


# Prototyping in Smart Product Design: Investigating Prototyping Tools to Support Communication of Interactive and Environmental Qualities

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## Abstract

The increasing availability of smart products creates a more pronounced need for designers to prototype and communicate interactive and environmental qualities of product during their design process. This paper explores which elements of User journey, Storyboards and Wireframes contribute to communicating these qualities, and how they might integrate with sketching. Results show depictions of user and temporal elements alongside low fidelity sketches are deemed most important. Our findings form the basis to propose and subsequently test combined prototyping approaches in future research.

*Keywords: smart product design, prototyping, communication, design activities, prototyping tools*

## 1. Introduction

New, step-changing technologies, such as the Internet of Things (IoT) or artificial intelligence (AI), have spawned the emergence of novel “smart products” in the market with features, such as being “intelligent” and data-driven (Ng and Wakenshaw 2017). These smart products are becoming increasingly feasible and widely available in a way that was either impossible or only reserved for very expensive technology until only recently. Smart products are defined as a class of products that use advanced technology and have smart features, consisting of physical components (for physical bodies) and data components (for intelligence) (Li et al. 2019), or in other words, tangible components combined with intangible ones. Tangible components (e.g., mechanical, electrical parts) are the foundation of smart products. The value generated by a product’s intangible components (e.g. software) is often anchored in its tangible components (Hoffman and Novak 2018) and regarded as the “enabler” of the product’s software-based functions (Raff et al. 2020). As such, the interconnectedness between tangible and intangible components of smart products dictates the need for a broad range of expertise but also a holistic view across all components as they emerge during the design process. It follows that there is a more pronounced need for designers involved in the process to communicate all elements of the product via prototyping during the smart product design process (Fiorineschi and Rotini 2019). In terms of the tangible aspects, there are numerous well-established tools to support prototyping (Camburn et al. 2017). Although not as well established, a range of prototyping tools for intangible elements also exist. What is lacking are prototyping tools that offer a comprehensive communication of both.

A previous preliminary study (Jing et al. 2021) surveying the use of prototyping tools in Smart Product Design (SPD), substantiates that SPD designers have an increased need for prototyping tools related to interaction design, such as User Journey, Storyboards and Wireframes compared to those mainly involved in Traditional Product Design (TPD). We refer to the named visualisation models as

'tools' in this paper, as the focus of our research is how the relevant visualisations entailed in these approaches are used to create a virtual prototype of the design at hand and as it emerges. Specifically, prototyping tools that communicate the interactive and environment qualities (more detailed definitions are given in subsection 2.1) of the products that arise from the more pronounced intangible elements in smart products. At the same time, the previous survey also indicated SPD still rely heavily on hand sketching to communicate their ideas but indicate such sketches primarily communicate the form and functional qualities of the product. Following on from these preliminary findings, the study reported in this paper aims first to further explore the elements of User Journey, Storyboards and Wireframes that contribute to communicating interactive and environmental aspects of a product. Second, it seeks to understand designers how sketching might integrate with these tools to communicate all qualities more holistically (form, function, interactive, environment) during SPD. The paper first gives some background to the typically used prototyping tools in smart product design, which are more concerned with communicating interactivity and environmental information, followed by a brief review of key elements of these tools. Section 3 describes the method used to organise the survey. Section 4 describes the results of the survey. Conclusions and implications for future design practices in SPD are given in section 5.

## 2. Background

### 2.1. Prototypes and Their Communication of Interactive and Environmental Qualities

There are many different interpretations of the term prototype, especially in the design field. Prototypes are described as a "physical or digital embodiment of critical elements in the design" that can be used "at any point in the design process" (Lauff et al. 2018, p. 10). They can turn ideas into visual objects that can be used to understand design ideas and communicate with others for feedback. Prototypes communicate various qualities of products, such as form and functionality. These qualities are covered well in the previous studies, Virzi et al. (1996) and Sauer et al. (2010) for example. However, qualities of interactivity and environment (Fiorineschi and Rotini 2019) relevant to smart products are researched much less.

