish ("feel").	2	4 months	Little
Null series (moulded)	Verification of software and manufacturing	50	4 months	Large

The interviewed design stakeholders expressed some additional remarks on strengths and weaknesses of these prototypes. A main weakness of the sketch prototypes (foam mockups) is that it does not support exploration of the graphical user interface and interactive behavior; the user interaction prototype had an extremely large lead-time and was not easily adapted. Conversely, this PC-based simulation did offer a good platform for usability analysis (related to the user's tasks) and acted as a concise specification of the UI for the software engineers. The User Experience prototype functions as a "design freeze", at approximately 80% of completion of the design aspects. The resulting milled mockups acted as a good internal promotion material and yielded managerial commitment.

Some of these statements can be translated in requirements for prototyping tools, many of these are already supported partially by techniques discussed in section 1.1.

4 Bottlenecks in the Development Process

The retrospective case study has not yet been completed. Definite challenges and bottlenecks have yet to be verified and validated with similar design processes. Furthermore, the technology employed in this project has been subsided by more capable ones, in particular in the field of graphic design and industrial design.

Bottlenecks that could be alleviated by augmented reality systems include:

- The separation between prototypes for interaction and industrial design.
- Specific flexibility in key layout/control selection in consideration with technical feasibility of placement (collisions with internal components etc).
- Complexity of the process, although no related bottlenecks have been not found up to this date.
- Development of embedded graphical user interfaces, with limitations in resolution and size.

Furthermore, prototyping activities in the early part of the project seem to have had a larger impact (combined with their explorative nature). It is interesting to acknowledge that similar opportunities arise later on, at the FOOT/SOOT stage (First out of Tool/Second out of tool). As a final note, we should acknowledge that studying design scenarios of the present might not generate the best solutions for the future. Our only hope is that the inspection of a number of diverse product designs might identify blind spots.

5 Conclusions and Future Work

This article presented intermediate results of a retrospective case study, covering issues in both industrial and user interface design. Although the product itself is meant for a specialized target group (diagnostics of electronic equipment), the characteristics show similarities to other information appliances. In our quest to develop advanced prototyping techniques that have a positive impact on the overall development process, a number of bottlenecks have been identified from revisiting the material and interviews. However, this work has not been completed yet, more effort will be put in investigating issues on project complexity and organizational bottlenecks. Furthermore, the findings will be combined with the currently running case studies.

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Appendix: Specification of Prototyping Aspects