APPLICATION OF SHAPE CHANGING SMART MATERIALS IN HOUSEHOLD APPLIANCES: A FRAGMENTED AND INCONSISTENT UPTAKE

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ABSTRACT

Shape changing smart materials (SCSM) have a wide range of applications, supporting product functions through material features. Surprisingly, their application in consumer durables such as household appliances is not as expected. This phenomenon could be related to a possible SCSM knowledge gap among designers, or unidentified design constraints; literature does not provide a convincing explanation. Our objective is to describe this phenomenon more accurately as a first step towards future analysis and improvement. We studied literature on SCSM applications in dissected consumer durable categories: consumer electronics, medical & healthcare devices, household appliances, wearable apparel and automotive. Through comparative research we tried to identify differences in design context considerations that could help to understand the phenomenon. From a product design perspective, using qualified reasoning, we investigated how SCSM have been considered (or scorned) to fit different design needs in terms of material behavior, applications, aesthetics, economic, manufacturing, and environment. Results shows that, (1) SCSM uptake in household appliances is lagging behind compared to other consumer durable categories, (2) with literature readily available, this is not just a knowledge gap, and (3) no compelling design reasons could be found rendering the observed phenomenon inevitable. Based on these results, we point out possible research directions for follow up analysis and possible improvements.

KEYWORDS

Shape changing smart materials, consumer durables, household appliances, product design, smart materials uptake

1. INTRODUCTION

Shape changing smart materials (SCSM) are engineered materials that retake their original shape upon exposure to a designated stimulus, such as a thermal impulse, electrical field, light, or magnetic field. Technically speaking, SCSM can be grouped under stimuli-responsive materials (SRMs) (Figure 1). Important SCSM family members are shape memory alloy (SMA), shape memory polymer (SMP), and piezoelectric composites. Owing to their ability to directly support the implementation of advanced product functions, SCSM have been introduced in the fields of aerospace, biomedical and robotics [1]-[3]. Typical applications include deployable structures (e.g. hinges and trusses) in aerospace, stimulus-activated medical devices (e.g. smart surgical sutures and stents), and artificial muscle actuators in robotics. Compared to conventional implementation principles, the use of SCSM often comes with a reduction of artifact volume and size, and henceforth decreasing energy consumption [4] [5].

Considering the above features, applications of SCSM have been foretold to become dominant in consumer durables (CD). However, we observed a peculiar phenomenon in the domain of consumer durables: the uptake of smart materials in CD design...
is fragmented, showing an inconsistent application pattern. Without a clear and immediate reason, smart materials successfully applied in one case seem to have been not even considered in other cases. We coined the question whether this phenomenon is just accidently spotted, or structurally present indeed.

1.1. Research object and objectives
A first step and the objective of this research, is to investigate this phenomenon by describing its characteristics, using household appliances as our research object. More in concretely, we want to find out whether or not the phenomenon is due to a mere knowledge gap, due to specific design (process) considerations occurring in the design of household appliances, or due to other causes.

1.2. Research methodology
The core of our methodology is to use qualified comparison: first, we sorted literature according to consumer durable category. Next, we analyzed the design needs and considerations in cases being compared. Qualified comparison in this case implies that we analyze and use qualified alignment of design needs and considerations to justify fair comparison. Our method is to identify reasoning patterns occurring in the application of SCSM in paired CD applications. In cases where the use of SCSM was not considered, we tried to uncover the background of the decision.

In forerunning research, we found out that the majority of published papers on the application of SCSM are coming from the fundamental research, especially the material engineering domain, while the contribution of papers from the application realization side particularly product design domain is hardly available in scientific databases. The novelty of the work presented here aims at exploring the interplay between SCSM knowledge offerings and the product design aspects of material considerations, which has not been well implicit in other survey papers.

1.3. Assumptions, restrictions
We limited our insight in several product design aspects which are (1) material behavior, (2) aesthetics, (3) economic, (3) manufacturing, (4) applications, and (5) environmental. We focus mostly on the designer. Furthermore, literature coming from both the material engineering domain and product design engineering domain should be compared with great care. We realized that the real reason is not necessarily made explicit in literature but might be obscured or covered up.