Raff et al. (2020) proposed a framework defining qualities of smart products based on the complexity of their software and hardware (the degree of intelligence is gradually increasing). The framework shows that the complexity and layers are growing in the intangible side of the product and thus require greater emphasis in the design process. Considering the complexity of smart products, especially the complexity of intangible aspects are increasing, such as connectedness and smart human interaction (Tomiyama et al., 2019), environment and interactivity will be focused on as in this study. The term "Interactivity" means the quantity and/or quality of possible interaction with users and/or other stakeholders, and "Environment" means the ability of the prototype to communicate the usage environment or context in which the product would be used (Fiorineschi and Rotini, 2019). While these qualities are raised in the literature, there is a lack of literature on prototyping that addresses these qualities.

### 2.2. The Elements of the User Journey, Storyboard, Wireframe and Hand Sketches

In the prior research (Jing et al. 2021), tools such as Wireframe, User journey and Storyboard are most commonly used by smart product designers (SPDs) to communicate environment and interactive qualities to stakeholders. These three tools are also regularly used in user experience (UX) design and interaction design. The tools are mainly focused on illustrating relevant aspects of physical or digital products that are useful, easy to use and provide a great experience in interacting with them and should ideally be used in the early phases of product development (Canziba, 2018). Each of these three tools has a particular focus but none is comprehensive in visualising the smart product under development. In order to develop better support for prototyping and communicating these aspects, we

need to understand these tools in more detail. This subsection includes several definitions used in this survey for clarity and consistency. These also form the basis of the questions used in the survey.

### 2.2.1. User Journey and its Constituent Elements

User journeys are employed to systematise and organise the entire concept of the product, hierarchise the needs of users and the functions of the product, and touchpoints that connect needs with functions (Table 1). They summarise and analyse users' experiences and context (Maioli, 2018).

**Table 1. The elements of the User journey and types of communication**

No	Elements	Description	Communication style
1	Personas	The character(s) represent user needs, goals, thoughts, feelings, opinions, expectations, and pain points.	Visual/ Written/ Verbal
2	Timeline	A finite amount of time or variable phases.	Written/ Verbal
3	Emotions	The feelings experienced by the user at a given moment in time.	Visual/ Written/ Verbal
4	Touch points	What customers are doing, their actions and interactions with the organisation.	Written/ Verbal
5	Channels	Where interaction takes place (the context of use)	Written/ Verbal

Personas are represented by a photo or avatar and function much like Characters in Storyboards. Emotions are usually listed verbally or through graphic illustrations (e.g., emoji). Other elements are recorded in the User journey in written form to facilitate communication between teams.

### 2.2.2. Storyboard and its Constituent Elements

The storyboard is a tool that conveys and expresses vividly, visually the telling of a story. As listed in Table 2, there are five main elements (UX studio, 2019):

**Table 2. The elements of the storyboard and types of communication**

No	Elements	Description	Communication style
1	Character	The specific persona involved in your story defines the main actor's characteristics, expectations, and overall attitude.	Visual/ Written/ Verbal
2	Scene	The place (environment) and setting in which the story takes place.	Written/ Verbal
3	Plot Steps	Narrative the pieces of problems, events, and solutions occurring during the story.	Visual/ Verbal
4	Emotions	The feelings experienced by the user at a given moment in time.	Visual/ Written/ Verbal
5	Scene details	Additional details to rich the story.	Written/ Verbal

Characters are usually presented as character portraits and include simple introductions to the user, typically depicted visually. Plot Steps are drawings within each small box representing the user's interactions and experiences like a comic strip, where scene details are also marked below the picture. Emotions are usually listed verbally or through graphic illustrations. The storyboard shows the experience and the context of a product.

### 2.2.3. Wireframe and its Constituent Elements

The wireframe determines a framework of the elements of an interaction based on the basic conceptual structure (Table 3). The framework is filled with the details of the functions that serve users, and at the same time, point out the direction in which the visual and interface should move (Canziba, 2018).

