Bridging the Theory–Practice Gap: Lessons and Challenges of Applying the Attachment Framework for Sustainable HCI Design

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ABSTRACT
Despite significant progress in sustainable HCI towards theoretical frameworks to guide design, there is a gap between theory and practice, so that the impact of such frameworks is limited. As an initial exploration in bridging the theory-practice gap, we conducted a study using one well-established design framework, the Attachment Framework, to evaluate its applicability in use. We conducted a comparative study with 14 designers to explore the effect of the Attachment Framework on design, and evaluated their designs with 10 design experts using a set of six design criteria. Our results indicated a positive effect on the criterion of novelty, with mixed effects on attachment, presentation, aesthetics, usefulness, and feasibility. We contribute a set of challenges in the application of design frameworks to practice and offer a critical reflection on how researchers can more effectively communicate sustainable HCI design frameworks to practitioners.

Author Keywords
Sustainable HCI; Frameworks; Product Design; Attachment

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H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Research in Human-Computer Interaction (HCI) often ends with design implications, guidelines, or frameworks that aim to guide future design. This can also be observed in the field of sustainable HCI (SHCI), which has seen a tremendous growth in design framework contributions in recent years. However, little research attention has been given to applying such design frameworks to practice [8, 29] where as a result, the practical impact of such frameworks is limited. We argue that the SHCI community should intensify its efforts to bridge the theory–practice gap in order to increase its impact on sustainability issues.

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As an initial exploration into this complex space, we conducted a comparative study using one well-established framework as a case study. The Attachment Framework [10, 26] is an empirically produced framework in the field of SHCI based on the concept that consumers who develop a notion of attachment to a particular device are less likely to dispose of it, ultimately leading to less obsolescence and therefore more sustainable behavior. In order to understand the applicability and value of using this framework in the design process we had 14 designers design a tablet computer that would foster such attachment, having 7 of the designers use the framework in their design and 7 not. Our main research question was: *What is the effect of using an empirically based theoretical framework from SHCI literature on the design process and outcome for SHCI?*

In order to assess the use of the framework we had 10 design experts assess the quality of the designs according to six criteria derived from the survey on product design literature [7, 23] and basic industrial design principles [37]: attachment, novelty, presentation, aesthetics, usefulness, and feasibility. Our evaluation results indicated a positive effect on novelty, where a subsequent evaluation suggested a clear link between novelty and attachment. However, we saw mixed effects of the Attachment Framework on the other five criteria. Based on a synthesis of the insights from our study as well as previous work in design research literature, we offer a deeper understanding of the challenges in applying theoretical frameworks to design practice.

We make two contributions: 1) We report on lessons learned in the application of the Attachment Framework for SHCI design, based on a set of six design criteria; 2) We identified a set of challenges in applying SHCI theory to practice. We discuss these challenges in light of design research, where our goal is to provoke rethinking of how researchers in SHCI can communicate SHCI knowledge to practitioners and designers outside of the field.

RELATED WORK
The lack of theoretical contributions being applied to design practice, commonly referred to as the "theory–practice

gap", was discussed in the last decade [e.g., 30, 36] and is still an ongoing topic [e.g., 29, 34] in the CHI community. This point has also been raised in SHCI, and some seminal works have argued for application of SHCI research to design practice [e.g., 3] or criticized the lack thereof [e.g., 8]. Previous work in SHCI has looked at successful examples of sustainable interaction design, in particular in the domain of eco-feedback technology, which has been one of the most active fields within SHCI. For example, Pierce and Roedl [27] as well as Strengers [34] looked at existing eco-feedback technology in the home, highlighting sustainable design in the wild as success stories and drawing valuable lessons for the field. Furthermore, several researchers have built prototypes for the sake of field studies in various domains, such as citizen science [e.g., 1, 20, 21] or water conversation [e.g., 2, 21] that highlight examples of SHCI design in practice, as a proof of concept and often applied by SHCI practitioners themselves.

While these efforts demonstrate that SHCI is addressing the concerns raised about HCI design principles in general (i.e., that those principles are not even applied by the researchers in the respective field itself [e.g., 30]), there is still a gap between available frameworks and their application to real-world practice. The goal of sustainable interaction design is to make environmental sustainability a central focus in design practice [3]. A variety of theoretical contributions offers opportunities for such high-impact design, e.g., design principles for sustainable mobile phones [18], more ecological use of time and travel [28], or resource consumption in the home [4], to just name a few. This design knowledge is frequently used to fuel other ideas in SHCI and these works have yielded fruitful discussion within the community – however, there is little evidence that it is being transferred to practice and little knowledge of how well it could support design. There are case studies about students [16], do-it-yourself practitioners, [20] and professional product designers [15] that investigated the use of sustainability principles being put to design practice. In this paper, we present a similar approach and report on a comparative study including an expert analysis to yield qualitative insights about the value of one SHCI theoretical framework – the Attachment Framework.