1.4. Organization of this paper
After the introduction in this section, we describe applications of SCSM in selected CD categories, as reported in literature. Section 3 presents a comparative study to learn differences in SCSM application, in otherwise comparable cases we draw from literature. In section 4, we present the results of the comparative study and analyze the findings. In section 5, we discuss our findings and its implications for the phenomenon under investigation. Additionally, we distilled successful SCSM application reasoning patterns found in literature and project them on household appliances. In the final section, we provide tangible and implicative conclusions and project possible research directions for our follow up study.

2. SCSM APPLICATION IN CONSUMER DURABLE PRODUCTS
A frequency analysis on the distribution of papers found, shows that the dissemination of SCSM applications is not equally distributed across consumer durables (CD) categories. Certain CD categories received higher application rates while others were limited (figure 2). There are several issues that are believed to prevent pervasive uptake of SCSM in some CDs. Forerunning literature surveying suggested that: (1) there are still unresolved material properties issues setting forth perceived technological barriers, (2) there is a lack of
market and functional acceptability, (3) there are no comprehensive design methods for SCSM inclusive designs, and (4) designers tend to fall back to proven technologies they became familiar with [7]-[11]. Such argumentations were observed in multiple CD categories literatures, including household appliances. Also, SCSM tend to be primarily the output of academic research. Whilst perhaps providing promising results from a theoretical point of view, in industry, stakeholders may include different stakeholder values, so that successful industrial applications remain long unseen.

Scholars suggest that it is necessary to involve a cross-disciplinary collaboration, by sharing knowledge between material engineering and product design engineering [7]. We estimate that the conventional approaches and ways of dealing with the application of SCSM are probably not suitable. Definitely there will be specific obstacles from both material engineering and product design domain. Hence it is important for scientific research to identify what both fields can offer in order to bridge the gap between SCSM and product applications. This paper is a first attempt to bridge the gap between these fields. Research steps needed for that are: (1) identifying the knowledge contribution coming from the material engineering domain towards the domain of product design, and, (2) to know how the knowledge fits product design.

The favorable material properties of SCSM are envisioned to furnish various innovative functions to CD applications. Below, we will review reported application of SCSM in various CD categories: consumer electronics (CE), automotive (AU), wearable apparel (WA), household hardware (HH), medical and healthcare (MH), and household appliances (HA). Table 1 shows the references classified according to CD category. We will discuss SCSM added functions - actuating, deploying, fitting, self-healing and sensing. The terminologies were introduced in [14]-[16]. Specific examples of the added functions can be found in section 2.1 – 2.6. The definition of these added functions are as the following.

**Actuating** entails the act of moving or controlling mechanism.

**Sensing** involves measuring a physical quantity and converting it into an observable signal.

**Deploying** implicates of unfolding an artifact from a programmed temporary state to a desired state.

**Self-healing** is the capability of repairing a physical surface in-situ when damage is detected.

**Fitting** involves the act of shrinking or expanding the dimension of artifact.

### Table 1 Organization of papers based on consumer durable categories reported on

<table>
<thead>
<tr>
<th>CD category</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE</td>
<td>11,17,18, 19, 20, 21, 23, 24, 25, 26, 27</td>
</tr>
<tr>
<td>WA</td>
<td>8, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 67</td>
</tr>
<tr>
<td>MH</td>
<td>40, 41, 42, 43, 45, 47, 48, 49, 50, 51, 64, 65</td>
</tr>
<tr>
<td>AU</td>
<td>4, 14, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 66</td>
</tr>
<tr>
<td>HH</td>
<td>6, 7, 67, 68, 69</td>
</tr>
<tr>
<td>HA</td>
<td>74, 75</td>
</tr>
</tbody>
</table>