**Table 3. The elements of Wireframe and types of communication**

No	Elements	Description	Communication style
1	Structure	Elements of user interfaces components – how they are structured, and where they have placed them.	Visual/ Written/ Verbal
2	Content	A list of components, elements, images or text for product design/element within the structure.	Visual/ Written/ Verbal
3	Information hierarchy	Organisation of the information presented to the user.	Visual/ Written
4	Functionality	How the user interface will work, how elements are connected, and how the users' complete tasks using this UI	Verbal
5	Behaviour	How the elements interact with users, how the user interface behaves, and how users act with the UI	Verbal

The first three elements are presented visually and show the operational process. The last two elements rely heavily on the verbal expression of the designers to explain the relationship between the different information layers. It follows that Wireframes focus more on interactivity (depicting a framework of interactions) while User journey and Storyboard show less detail of interactive qualities but more of the product's environment.

#### 2.2.4. Hand Sketches and Their Constituent Elements

According to a previous study, the frequency of use and satisfaction with hand sketches is high in SPD, especially as a low-fidelity tool. The relevant elements of hand sketching and its applications are explained in this subsection. The five elements of sketches are monochrome line drawing, annotations; shading; colour, and 3D form, as categorised by (Rodgers et al. 2000). There are also four explorative categories of design representation (Pei et al. 2011; Self 2019) listed in Table 4. Thus, to support communicating all qualities holistically (form, function, interactive, environment), we want to explore how sketches elements (widely used) may be combined with elements of the tools listed above.

**Table 4. The four explorative categories of sketches**

Category	Description
Idea Sketches	Employed at a personal level to quickly externalise thoughts using simple line-work.
Study Sketch	Used to investigate appearance, proportion and scale in greater detail than an Idea Sketch, often supported by the loose application of tone/colour.
Usability Sketch	A type of representation focused upon usability, suggesting the designer's concern for usability during conceptual design.
Memory Sketch	Used to expand ideas during conceptual design through expression and communication by way of mind maps, notes and annotations.

### 3. Research Design

The overall aim of the study is to understand these tools' key elements in more detail to support communicating interactive and environmental qualities and explore how sketching might integrate with these tools to communicate all qualities more holistically (form, function, interactive, environment) during SPD. As such, we formulate the following research questions:

- RQ1: What are the designers' preferences for prototyping tools (User journey, Wireframe and Storyboard), especially when using these tools to communicate interactive and environmental qualities of the smart product?
- RQ2: Which elements of the above tools are most important to communicate interactive/environmental qualities?
- RQ3: Which elements of the above tools might be combined to help designers to communicate interactive/environmental qualities?

A survey is used to learn from the participants' experiences and further understand their prototyping practices for our study. In the research related to prototyping tools, many scholars (Häggman et al. 2015; Isa et al. 2015; Deininger et al. 2017; Coutts and Pugsley 2018; Coutts et al. 2019) have chosen survey as the research method as an efficient way to ask many participants about the tools they use. This study follows the same rationalisation, aiming to understand experiences from a large sample. The survey is divided into two parts.

1. The designer's views on these three tools concerning the two aspects of interactivity and environment. We divide each tool into different elements to understand the degree of influence of various elements on the quality of communication; for example (Figure 3), "*Rank the effectiveness of the following elements of a user journey to communicate the interactive qualities of the product.*" The question is repeated for each of the three tools to understand environmental qualities.
2. The combination of tools helps designers improve their understanding of interactivity and the environment. Mainly the use of these three tools with Hand Sketches; for example, "*Think about using a sketch in combination with a user journey when communicating your ideas about a smart product. Which qualities/ purposes of a Hand Sketch and which elements in the User journey do you think are most important to communicate interactivity? The question is then repeated for each of the three tools studied.*"

**Table 5. Participant Information**

Occupation	Product designer	Industrial designer	Interaction designer	UX/UI designer
Number	25	20	4	1
Averages age (range)	28.72 (20-38)	26.85 (20-35)	29 (26-33)	26
Average years of professional experience (range)	5.64 (1-16)	4.15 (1-10)	5.75 (2-8)	5

Participants from product/ industrial/ UX/ UI/ Interaction design industries were recruited, including designers with smart product design experience and some without experience. A total of 50 valid responses to the survey could be analysed. The age range of participants is from 20 to 38 years old, and the range of professional experience is from 1 to 16 years. Thirty-eight participants have experience in smart product design (SPD), while 12 do not or were not sure (counted within the TPD groups). Consequently, extensive analysis (4.2 onwards) excludes those 12 without SPD experience.