THE ATTACHMENT FRAMEWORK

One of the many problems that SHCI is trying to tackle is that of obsolescence [38, 18]. By encouraging longer use of devices, the *Attachment Framework* [26] presents a solution from SHCI research to tackle this issue. We believe that the Attachment Framework lends itself particularly well to a case study of exploring SHCI design practice as it is a well-established, empirical framework that has recently been extended, and first attempts of applying it to practice have suggested its usefulness [10]. In their initial study, Odom et al. [26] surveyed people about objects that they felt attached to, such as heirloom items, collected stories about the shared history between the object and the owner, and identified common themes for the attachment's reason. The resulting Attachment Framework offers design principles, accompanied with examples, which can be applied to new designs to achieve a similar effect. The Attachment Framework was extended by a follow-up study which in particular aimed to identify design principles for fostering attachment in the domain of consumer electronics [10], resulting in seven principles:

- **Histories**: Preserve memories connected to the device
- **Augmentation**: Re-use beyond its intended purpose
- **Engagement**: Promote physical engagement in use
- **Perceived Durability**: Long-lasting in terms of function or longevity or both
- **Earned Functionality**: Device is continued to be used because of the effort put into becoming familiar with it
- **Perceived Worth**: High perceived value of the device
- **Sufficiency**: Capable of serving its intended purpose

STUDY DESIGN

In order to understand the impact of theoretical frameworks from SHCI applied to design, we choose tablet computers for the design activity. We gave an extended version of the Attachment Framework [10] that is specifically directed towards electronic devices to designers and assessed the outcome in terms of quality of overall design as well as the understanding and interpretation of the attachment values as a means of evaluation. Using an extended version of the Attachment Framework that is directed towards electronic devices allowed us to use picturesque examples "as is", thus reducing potential bias in our study design. The benefits of using examples to foster the creation process have been studied in HCI before [17]. In the following, we will elaborate on the study design (step 1), the evaluation of design quality (step 2), and our analysis of

Step 1: Data Collection

We asked designers to create 2-4 preliminary design sketches of a tablet computer that fosters a strong bond between the device and its owner. We explained the basic concept of attachment as a way to promote environmental sustainability in a brief statement without giving away any details of the framework's design principles. Participants were then divided into two groups, with one of these groups receiving supplementary material explaining the Attachment Framework in detail, and the other group acting as control group that was not given any further advice. This ensured that both groups were on the same track with regard to their design goal, and the only difference was the framework whose value we wanted to assess. The supplementary material included a four page document with the Attachment Framework principles (engagement, earned functionality, augmentation, histories, perceived durability, perceived worth, sufficiency; cf. [10]). Each of the principles was illustrated by 2-4 non-technical examples by using unaltered participant quotes from the original study (cf. [11]). The design task was created in collaboration with

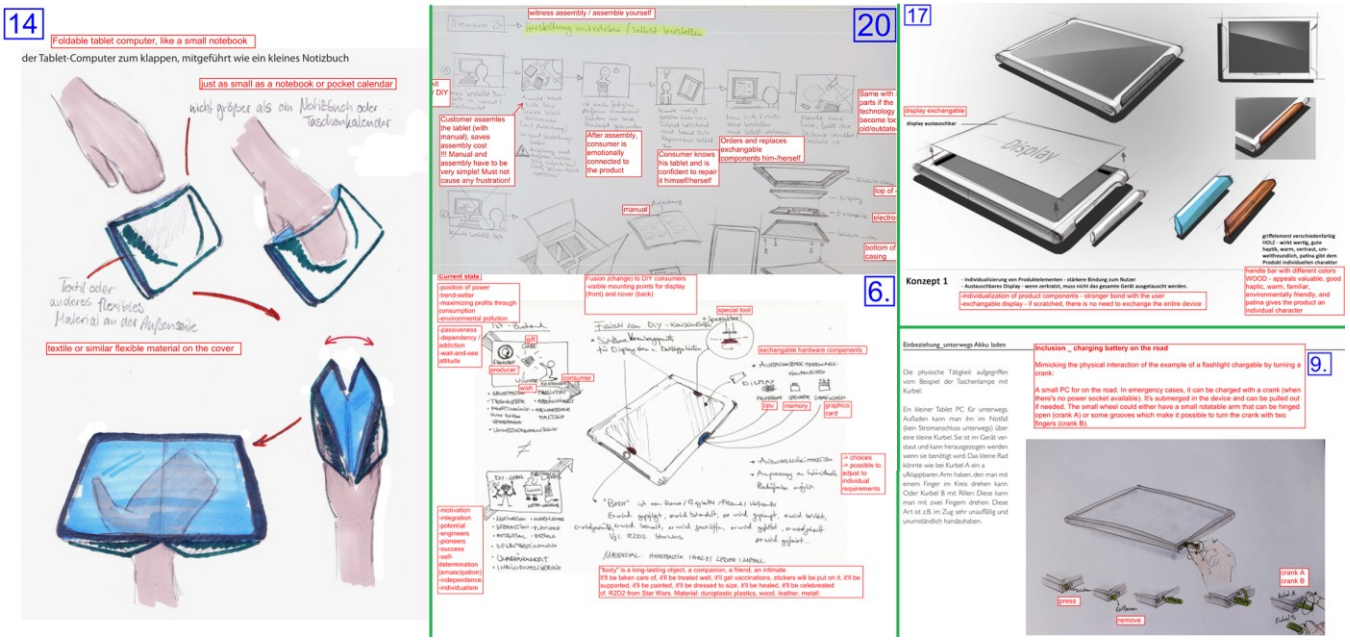

Figure 1: Four examples of the design sketches as presented to the design experts for the evaluation: designs CD5 (left), CD19 (top middle), FD 11 (bottom middle), CD12 (top right), and FD17 (bottom right).

a design expert and piloted with three designers to ensure that it did not deviate from the designers' typical process.