#### 2.1. Consumer electronics

The applications of SCSM in this CD-category cover a variety of conventional and new products. Many SCSM consumer electronics applications are in actuators, developed from SMA, SMP or a composition of the two materials (shape memory composite or SMC). SCSM actuators are used in active disassembly (AD) components for the purpose of components recycling in CE products. In the AD process, a sequence of control temperature changes activates SCSM actuators to self-dismantle different components. SCSM actuators for AD were reported to be applied in mobile phones, modems and LCD monitors [11] [17] [18]. Secondly, SCSM can serve as actuator and sensor in safety control switches.
They occur in products with thermal actuated switches for overheat protection [19] [20]. Third, SCSM actuators had been proposed for tactile displays and interactive pervasive display. SCSM-actuators are used to establish a computer controlled patterning surface: changing of shapes on a surface produce braille characters or tactile objects, serving blind and sight-impaired people in [21]-[24]. The application of SCSM provides intrinsic recovery to minor damages on CE products. This electrical or thermal driven self-healing function of SCSM repairs the formation of micro-cracks in CE products, caused by exposure to continuous and/or cyclic stress [25]-[27].

### 2.2. Automotive

In automotive, SCSM’s most prominent application is also in actuators. SCSM are reported to implement linear and rotary actuators in car and motorcycle components [28]; to provide car drivers with operating comfort through the control of rear view mirrors, smart windows, seat assemblies, active headrest, adaptive headlights, and climate control flaps [14] [29]-[32]. Additionally, there are also applications in car safety systems, like: bonnet lifting system, seatbelt pre-tensioner, and adaptable seats reacting to crashes [33]-[35]. For the operational performance of cars, SCSM actuators are used in valves, pumps, and engine air intake tumble flaps for better gas combustion and reduced fuel consumption [4] [36]-[38]. Further usage includes transmission control and suspension adjustment [4] [36]. A few concepts on sensing, deploying and self-healing application have been considered for driver’s safety and automobile security system. Examples of added functions provided by self-healing materials include morphable car body molding, and tunable vehicle structures [4] [66]. However, no test-of-prototype or commercial applications were found in any of these papers.

### 2.3. Medical and healthcare

The use of SCSM in MH includes interventional cardiology, neurology, radiology, vascular surgery, health monitoring and rehabilitation. In these applications, the added functions of SCSM involve actuating, deploying and fitting. The deploying applications of SMPs and SMAs enable products to be self-executable without any complicated system or mechanical structure. MH devices that deploy this added function include expendable stents for cardiovascular intervention and drug delivery [39]-[44]. Deploying in MH also involves medical adapters such as needles, positioned in a target location and retaking original shape by temperature activation of human blood [45] [64] [65]. There are also clinical instruments such as biopsy forceps and hinge-less graspers exploiting SCSM added functions [46]. For fitting, both SMAs and SMPs have been used in orthodontic wires [47]. These SCSM applications enable a constant shape recovery force to teeth over a long period of time. In this case, SMP are advantageous over conventional material because they are available in transparent or multicolor, providing a more aesthetic pleasing appearance. SMAs can provide fitting to medical casts, which are commonly used to heal broken bones, tendon tears and limb injuries [48]. Fitting functions through SMPS are also applied in smart surgical sutures that shrink to close an opening wound when activated by an external stimulus [49]. For actuating, SMPS and SMAs based actuators have been investigated for practical MH applications [50] [51]. Scholars studied biocompatibility of SMA and SMP actuators in human body conditions. However, these papers have not concluded any concrete applications of SCSM actuators for MH devices.

### 2.4. Household hardware

The combination of actuating and sensing of SCSM have been applied in passive temperature sensors that precisely control the evolution of shapes, during a thermally triggered shape recovery effect [67]. Applications are in thermally activated alarm devices and thermally activated locking mechanisms for doors, and anti-scald shower valves [68] [69]. The applications of SCSM in such HH products offer user safety and comfort. For deployment, (potential) applications of SCSM have been reported in smart tents and smart umbrellas [6] [7] [69]. Thermally controlled switches can be activated to deploy these products from a small package. HH products can be assigned superior operating while compact in size.