## 4. Results

### 4.1. Frequency of Using User Journey, Storyboards and Wireframes

Firstly, the ranking of the three tools will be explored to understand how often the three tools were used in practice. It looked at whether participants used the three tools frequently or occasionally as a primary (who use these tools as their preferred design tool) or secondary (who use these tools as their aid/support primary tools). The results are visualised in Figure 1, and this data is used to answer RQ1. Figure 1 presents frequency in terms of 4 categories (Don't use, Frequently used, Infrequently used, Don't know). The bar chart then shows the percentage of respondents indicating categories for the three tools and between the SPD and TPD groups.

In the SPD group, the Wireframe is the most frequently used tool, while storyboard is used most infrequently. In TPD group, the wireframe is used substantially less than the SPD. User Journey and Storyboard are used with similar frequency by both groups. Also notable is that only two participants with an SPD background do not use or do not know storyboards. Those remaining after the two are subtracted experiences with these tools, giving confidence that all participants surveyed have experience with the tools investigated.

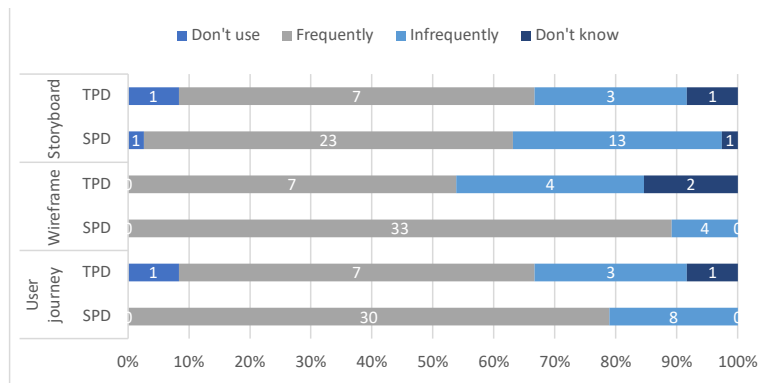


Figure 1. Frequency of using tools (Responses to: “Which prototyping tools do you use in the early stage of the smart product design process?”)

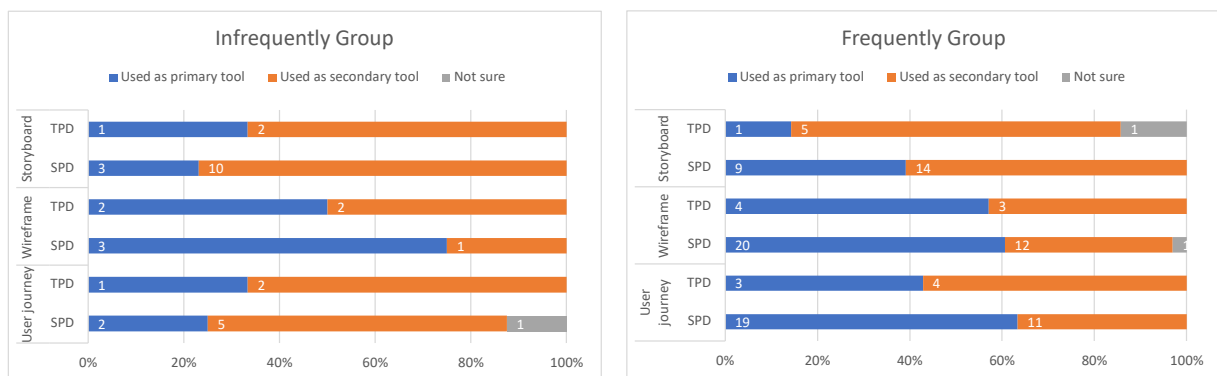


Figure 2. Specific roles of the three tools

Figure 2 illustrates the breakdown of primary or secondary use of tools. Logically, in the Infrequently used group, these three tools are used as a secondary tool. The storyboard is mostly used as a secondary tool, followed by the user journey. Wireframe and user journey are largely used as primary tools in the frequently used group, and the storyboard is still typically used as a secondary tool.