Fourteen participants were recruited using convenience sampling and split into two groups, having equal size of the framework group and control group (7 participants). Participants averaged 3.8 years of experience (st. dev. 1.6 years) and were compensated with an equiv. $100 US Amazon voucher. Participants' expertise was in product design, except for one participant who was an interaction designer. Their secondary expertise was in industrial design (four participants) and architectural design (two participants). Gender distribution was equal (seven female, seven male). Majority of participants were between 20 and 29 years old, and one was in his thirties. All designers were recruited in major central European cities and the study was carried out in the participants' native tongue. Based on their background information and previous experience, both groups of designers had similar experience in practice.

The designers received their task via email and sent us scanned copies of their design sketches. We asked them to include explanatory details, such as annotations, descriptions, or storyboards with the design sketches. Altogether, the participants generated 40 design sketches (21 from the group with framework, 19 from the control group), from 1 to 5 per designer. After completing the design task, all participants answered survey questions about their design background, previous experience in "green design", their typical design process, their approach for this particular task, and their thoughts about the activity (e.g., satisfaction with their sketches and difficulty of task). Four of the designs can be seen in Figure 1.

Step 2: Evaluation by Design Experts

To assess the value of the Attachment Framework and see what effects it had on the designs, we recruited ten design experts to analyze the sketches according to six different criteria. Besides the "attachment" criterion, which resembles the basic idea of the Attachment Framework itself, it is important to consider other aspects of design as well, since attachment alone does not suffice for a design to be successful or of good quality. The criteria were developed from surveying product design literature [e.g., 7, 23], product design award criteria [e.g., IDEA[1], iFDA[2], Red Dot Award[3]], and basic industrial design principles [e.g., 37]. They were refined through pilots of the evaluation with design experts, and the final criteria were:

- Attachment (does the design encourage longer use and foster attachment between the device and its owner)
- Creativity and novelty (is the design idea original)
- Presentation (is the design clearly communicated and well-presented)
- Aesthetics (how aesthetically pleasing is the design)
- Usefulness (would a product based upon this design be useful and effective)
- Feasibility and credibility (is the design idea feasible, credible, and applicable to a real-world product)

The design experts (two female, eight male) had an average of 4 years of training experience (st. dev. 1.6 years) and 7.5

[1] http://www.idsa.org/idea-2014-entry-rules-criteria-instructions
[2] http://www.ifdesign.de/awards_product_index_e
[3] http://red-dot.de/pd/jury-2012/adjudication-criteria/?lang=en

years of working experience (st. dev. 4.6 years). Participants had a diverse, often multidisciplinary background and identified their specialization as product design (7), interaction design (7), industrial design (4), and graphics design (2). While we told the evaluators that the task was to create tablet computer design sketches that fostered attachment, we did not give them the Attachment Framework itself nor told them that this was a comparative study in which one of the group received such a framework. Since pilots revealed that the evaluation takes a significant amount of time, we decided to split the designs into two groups of 20 designs each, resulting in two interchangeable sets. All annotations and descriptions on the design sketches were translated to English and were visually distinct (red text box) to distinguish our text from the original design sketch. We encouraged the experts to be critical since we did not pass the feedback to the designers.

We asked designers to select up to three designs that they felt best met each criterion and provide a justification for their choices. Pilot participants expressed concerns about exhaustion towards later criteria that might result in shorter answers, which is why we alternated the order of questions using a Counterbalanced Latin Square distribution. Participants had a choice to complete the task digitally at their computer or hand-written on paper, as the evaluation sheets were printable PDF forms. The activity was accompanied by a short eight-question survey about their background, design process approach, and experiences with regard to sustainable design. Participants received an Amazon voucher worth $50 US or 40€, as preferred.

Step 3: Analysis and Attachment Evaluation

For the analysis of the evaluation results we were mainly interested in qualitative data from the design experts' justification for their selected designs. We analyzed the data using open coding to search for common themes across the comments for each of the criteria on the quality of the design sketches, in particular themes that would only occur for either the framework or non-framework condition. Our approach was to find patterns and themes in the evaluation responses, according to the six different criteria.

The criterion "attachment" was arguably one of the most important ones to us, as it aimed to assess the core aspect of the framework and how designers interpreted it. However, most design experts indicated in their survey background questions that they had no in-depth knowledge of or experience with sustainable designs, and none of the experts had any knowledge about the Attachment Framework as such. Therefore, we added an additional evaluation step by asking three Attachment Framework experts to go through all 40 designs and, for each of the seven Attachment Framework criteria, decide whether or not they think the design exhibits this particular criterion.