### 2.5. Wearable apparel

There are interesting developments in WA. SCSM have been used for electronic textiles, smart clothing and related products in the form of shape-memory fibers, shape-memory yarns and shape-memory fabrics [52]-[54]. Fitting is used in fashion design especially for smart clothing [55]-[58]. SCSM are utilized for their high shape fixity and shrinkage to produce style change effects. Other uses of fitting are observed in pressure garments, such as burn cure.
garments and pressure sportswear, and comfort garments that includes footwear, gloves and socks [8] [59]. The application of SCSM in these products accommodates safety and comfort to its wearer [60]-[62]. Deploying is an added function applied in eyeglass frames [63] [67]. The frames are usually made out of SCSM such as SMA and SMP. SCSM eyeglass frames are super-elastic providing improved comfort and great resistance to damages.

2.6. Household appliances

Only a limited number of papers were found on SCSM applications in household appliances (Table 1). In contrast, unexpected applications were reported from Japan: the fitting capabilities of SMPs are exploited for improved hand-to-spoon handgrip adapting, and likewise for toothbrush, razor and kitchen knife; the adopted hand fit is kept intact [74]. Another use of SCSM was reported in the design of built-in capabilities for easy separation of household appliances components for recycling [75].

2.7. Literature findings

SCSMs are applied in all CD categories, but the spread in uptake is large. Some of the added functions coming with SCSM are shared across several CD categories. We have specifically looked for reasoning patterns to exploit added SCSM functions in the design: there are similarities and differences in the design considerations which could point at reasoning patterns. These reasoning patterns can be used to carefully project potential applications from one CD into the next; in our research case: into household appliances. The next section is dedicated to analyze reasoning patterns with SCSM from the context of product design.

3. COMPARING SCSM APPLICATIONS

To compare between the CD categories in a structured manner, we used design material evaluation aspects outlined in [70] [71] [72] [73]. The six evaluation aspects are: material behavior (C1), aesthetics (C2), application (C3), manufacturing (C4), economic (C5) and, environmental and safety (C6) (Table 2). From this study, we (1) compare reasoning between CD categories, (2) analyze whether from a product design perspective SCSM knowledge and design considerations concur, and (3) identify and project new opportunities of applying SCSM in HA.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Description on product design aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspects</td>
<td>Considered characteristics</td>
</tr>
<tr>
<td>Material behavior (C1)</td>
<td>Physical: Structural, volume, mechanical, thermal, electrical &amp; chemical properties</td>
</tr>
<tr>
<td>Sensory: Stimulation of senses by thermal, light, pH, or electrical</td>
<td></td>
</tr>
<tr>
<td>Aesthetics (C2)</td>
<td>Appearance: Color choices, texture and pattern of material</td>
</tr>
<tr>
<td>Form giving: Capability to manipulate SCSM to provide desired form and geometry</td>
<td></td>
</tr>
<tr>
<td>Application (C3)</td>
<td>Function: SCSM added functions for: sensing, deploying, actuating, self-repair, fitting</td>
</tr>
<tr>
<td>Use: Purpose of applying and the place of applying regarding the function of SCSM</td>
<td></td>
</tr>
<tr>
<td>Manufacturing (C4)</td>
<td>Process &amp; assembly: Possibilities to use SCSM with certain fabrication techniques</td>
</tr>
<tr>
<td>Finishing: Possibilities of finishing SCSM by certain techniques, surface properties</td>
<td></td>
</tr>
<tr>
<td>Economic (C5)</td>
<td>Material cost: Market price of producing, installing or maintaining a SCSM based component</td>
</tr>
<tr>
<td>Environmental and safety (C6)</td>
<td>Life cycle: Decompose readily by biological process (biodegradability) and recyclability</td>
</tr>
<tr>
<td>User safety: Compatible with living system (biocompatible) and toxicity</td>
<td></td>
</tr>
</tbody>
</table>

4. RESULTS AND ANALYSIS

In this section, we present the results in three parts. Firstly, 4.1 summarises the results of the comparative study, for C1 to C6. Secondly, 4.2 gives our analysis of the obtained results. Finally, 4.3 presents our projection of the new SCSM opportunities to HA appliances.