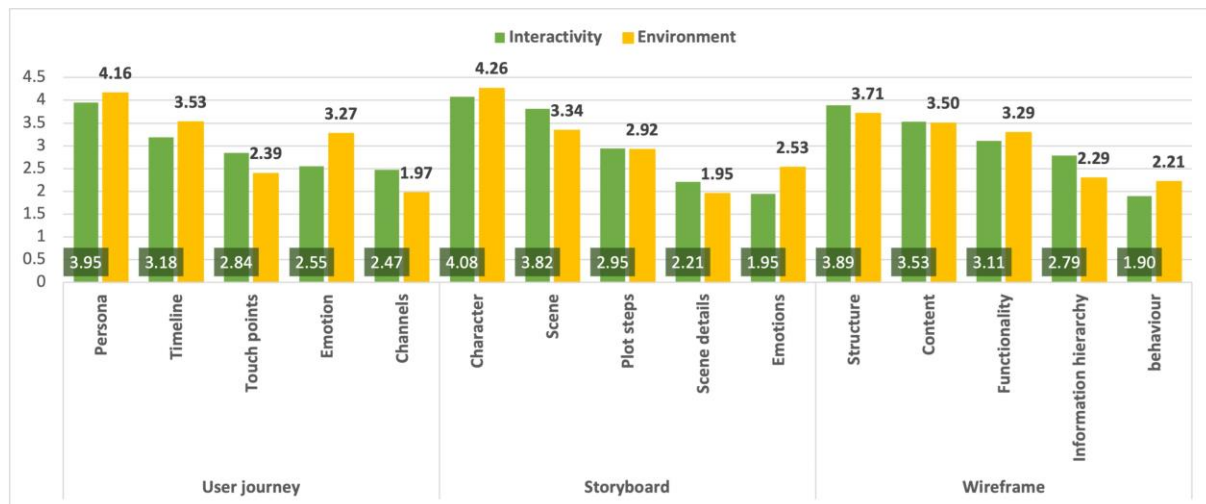
## 4.2. Different Ranking of Key Elements in the User Journey, Storyboard and Wireframe

In this section, the analysis of two main ranking questions is included. Firstly, the ranking of important elements to communicate interactivity and environment within each tool. Secondly, the ranking of the most helpful combination support from two different tool's elements. This data will answer RQ2 and RQ3, respectively.

### 4.2.1. User Journey

The data in Figure 3 is the average for each element. The first element ranking counts as 5 points, and the fifth counts as 1 point. The element most effectively used to communicate the interactive qualities of the product in SPD group is Persona, which is also the same within the environment. There is only one difference in the ranking of elements in interactivity and environment; in interactivity, the touch point is above the emotion, while it is the opposite in the environment.

Table 6 presents data resulting from the group of questions (on Page 5) (*Which qualities/purposes of a Sketch and which elements in the User journey do you think are most important to communicate interactivity/environment?*). And then, I repeat it for the other tools, like Table 7 and Table 8. These data were retrieved from a ranking question: First important: score 5; Second important: score 3; Third important: score 1.



**Figure 3. Ranking of elements in terms of effectively communicating interactive/environmental qualities. Ranking for user journeys is shown on the left, storyboards in the middle and wireframes on the right**

The combination support 1 is a combination of sketching elements and tool elements, and combination support 2 is a combination of sketching purpose and tool elements (as shown in Table 6). When discussing interactive qualities, in combination support 1, the first three important elements in the sketch are monochrome line drawing, 3D form and annotations. The first three important elements in User journey are Persona, Emotion and Touch points. In combination support 2, the first three important purposes in the sketch are Idea, Study and Usability. The first three important elements in User journey are Persona, Timeline and Touch points. The results of environment qualities are slightly different from those of the interactivity.