We will refer to the designs as FD1 to FD21 for the designs from the framework group and CD1 to CD19 for the designs from the control group. E1 to E10 refers to comments from the evaluators. For example, E7-FD13 would be the justification provided by evaluator 7 about why she picked design number 13 (which happened to be from the framework group) for a specific criterion.

Limitations

Despite the relatively high incentive, all participants recruited for the first study were relatively young and had only a few years of working experience. One of the reasons may have been the rather substantial work load of the study (pilots indicated an estimate of four hours of work time). Another limitation was the fact that both studies were conducted remotely; however, especially for recruiting evaluators a remote study allowed us to get a diverse set of experts from all over the world. Furthermore, we only look at one specific family of devices with tablet computers, and we acknowledge that the results might not be representative findings regarding attachment for other technical devices.

RESULTS

In the following, we report on the insights from our data analysis in detail, grouped by the six design criteria that were used in the expert evaluation. While the framework seemed to have no effect on the *attachment* values communicated in the designs, there was a noticeable effect on *novelty and creativity* of the designs. However, this advantage came at the price of seemingly losing out in two other criteria, *aesthetics and presentation*, and a tie in the *usefulness* and *feasibility* criteria. Overall, the non-framework designs were mentioned slightly more often than design concepts by the framework group (85 vs. 72, not significant with $p=0.102$ for χ^2), and the qualitative results did not clearly favor one of the groups either.

Attachment

Since the task was to create a tablet computer that fostered attachment and this study is about evaluating the impact of the attachment on design, this was arguably the most important design criterion for us. Therefore, the results of this part of the evaluation were the most surprising for us: we found no evidence that the group of designers that had been given the Attachment Framework produced any better results in that regard compared to the control group. Our design experts selected eleven designs from both groups respectively that stood out as showcasing a particular idea of encouraging a stronger bond between a device and its owner. Likewise, the derived themes from the design experts' responses spanned across both groups of designs.

One design concept that was frequently mentioned was the material and its ability to develop patina or a worn-out effect over time, as was mentioned by these two evaluators: *"the use of tin as material is unconventional and nice. tin tells a story. it is used by products that proved to be able to survive under all circumstances. using materials that collect patina is essential I think.it makes a product a*

personal belonging" (E6-CD1) and *"The feeling of attachment comes when something looks more aesthetic and apealing. The unique patina background will help the user with that sense of attachment. An analogy to the above is my jeans. The older it turns the more attached and more comfortable I am to that jeans" (E10-CD15).*

Similar remarks were made by other design experts (e.g., E1-CD15, E3-CD5, E4-FD12, E4-FD18, E5-CD15). Another example for a design approach that participants thought of as fostering attachment was that of being able to replace parts (FD11 and CD19, see Figure 1): *"Exchanging parts will keep the device up-to-date through more than just software updates. It is less likely to become obsolete."* (E1-FD11) and *"the possibility to exchange parts as they break or because of changing preferences helps the product to survive over a longer period of time"* (E4-CD19). Other themes that we found in our analysis were personalization of the device's hardware (E3-FD6, E5-FD11, and E8-CD10) and software (E3-CD16, E8-CD16, E9-FD5, and E10-FD21).

Evaluation by Attachment Experts

One might argue that this result is not surprising or has little validity as the design experts were no experts for sustainable design or had no knowledge of the Attachment Framework besides the short introduction provided by us. However, the evaluation of attachment criteria by the Attachment Framework experts yielded similar results: counting every single instance of attachment identified in all of the designs, the evaluators found 103 in the framework group and 77 in the non-framework group (not significant with $p=0.246$ for χ^2). This becomes even more apparent if we look at instances for which two or all three evaluators agreed on one criterion for a specific design: for eleven (framework) and eight (non-framework) designs all experts identified the same criterion; for fourteen (framework) and twelve (non-framework) designs at least two experts agreed on the same attachment value. An interesting observation was that there was less agreement on the attachment criteria than one might expect, especially given that all three evaluators had the same background.

Novelty

In terms of novelty of the design ideas, this was the only of the six design criteria where the framework-supported designs achieved clearly better results in the evaluation. The design experts deemed ten such designs as more creative and novel (17 comments), and only five of the control group (seven comments). We found three themes that were present in both groups: unusual choice of material (E7-CD1 and E10-FD6), development of patina (E6-FD18 and E10-CD15), and an adaptive user interface:

"This design concept focused on an interface that adapts to the user and gets to know her, in turn building loyality. It anticipates my needs - a big trend as we move to smarter devices and software." (E1-CD16)

"I think the thought about the computer interface that adapts to the user is quite novel and is definitely a step forward from todays UI paradigms" (E4-FD5)

A similar notion was observed by the same design expert in E4-FD21. Furthermore, two design concepts were mentioned for the non-framework group only: a foldable display (E2-CD4, E4-CD4, E5-CD5) and a design sketch that showcased multi-purpose use in context (E5-CD9), which was praised for its flexibility. Interestingly, a sketching tablet received critical acclaim for the opposite concept – a single-purpose device focusing on one task only (E6-FD9). All other themes of novel concepts (e.g., exchangeable parts, personalization, visual feedback through changing color) occurred in the framework group only. However, there was no overlap between ideas within that group either – rather, one idea per design was seen as the core novel aspect or creative design concept. Three of these novel concepts were mentioned by multiple evaluators: a tablet computer that could be re-used to serve a new purpose (FD7, mentioned by E1 and E3); a display frame that would change its color according to battery charge left (FD21, mentioned by E2, E6, and E7); and a small lever that allows for a quick emergency battery recharge by winding up (FD17, see Figure 1, mentioned by E3 and E8).