4.1. Comparing aspects

**C1 Material behavior**

Table 3 presents the results of comparing the material behavior between the CD categories. Results suggest that comprehending the material behavior aspects is essential for application. In general, literatures have discussed advantages and limitation of applying SCSM along the lines of the considered characteristics. The different physical and sensory characteristics need to be concurrently considered. For example, in incorporating shape-memory effect to MH, it is essential to comprehend how it will match thermal and chemical stability, recovery stress and strain, and super-elasticity of SCSM in parallel.

**C2 Aesthetics**

Table 4 presents the results of comparing aesthetics aspects; appearance and form giving. The availability to have SCSM in different colors is important to MH.
and WA applications. Additionally, diverse tactile quality for SMP fibers, yarns and fabrics is important in WA applications. Peculiarly enough, we were not able to find any information conveying aesthetics aspects in other CD categories.

C3 Application

Table 5 presents our comparison on the application of SCSM between the CD categories. Results shows that different added functions are applied in multiple CD categories. The added functions demonstrate the versatility of SCSM to fit multiple purposes. Conversely, the results demonstrate that specific added functions of SCSM directly contribute to the implementation of certain product functions. For instance, sensing and actuation support energy saving, recycling and mechanism control of products. Generically, deploying can be seen as a means to reduce the size of products, often at the same time increasing user safety and comfort.

C4 Manufacturing

Table 6 contains the results of comparing manufacturing aspects. Most manufacturing considerations we found were based on SMPs. In literature, the success of applying SMP relies heavily on the compatibility of the material to be used with conventional manufacturing processes such as injection molding, thermoforming and extrusion. For WA, SMP needs to be available in the material form of yarns, fabrics or fibers in order to be suitable for weaving. No assessment could be made as to the adequacy of such conventional manufacturing processes for this purpose. No emerging
manufacturing technologies have been evaluated.

**C5 Economic**

Table 7 shows the different considerations occurring in C5. Literature tells us that considerations have been made on the cost of material, cost for material maintenance, and cost for integrating the material in product assemblies. Most application cases in CD still portray SCSM as an expensive alternative to replace conventional material. In contrast, SCSM have been reported as a low cost solution in MH and CE categories. Considering CE characteristics in Table 5, this is according to expectations; apparently successful deployment of added function leads to more favorable cost perceptions. Also observe that CE characteristics in Table 7 span more of the CE application life cycle costs, whereas with other categories, primarily development and manufacturing costs are taken into consideration.

**Table 7** Material cost aspects.

<table>
<thead>
<tr>
<th>Category</th>
<th>Considered characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE</td>
<td>Material, maintenance and installation cost</td>
</tr>
<tr>
<td>WA</td>
<td>Material and processing cost</td>
</tr>
<tr>
<td>MH</td>
<td>Material cost</td>
</tr>
<tr>
<td>HH</td>
<td>Material, maintenance and installation cost</td>
</tr>
<tr>
<td>AU</td>
<td>Material, maintenance and processing cost</td>
</tr>
<tr>
<td>HA</td>
<td>Material and processing cost</td>
</tr>
</tbody>
</table>

**C6 Environmental and safety**

Table 8 shows the variety of environmental and safety aspects that were considered in each CD categories. There are some differences in the considered characteristics, between products that have direct contact to human body and those that do not. WA and MH are the categories of CD with possible direct contact to human body use.

**Table 8** Considered characteristics of lifecycle and user safety aspects

<table>
<thead>
<tr>
<th>Category</th>
<th>Considered characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE</td>
<td>Recyclability and biodegradability</td>
</tr>
<tr>
<td>WA</td>
<td>Recyclability, biodegradability, biocompatibility, toxicity</td>
</tr>
<tr>
<td>MH</td>
<td>Biodegradability, biocompatibility, toxicity</td>
</tr>
<tr>
<td>HH</td>
<td>Recyclability</td>
</tr>
<tr>
<td>AU</td>
<td>Recyclability and biodegradability</td>
</tr>
<tr>
<td>HA</td>
<td>Recyclability</td>
</tr>
</tbody>
</table>

In terms of aesthetics aspects, there is some evidence that this is a consideration that applies to multiple CD categories. SCSM offers multi-color choices, different tactile qualities, and manipulating shapes for form giving purposes. Apparently, aesthetics aspects were considered because of apparent styling features such as in fashion garments. In MH, aesthetics are considered because there is a user demand for more pleasing appearance of orthodontic braces. Aesthetics aspects were apparently not considered in CD designs in which SCSM were considered for internal components, hidden from user interaction. The aesthetic aspects of SCSM seem to have been comprehended well by product designers.