**Table 6. Preferred combination of elements to support communication of interactive and environmental qualities (User journey + Sketch)**

	Combination support 1				Combination support 2			
	User journey Elements		Sketch Elements		User journey Elements		Sketch purpose	
Interactivity	Persona	3.41	monochrome line drawing	4.42	Persona	4.03	Idea	3.74
	Emotion	3.19	3D form	3.40	Timeline	3.52	Study	3.34
	Touch points	3.14	annotations	2.68	Touch points	2.71	Usability	2.33
Environment	Persona	4.33	monochrome line drawing	4.16	Persona	4.13	Idea	4.03
	Timeline	3.50	annotations	3.08	Timeline	3.20	Study	3.14
	Emotion	2.53	3D form	2.89	Touch points	2.60	Usability	2.56

#### 4.2.2. Storyboard

The element most effectively used to communicate the interactive qualities of the product in SPD group is Character, which is also the same within the environment (see Figure 3). There is only one difference in the ranking of elements in interactivity and environment; in interactivity, the Scene detail is above the Emotion, while the environment is opposite. When discussing interactive qualities, in combination support 1, the first three important elements in the sketch are monochrome line drawing, annotations and shading. The first three important elements in Storyboard are Scene, Character and Plot steps. In combination support 2, the first three important purposes in the sketch are Idea, Study and Usability. The environment qualities' results are the same as those of the interactivity (as shown in Table 7).

**Table 7. Preferred combination of elements to support communication of interactive and environmental qualities (Storyboard + Sketch)**

	Combination support 1				Combination support 2			
	Storyboard Elements		Sketch Elements		Storyboard Elements		Sketch purpose	
Interactivity	Scene	3.59	monochrome line drawing	4.23	Character	4.19	Idea	3.80
	Character	3.48	annotations	3.41	Scene	3.43	Study	3.69
	Plot steps	2.71	shading	2.68	Plot steps	2.48	Usability	2.87
Environment	Character	4.17	monochrome line drawing	4.25	Character	3.94	Idea	3.81
	Scene	3.78	annotations	3.45	Scene	3.62	Study	3.40
	Plot steps	2.48	shading	2.84	Plot steps	2.71	Usability	2.33

### 4.2.3. Wireframe

As shown in Table 8, the element most effectively used to communicate the interactive qualities of the product in SPD group is Structure, which is also the same within the environment. There is the same ranking of elements in interactivity and environment.

**Table 8. Preferred combination of elements to support communication of interactive and environmental qualities (Wireframe + Sketch)**

	Combination support 1				Combination support 2			
	Wireframe Elements		Sketch Elements		Wireframe Elements		Sketch purpose	
Interactivity	Structure	3.44	monochrome line drawing	4.03	Structure	3.92	Idea	3.87
	Content	3.09	annotations	3.07	Content	3.85	Study	3.59
	Information hierarchy	3.00	3D form	2.68	Information hierarchy	2.76	Usability	2.33
Environment	Structure	4.46	monochrome line drawing	4.33	Structure	3.97	Idea	4.10
	Content	3.59	annotations	3.07	Content	3.46	Study	3.37
	Information hierarchy	2.76	3D form	2.90	Information hierarchy	2.77	Usability	2.45

When discussing interactive qualities, in combination support 1, the first three important elements in the sketch are monochrome line drawing, annotations and shading. The first three important elements in Wireframe are Structure, Content and Information hierarchy. In combination support 2, the first three important purposes in the sketch are Idea, Study and Usability. The environment qualities' results are the same as those of the interactivity (as shown in Table 8).