Connection between Novelty and Attachment

Upon identifying those themes, many of them resembled features that can be attributed to sustainable design, which led us to ask the question if there is a connection between the novelty aspects as identified by the evaluators and the attachment values as provided by the framework. We therefore added an additional layer of analysis: all of the evaluators' comments for the novelty aspects were analyzed with regard to values of the Attachment Framework. Three Attachment Framework experts individually decided for each comment about novelty if it resembled one (or multiple) of the attachment criteria.

Similar to the attachment evaluation, there was a strong subjectivity noticeable in the results. Only for three designs did all evaluators agree on one attachment criterion; for most of them (seven) two evaluators identified the same attachment criterion. For two designs the attachment criteria were different, and for the remaining three designs only one evaluator found that the novelty aspect was connected to attachment. Overall, 40 instances of attachment were identified in the novelty comments and only eight times was no criterion found to be present in the novelty justification, whereas at least one attachment expert saw attachment criteria present in any of the designs. Two examples for the novelty-attachment relationship can be found in Figure 1: E5 praises CD5 as *"the designer re-considers the form factor"* in the novel foldable design, while E3 points out that the *"similarity to a pocket diary/wallet would make it more likely for users to foster an attachment"*. Similarly, E1 considers FD11 to be novel as

"this design went the opposite direction [to the throw-away paradigm], emphasizing exchangeable parts" which contribute to attachment as they *"will keep the device up-to-date"* and *"less likely to become obsolete"* (E1), and even allow for *"strong personalization"* (E5).

Presentation

The criterion of presentation quality yielded the most clear-cut result: only seven times was a design sketch from the framework group among the top three, compared to 20 from the control group. As mentioned earlier, we notified participants that we were to blame for the text clutter since we provided red-colored translations to the original designers' comments. However, the designs produced by the framework group already had a significantly higher amount of text and our added translation multiplied this clutter effect. The designs that were selected for best presentation, on the other hand, were those that came with less text and more polished graphical concepts, with two exceptions: *"Concise text. Simple reference points. Easy to understand instantly." (E6-FD9)* and *"Very well explained on how the complete flowchart would look like. Different ways to personalize your tablet is presented with good description and clearly communicated" (E10-FD6).*

The majority of comments, however, preferred sketches that were understandable without the necessity to read large amounts of text (E7-CD1: *"I don't need to read anything and I get it immediately"*) or praised good drawing skills. One evaluator even presumed that the concept was created by someone *"who knows how to render 3D objects with light + shadow"* (E1-CD13). CD12 (see Figure 1) stood out as it was praised by four different design experts for its *"good rendering"* (E2), *"detailed product design sketches"* (E4), being *"easy to understand within seconds"* (E7), and ready for *"showing [it to] a client"* (E9).

Aesthetics

Designs from the control group were more often mentioned as being particularly aesthetic (18 times) than framework designs (ten comments). Interestingly, if we were to look at the number of designs those comments were attributed to, it is evenly split among both groups (nine each) since three designs in the control group were mentioned repetitively by at least three evaluators. Four design experts (E1, E3, E6, and E8) mentioned patina as an aspect that would lead to increased aesthetics of the device. This was especially surprising as the two sketches that the evaluators referred to were produced by the control group (CD1, CD15) only. Surprising because patina was identified as a theme for the novelty and attachment criteria as well – but in those cases, stretching across both groups.

Besides other single mentions that we cannot really classify as themes (e.g., *"'easy-to-carry' style"*, E3-CD5; foldable display, E2-CD4), there were three main aspects that the design experts highlighted as particularly aesthetically pleasing. First, showcasing context of use (E5-FD7, E6-FD7, and E6-CD14), which might not appear as an aesthetic property as such, but E5 justifies it as follows: *"The idea has [s]ome poetic value, as the designer con[s]iders the device part of an environment"*. Second, exchangeable parts contributed to the aesthetics of two designs (E2-CD12, E3-FD6, and E7-CD12). Third, the most frequent pattern across all sketches that the design experts found to be aesthetically pleasing was the choice of material (e.g., E1-CD9, E4-FD16, E8-CD2, and six more). This differs from the patina theme as the evaluators' point was not about gaining a visually pleasing effect over time, but that the design came with a *"classy and high quality metal"* (E7-FD18) or *"ruggedness"* (E1-CD2) by default.