Literature tells us that SCSM is best applied for the added functions: sensing, actuation, fitting and deploying. The results show SCSM’s versatility in that respect. Moreover, we found added functions to form a kind of reasoning pattern. The reasoning patterns are as follows:

- Sensing and actuating are considered for product safety, user comfort, and energy saving, and for recycling support.
- Fitting can be used for user safety and comfort, and energy saving.
- Deploying can be used for reducing product size, and support energy saving.
- Self-healing can be used for product safety
Research in self-healing as an added-function is still developing and will require more time before breakthrough applications will be seen [3, 19, 20]. Generally, we believe that the added functions are transferable across the CD categories. The uses of SCSM in different CD categories are largely comparable. However, there have been very few approaches to address how these added functions can be integrated to provide novel concepts. Contradiction-solving is generally needed to find such integrative solutions [12]. The compatibility of SCSM with conventional manufacturing processes has been identified as an important factor in product design consideration. SCSMs such as SMP are reported compatible with injection molding and thermoforming processes. In contrast, only few processes are suited for SMA [24]: here, SMP can be more advantageous compared to SMA [4] [13].

To our surprise, information on economic aspects showed less transparent in literature. Papers fail to clearly convey the true economic benefits of applying SCSM. This could potentially become an issue that will bias future studies on SCSM uptake. For certain CD categories, SCSM were reported to provide good economic solution compared to the use of conventional material. We refer to SCSM uses in active disassembly. MH applications also have the generic potential for low cost solutions. As expected, successful deployment of added function leads to more favorable cost perceptions (c.f. CE in Table 5). With regard to environmental aspects, SCSM can be very beneficial to the product lifecycle. Also, SCSM have been tested for user safety; toxicity and biocompatibility in human body [40]. SCSM can be considered for most applications to support recyclability owing to good biodegradability [21] [32].

4.3. Projecting SCSM applications to HA

So far, literatures have provided sufficient guidance to inform us with the current opportunities of applying SCSM in the selected CD categories. In these selected CD categories application cases are sufficiently comparable to consider transferable SCSM usage. In HA, SCSM have been specially applied to provide user comfort on handgrips of small appliances and in recycling HA components. Apparently, designers recognized that SCSM can be applied for: (1) adaptive user comfort, and (2) support recycling components of CE product. However, we observed that there are more opportunities of applying SCSM to HA:

- HA with adaptive energy saving capabilities.
- HA with more pleasing aesthetics
- HA with enhanced biodegradability
- HA with the capability to deploy products from smaller packages or operated in confined working space

We found that adaptive energy saving capabilities for HA can be considered by referring to the applications of SCSM in CE and AU. Adaptive switches that control the flow of electricity can be implemented in products such as air-conditioner or air-fans. Here, thermally activated sensors and actuators detect the changes in environment conditions which in respond reduce the speed of the motor. This is a conceptual means of providing adaptive electricity control ability. Such system can also rely on the possibilities to use wireless and remote controllable SMPs [4]. There is no reason to believe that SCSMs for aesthetics are irrelevant to HA. Also, HA enter the waste streams in vast amounts. There is no reason to believe that biodegradability isn’t an issue in HA either. These two SCSM application considerations can therefore be transferred to HA as well. As to the compactness of HA products: SCSM offers volume and size reduction comparable to HH and WA.