## 5. Discussion

Results on the frequency of using tools indicate Wireframe is used most frequently, while User journey and Storyboards are used marginally less frequently. None of the three tools is used substantially more than the others. The type of use (primary/secondary) indicates that many participants use these tools as secondary tools. This suggests that often these tools are used alongside other tools (used frequently as a secondary tool or infrequently as a primary tool). With respect to RQ1 (preferences for tool use), we see a high proportion of SPD use these tools, but if so, then mainly in combination or in support of other tools. This is notable as it substantiates the diverse range of tools required in SPD and the prospect to combine elements of these tools with other tools, such as sketching.

Concerning RQ2, we see the importance of elements ranked similarly for communicating interactivity and environmental qualities for each of the three tools. For example, Personas in storyboards are



ranked the highest for interactivity and environment. There is also some alignment between tools. The Character in storyboards is ranked highest much like the persona in a user journey. After user depiction/explanation, description of context or temporal aspect of the product interaction (timeline for User journey and plots steps and scene for storyboards). Regarding Wireframes, structure, content, and functionality are relatively close in level of importance. This indicates that information about the user is highly important to communicate interactivity and environmental qualities of prototypes, followed by information that describes context or temporal aspects of the product use (timeline, plot steps, structure and scene).

In terms of possible combinations with sketching, data corroborates the importance of user and contextual information (see highest ranked elements in Tables 6-8). Regarding the elements of sketches and purpose, participants prefer lower fidelity sketches, the idea sketch, focusing on communicating overall ideas rather than significant detail. Interestingly, the usability sketch is only ranked in third position or lower. We expected this to be ranked higher because of the focus on interactivity qualities. A possible explanation relates to the preference for lower fidelity sketches and an expectation for usability sketches to be higher fidelity.

In answering RQ3 (tool combinations to help designers communicate interactive/environmental qualities?), data indicates ideal combinations would be low fidelity sketches that incorporate some user depiction and illustrate temporal/timeline. The data indicates the use of annotation to assist in this rather than depicting elements visually in a high level of resolution/fidelity. Temporal or contextual elements could be illustrated visually but using the approach of Wireframes to create an overall structure of interaction. In summary, we contend the above combination of elements would support a more holistic communication of tangible and intangible aspects of smart products.

Data generated from the survey is rich in terms of how tools are used and the respective important elements. It forms a valuable starting point for exploring the qualities of these tools that contribute to communicating interactive and environmental aspects. Nevertheless, given the limited total sample size of this study and the uneven distribution of participants' occupations, there are natural limitations to the extent to which we can conclude about general best practice in smart product design. A larger sample size would also enable a better comparison of data from the traditional product designer group to the smart product designer group. Likewise, a more comprehensive study covering different smart products would provide more general conclusions about how best to account for smart products' interactivity and environmental qualities. Our confidence in possible combinatory support is limited as participants were asked to imagine possible combinations. The manner in which a combination is implemented is the subject of further research and thus not shown in the survey reported. Hence, further work will focus on creating different combinations of support in line with this study's findings. Likewise, further research will seek to test possible combinations to validate how the inclusion of relevant elements from the Storyboard/User journey/Wireframe in the sketches contributes to the quality of the communication.

## 6. Conclusion

Research addressing the new paradigm of smart products is increasing, but extant literature lacks exploration of prototyping tools and approaches that are designed for the particular requirement of smart product development. The study reported in this paper follows on from earlier research indicating the importance of User journeys, Storyboards and Wireframes as tools to communicate interactive and environmental qualities of products being designed. The study presented in this paper explores the elements of these three tools that contribute to communicating interactive and environmental aspects of a product. Second, it seeks to understand how these tools might be integrated with sketching. Results show that elements relating to the target user and context/temporal elements are considered most important to communicate interactive and environmental qualities. Possible combined approaches should integrate these elements in lower fidelity sketches relying primarily on monochrome line drawings and annotation. These findings provide a clearer picture of the more important elements of existing tools in the practice of smart product design. The findings of this paper set the foundation to create and test such combined and hybrid prototyping approaches. Future

research to test their efficacy in communicating are qualities of smart products (form, function, interactivity and environment) holistically to a range of stakeholders.

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