Usefulness

In raw numbers, the non-framework group was slightly ahead, with fourteen comments on this criterion, compared to twelve comments by the framework group. However, in terms of themes that emerged from our qualitative results, there was no clear winner. Several of the features that were attributed to usefulness did not fit onto overarching patterns and therefore stood out as single concepts depicted in one design, such as a sturdy and break-proof design (E1-CD9) or a wind-up crank for quick battery recharge (FD17, see Figure 1). The latter received positive comments from three evaluators: E3 liked *"the combination of such an old-fashioned mechanism with a high-tech gadget"*, especially if it were to be coupled with a *"cute charging UI"*, E5 envisions *"the user [to be] more mobile and less dependent from infrastructure"*, and E10 notes that the mechanism *"is the need of the hour […] and can help one for longer use"*.

One theme we identified in three designs was adaptability (E1-CD16, E3-CD16, E5-FD5, and E10-FD4). E1 pointed out: *"A device that learns my needs and behavior, leading it to adapt is incredibly valuable in streamlining my life"*. While this pattern of usefulness mainly referred to software and user interface features, the most frequent themes were flexibility (six designs) and the ability to transform (five designs), originating from either group. A quote for the justification of E5-CD9, summarized the evaluators' opinion about design concepts quite well: *"A tablet that can be mounted in many different ways and places is very useful, and I liked the mention of future technology-screens that are foldable, durable and not so precious"*.

Feasibility

As with usefulness, feasibility and credibility of the design sketches was almost evenly split between the two groups (thirteen comments on eleven designs with framework, twelve comments on nine designs without). Two dominant themes emerged in our analysis: many evaluators picked designs that were about a specific material (eight designs) and pointed out that *"it could be produced today"* (E1-FD1). By relating the proposed design concept to already existing products, the design experts highlighted that some

of these ideas are *"totally feasible"*, such as E7-CD1: *"it's essentially an iPad with a leather skin."*

The other theme that had almost as many occurrences as material was software (seven designs). The design experts mentioned existing software products or concepts that would solve the main problems in bringing the design sketch to reality, such as *"Google Now"* (E1-CD16) or *"TimeHop with a diary twist"* (E6-CD14).

Summarization of the Results

We conclude that the framework had a positive effect on the novelty criterion and mixed effects on the other five criteria (attachment, presentation, aesthetics, usefulness, and feasibility). Especially surprising was that the control group had almost as many attachment criteria present in their designs as the framework group. One possible explanation might be that many of the designers expressed in their background survey having had experience in sustainable design ("green design" was a frequently mentioned term) during their studies or a personal interest in those fields, and thus possessed an already existing knowledge repository. However, the framework group's designs displayed a significantly higher quality with regard to novelty and creativity, which in turn can be linked to attachment criteria. The results indicate that the Attachment Framework might hold value for designing products that exhibit both sustainable as well as novel design.

Despite the success of our design activity in this particular aspect, the limitations of using this framework in SHCI design lies in the fact that in other five criteria – attachment, presentation, aesthetics, usefulness, and feasibility and credibility – the Attachment Framework did not perform better. Similarly, the ambiguity in evaluating the attachment criteria highlights that the framework can be interpreted in many different ways. In the following, we discuss how the insights from this study can inform future research by presenting a set of challenges that need to be addressed when applying theoretical frameworks from SHCI or similar fields to design practice.

BRIDGING THE GAP: CHALLENGES IN APPLYING SHCI THEORY TO DESIGN PRACTICE

Based on the insights from our study we identify and discuss a set of four challenges that aim to bridge the gap between SHCI theory and design practice, which can be separated into two different categories:

Category 1: The first three challenges address issues in the earlier stages of SHCI design knowledge transfer, in particular, identifying 1) the suitable target audience, 2) the appropriate stage in the process, and 3) the most effective medium of communication. Each challenge is organized as follows: first, we elaborate on how we identified the challenge based on the study insights. Second, we discuss the challenge by drawing lessons from design research literature, including fields such as product, industrial, and architectural design. Our goal is to provoke discussion and reflection on how to address these challenges.

Category 2: The fourth challenge addresses an important question in a later stage of the design process: once we have examples of SHCI research applied to design practice, how do we evaluate those instances of design in light of the given framework? We discuss this challenge based on previous SHCI research insights and the experience from our own evaluation in our study.

Challenge 1: Addressing the Right Target Audience

The potential differences in target audience became apparent when comparing the background surveys of the two different group of designers we recruited – the fourteen designers for the design activity and the ten design experts for the evaluation. While the designers had less experience in design overall in terms of years of expertise in teaching and practice, all of them expressed interest in or even experience with the design of sustainable products. The design experts, on the other hand, expressed only borderline knowledge or interest in sustainable design, but a significantly longer amount of working expertise in design practice. This sparked our interest to see if there are other differences with regard to the target audience that impact the knowledge transfer between disciplines.

Insights from Design Research

In a survey of design expertise studies, Cross [5] points out that expert designers tend to spend less time on the problem definition and more on actually developing the solution (solution-focused versus problem-focused). A survey of 103 novice designers and 52 expert designers by Gonçalves et al. [14] confirms these insights with empirical data of actual design practice. An implication would be to tailor frameworks or design guidelines to the respective stage these designers deem to be most important and spend more time on; e.g., in the case of expert designers this would be the solution generation process, while for novice designers one might focus on supporting the problem elicitation stage.