The act of deployment ascends from the shape-memory function of SCSM. This function can be self-executable without complicated system or mechanical structure [16]. Projected HA products are expendable plates or kitchen utensil making up a lot of space for storing. SCSM based actuators can potentially be used to replace conventional motors and other electronic components, to reduce volumes. Besides these cases, SCSM should also be studied in adaptive user comfort and support for recycling components of CE product. Literatures are still scarcely available in these areas, and this suggests that there are more prospects to be expected. For instance, research can expand the application of adaptive user comfort in HA products. Additionally, scholars have proposed future studies to design HA products for active-disassembly [11].

Results revealed that there is sufficient knowledge available related to the material behavior of SCSM. However we feel that it was not sufficiently articulated and concrete for immediate use in product design domain. We believe that this phenomenon is
not merely caused by a knowledge gap between product designers and material engineering domain. Product designers could also have done the above projection. Most of the knowledge on SCSM originates from fundamental research. Based on our findings in C2, C4 and C5, we feel that fundamental research failed to clearly address these aspects, probably because of their unfamiliarity with the design domain. As we mentioned in the introduction, there is a one sided view in the literature on SCSM applications. We encountered no substantial and successful cross-disciplinary collaboration in the research here, with ditto application. In order to apply SCSM in household appliances, we find it essential to discuss ways to refine C1-C6 aspects for product design practice.

Aspects on C1 are plentiful in literature, for instance. However we argue that the information needs to be tailored and advocated to improve comprehension among product designers. A cross-disciplinary approach is deemed necessary to produce adequate SCSM uptake [6] [7] [11] [12]. Such collaboration shall involve knowledge sharing among material engineers, product designers and other experts in this highly specialized field. SCSM introduces new terms such as added functions, shape-memory effect and triggering stimulus, product designers will have to familiarize with before including them in their design considerations. C2 is an important aspect that can attract product designers to creatively ideate new product concept. Information on colors, tactile properties and form giving offered by SCSM should be contesting current product design practice.

Product design analysis on C3 could support analogizing designs of innovative household appliances. Comprehending C4 aspects enables product designers to manufacture resourceful products at competitive prices. In terms of C5, product design practice will need revised cost-benefit calculations on applying SCSM in household appliances. Product designers should be realistic about total cost of SCSM application. Finally, C6 should become the key feature in consumer acceptance of new household appliances. SCSM should be beneficial and safe for human and in the long run provide good environmental impact.

5. CONCLUSION

The aim of this study was to concisely describe the phenomenon of hesitating SCSM uptake in CD, studied by evaluating home appliances. Our statistics-underpinned results show that indeed, this phenomenon can be shown to exist. We studied SCSM aspects from a product design perspective and identified reasoning patterns for considering SCSMs in HA. We projected application opportunities to household appliances, and through structured inductive reasoning, we conjectured convincing counterexamples showing that in HA, a similar uptake could have been achieved. We found no reasons explaining why designers could not have done so themselves.

We believe (1) that knowledge on SCSM has penetrated literature pervasively enough to reject characterizing the daunting uptake as a mere knowledge gap. Furthermore, studying the hesitating uptake in HA, we found (2) that no fundamental and compelling reasons could be found, explaining why SCSM could not be applied in this CD category in the same way and to the same degree as in other CD categories with compatible design problems.

We therefore conclude that:

- The phenomenon of hesitating uptake of SCSM in HA has been demonstrated to exist;
- It cannot be characterized as a mere knowledge gap;
- Nor is it due to unidentified HA-specific design characteristics.

On the other hand, we observed that SCSM application knowledge is not always presented in a form a designer can use straight away. Although further causal analysis has to done first, we believe here is the room for further improvement. Some restrictions and limitations also apply. The amount of papers available for our study was limited and unevenly distributed. Next, we have only studied the phenomenon from the angle of product design. Also, we restricted our evaluations to (early) design, mostly neglecting considerations that may pop up further down the HA life cycles. We did not distinguish between routine, re- and new product designs, and didn’t look into the adequacy of existing design methods and tools to reason with SCSM. Finally, we realized that in literature, the real reasons for considering SCSM or not, could have remained unreported or covered up. The complexities of the phenomenon under study will need further understanding. Future research is targeted at uncovering and analyzing causes of the phenomenon and finding solutions for the issues explored.
REFERENCES


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