Cross concludes his survey with a warning that seems to be counter-intuitive to some HCI researchers: *"Generating a very wide range of alternatives may not be a good thing"* [5]. This is based on the fact that expert designers tend to focus on a single design quite early in the idea generation phase. Combined with his advice to be *"wary about importing behaviour from other fields"*, one should be careful to not cause any changes to the designers' practices when offering tools to support the design process – unless the designers agree to (or even ask for) the change and the benefits are clearly communicated. Otherwise, such a tool might not make its way into designer's practice and the design knowledge transfer will not be successful.

Challenge 2: Finding the Appropriate Stage in the Design Process

Another insight from the background survey of our participants was that their typical approach to design tasks differed from designer to designer. Some designers mentioned they would usually spend more time on background research – which was limited due to the time constraints in this experiment – while others did not put as much emphasis on this part of the process, mainly because the already had a repository of background from a previous, similar design task. There were also differences in their approach to brainstorming designs: most of our designers liked to sketch many different ideas and pursue one (or a few selected ones) more in-depth, while some designers mentioned they would sometimes just take the first idea that comes to their mind, sketch it in detail, and then go back and think about other ideas and repeat the process. We therefore looked into design research literature to see if there is a typical design process, if so, what it looks like, and how this changes the way we try to apply our SHCI knowledge to this process.

Insights from Design Research

The basic concept of many design disciplines looks similar to HCI's iterative design cycle [e.g., 25]. For example, for product design and engineering, Cross [6] provides a simplified four-stage model. The four different steps are exploration, generation, evaluation, and communication; the cyclic resemblance of iterative design is depicted by a repetition of generation and evaluation. For another discipline, architecture design, Lawson's model [22] is more generalized with a three-stage "analysis – synthesis – evaluation" circular process, almost identical to the HCI iterative cycle. Both authors, however, point out that as one looks closer at either of these models, the individual steps differ from discipline to discipline, product to product, and even designer to designer.

When SHCI researchers propose theoretical frameworks to be used by other disciplines, these frameworks need to fit into the target audience's work process. For example, in our study the target audience would be industrial and product designers. Looking at one more detailed model of that discipline – Kruger and Cross's expertise model of product design [19] – we highlight how complex the process, and therefore identifying the most suitable stage, is. Kruger and Cross's model is accompanied with a breakdown of eight tasks and activities: 1) Gather data, 2) Assess value and validity of data, 3) Identify constraints and requirements, 4) Model behavior and environment, 5) Define problems and possibilities, 6) Generate partial solutions, 7) Evaluate solutions, and 8) Assemble a coherent solution.

As these stages highlight, there exist different opportunities to transfer knowledge, depending on which stage is to be addressed. For example, in a design process mimicking Kruger and Cross's model, SHCI design knowledge can be fed into the first step as part of the designer's background research. This might be a stage where designers are likely to be more open towards traditional HCI design principles, as their background research process is relatively widespread at this point. But in the later steps (e.g., step six), concrete tools and applications that support the ideation process might be more helpful. Traditional guidelines are likely to be neglected at this stage in the process; however, they might be helpful if tailored to the specific stage and embedded into the tools used during the solution generation process. We therefore believe that HCI researchers have to be aware of the complex stages of the design process, consider at which stage(s) their findings may be most beneficial, and tailor their frameworks and guidelines for the appropriate stage(s) of the design process. This may significantly increase the chance of SHCI design knowledge to be applied to real-world practice.

Challenge 3: Transferring and Transforming SHCI Design Knowledge

It is important to keep in mind that the designers did not implement the Attachment Framework's principles, but their *interpretations* of those principles in the ideation phase. This matters because interpretations can be both beneficial and unfavorable: interpretation allows for less restricted thinking and enables designers to explore many different ways to apply design knowledge to their activities; but it can also lead to misinterpretation and therefore mean that it has no or even an adverse effect on design. While we do not want to limit the benefits of a framework that is open to interpretation, we need to make sure the essence of the framework communicates the same values. One approach to how this challenge can be addressed is to explore ways in which frameworks and guidelines can be presented in the designers' ideation process.

Insights from Design Research

HCI research literature often ends with implications for design, guidelines, design principles, or a framework – as in the example of the Attachment Framework that we applied in our experiment. But if such work aims to inform future design, the theoretical, text-based form of conveying the findings and insights might not be enough to reach its goal. Textual guidelines are by themselves not applicable to all stages of the design process and are not what all target audiences might prefer. There is an ongoing debate over the different impact that visual and textual stimuli have in the design process [e.g., 9, 12, 13, 24]. A balanced approach of textual and visual stimuli might present a good middle way, noting that one should rely more on visual stimuli with expert designers, as they tend to be less susceptible to be biased by these examples and make less use of text [14].

Therefore, we propose that SHCI should search for ways to not only transfer its knowledge into other domains, but also present and communicate the knowledge using representations that take the needs and practices of the target audience into account. One way to go about this is by

using examples to fuel the ideation process [17]. Based on the target audience's preferences, mixing verbal examples and pictures can be useful, but if possible also including real-world objects such as end-products or prototypes; this can be especially useful for expert designers [14].

There is a variety of different ideation techniques used by designers: Smith identified 172 different techniques [31], Gonçalves et al. reported on the frequency in actual use of 14 of those [14], and Herring et al. provides an in-depth analysis of 19 [17]. If one aims to support the ideation process, SHCI design knowledge could also be integrated into tools and applications supporting these techniques instead of simply providing examples that are being used during the ideation process. While brainstorming seems to be the most frequently used and most preferred method by designers [14], there are many different ways to approach brainstorming and therefore different ways to support this process by developing tools for it. SHCI principles could be embedded into applications that facilitate the creation of checklists [14] or attribute lists [17], or serve as basis for new axes of classifications in either of these.

One has to keep in mind that the ideation process is a concrete step in only one specific stage of the design process (step 6 in the expertise model [19]). Since ideas can emerge indirectly anywhere in the cyclic design process, there might be other ways to embed design knowledge into designers' practices beyond this phase. If formulated as rules that blend into the constraints and requirements being identified in step 3 [19], abstract design implications can be turned into concrete guidance for designers. This ensures that the design process is not altered, yet the SHCI principles are considered in the design process – with equal importance to other design rules.

Challenge 4: Evaluating Applications of SHCI Design

The last challenge we encountered (as also articulated in [31]) is one that poses a more general question: *How do we evaluate the impact of our contributions in SHCI once they have been applied to practice?* To answer this question, we contrast our evaluation approach with that of Grosse-Hering et al. [15], which is to date the only evaluation of this kind.

Grosse-Hering et al. [15] performed a case study of the application of slow design principles to design. They evaluated their design by asking six participants to imagine the use of a mock-up device and report on their experience. This works because for slow design the interaction is meant to actively engage and change people's practices and thinking immediately; some of the Attachment Framework principles, however, are more subtle and require a ready-made product (sufficiency, earned functionality) or a long timeframe to be applicable (histories, perceived worth). Therefore, building prototypes and mock-ups is not a suitable strategy for evaluating attachment. Some of the designs in our study resembled storyboards or use-case scenarios (e.g., CD19, see Figure 1), but this approach does not work for all designs. This hints that a "one size fits all" solution it is unlikely to be found, but rather that every application of SHCI research requires its own evaluation, depending on its goal – which is a notion expressed by the SHCI community itself recently [32].

In our own case we used the Attachment Framework itself as an evaluation tool. This raises an additional question: *Can we use a framework that is intended to inform the design of objects for the purpose of evaluation?* The attachment experts who have had extensive experience with the framework itself did not agree on all the criteria for all the designs; in fact, there was more difference in assessing the attachment values than agreement. Despite the differences in assessing *which criterion was expressed in a certain design*, there was a general agreement on particular designs *that a design displayed some notion of attachment*. Silberman and Tomlinson [31] provided a categorization of evaluation tools, in which the Attachment Framework falls into the category of "principles" for which a certain amount of ambiguity is expected and needs to be dealt with.

The fact that both the design experts, who had no previous experience with attachment, and the attachment experts came to roughly the same results in assessing the attachment values in the designs – no clear evidence that the framework group did significantly better than the control group – might imply that the Attachment Framework holds some value to serve as a means of evaluating attachment in designs. However, the definition of the attachment principles should be phrased much more unambiguously to allow for more agreement among the evaluators. Contrary to the purpose of applying frameworks to design practice, when room for interpretation can be desirable, we argue that such frameworks should be more constrained and have as little ambiguity as possible when being used as a tool for evaluation.

We included general design criteria in our evaluation since attachment alone does not suffice as the only criterion for successful design if a product were to appeal to a broader audience. However, maybe one of the obstacles in bridging the theory-practice gap is that traditional design and evaluation criteria are not compatible to sustainable design and the emphasis for evaluating success should only be on sustainability; one of this paper's reviewers noted: "Maybe it is our notions of successful design that need to evolve".

CONCLUSION

In this paper, we investigated the application of a theoretical framework from SHCI to design practice by studying its effect on the design process and outcome. We have conducted a comparative study where half of the participants designed with the use of the framework and the other half did not. The evaluation of the produced designs was done with 10 design experts against a set of design criteria derived from the product design and industrial design literature: 1) attachment, 2) creativity and novelty, 3)

presentation, 4) aesthetics, 5) usefulness, and 6) feasibility and credibility. Our evaluation results indicated a positive effect on novelty, where a subsequent evaluation suggested a clear link between novelty and attachment. However, we saw mixed effects of the Attachment Framework on the other five criteria. We believe that the lessons learned from our experiment can help inform future applications of SHCI design knowledge to design practice. In particular, we propose a set of challenges that researchers might face when frameworks are being applied to practice, and ultimately might help to re-think the way we communicate and evaluate frameworks and other theoretical contributions that emerge from SHCI research.

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