Development of Innovative Product Designs with Stretchable Displays Based on User's Expected Experience

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Abstract

This research identifies specific user experience factors that have positive impact on user's behavior intention to use so that a new technology called stretchable display(SD) can be accepted and spread in the market. To show how these factors can be applied to SD home appliances, a few concrete designs have been suggested. In the first stage of the research, the initial concept of innovative product design with stretchable display was derived by developing a scenario that solves the expected experience by home product users through the attributes of the SD technology. In the second stage, a scenario of the product to which a stretchable display was applied was suggested to investigate the expected experience factors that influence the behavior intention to use. As a result of the analysis, users showed a positive intention to use for the factors of Functionality of Space and Life Support, Presentation of Preferences, and Customization of Emotions, provided by the product with SD technology applied. In the next stage, based on the verified user experience factors, multifunctional kitchen appliances design, smart furniture design with flexible surfaces, and smart interior wall tile design have been derived. After all, the differentiated transformable interface designs shown through this process have been suggested as three-dimensional soft-physical button design and attachable design for multi-curved soft furniture. This study is significant as it emphasizes a user-centered design process over a technology-centered approach, enhancing market acceptability and focusing on design features aligned with the user's expected experience.

Keywords: Stretchable Display, User Experience Design, Smart Home Appliances

1. Introduction

Residential environment keeps changing due to the constant technological development and spread. In turn, home appliances also continue to evolve and with new technology and reflecting the user's needs, customized electronic products are becoming an important part when it comes to home interior and lifestyle. With the increasing demand of the wide selection of products to fulfill the user's tastes and situation and products with transformable design, researches and development on electronic goods are being actively conducted through technology development.

In the display field, studies and development of the display that can transform into various shapes and forms are in progress. Stretchable display has the attributes of flexibility and elasticity so it is also referred to Freeform display that is not limited to directions or angles[1]. Since it can be folded multiple times and return to its original form, it can be applied to various products in home appliances and home furniture[2]. With these key characteristics, the stretchable display can transform according to the situations or purposes, for example, covering an uneven-surfaced product, and it will provide various interactions through the elastic material properties. In terms of space interface, it can be considered to be applied to many objects that can be found in the category of home appliances and furniture.

Although the commercialization of the stretchable display is becoming visible with the active technical research, it is uncertain how the stretchable display should be applied to which product in order to be accepted in the market. To expand into a variety of industries and to secure the market competitiveness of stretchable displays, there is a task to accomplish to investigate the products that the users will accept. Thus, this research is to examine the user's potential needs that are related to user's acceptance in the market, and to derive the home appliances design to satisfy them through the stretchable display's technical features.

To do so, analysis of the current status of stretchable display technology development and commercialization technology features is needed to identify the form factor characteristics that can be used distinguishably in the product design. Next, the home appliances design trends are to be analyzed to understand the industrial environment where the products are to be applied within, the scope of application is to be examined. For the development of user-centered innovative products in the near future, previous studies on user expected experience design and acceptance are to be reviewed, and based on the findings, the designs of home appliances design with stretchable displays are to be derived.

2. Theoretical Background

2.1 Current Status of Stretchable Display User Interface Technology

Flexible display is a display that is very thin like a piece of paper so that it can be bent or rolled without causing any damage to itself. The flexible display market is expanding around the small sized displays such as sports goods, watches, and e-book devices[3], along with the fold smartphone by Samsung Electronics and the rollable device, such as rollable TV launched by LG Electronics in 2020[4], it is now at the commercialization stage. However, there are limitations to flexible displays as they can only be transformed in certain directions or specific parts along a single axis, allowing only bendable, foldable, or rollable shape changes. This restricts their ability to achieve freeform shape transformations.

In contrast, stretchable displays can simultaneously expand or contract in multiple directions, enabling multiaxial deformation in various orientations. This capability allows them to adhere

to complex curved or irregular surfaces, facilitating freeform 3D shape transformations. As it needs to have elastic attributes in order to apply it to the display of an object in various shapes and forms, stretchable display technology is being on the spotlight as the next-generation display. Based on the unit technology research, such as the micro-LED light source material and transfer technology, the stretchable substrate electrode for backplane and modularization equipment technology, and the highly elastic film form substrate technology, the process development of the module and stretchability to commercialize the stretchable display is underway. To briefly look at the development status, Samsung Display first launched the 9.1-inch stretchable display that has 5% stretchability in 2017[5], and five years later in 2022, LG Display successfully materialized the 12-inch stretchable display with 20% stretchability with 100 ppi high resolution, almost similar to the regular monitors[6].

LG Display introduced it at the Society for Information Display(SID) 2023, as in the free-form demonstration examples based on the elasticity as well as the prototypes of the stretchable display covering over a multi-surfaced object as presented in "**Fig 1**" [7]. The current stretchable displays under development have full-color high resolution and they can reproduce vivid images. They can also cover the multi-surfaced three-dimensional everyday objects in various forms due to its stretchability; consequently, they are getting attention as DOT, Display of Things.

Fig. 1. LG Stretchable Display demonstrated at the Society for Information Display (SID)
(Left) Demonstration of freeform deformation, (Right) Prototype covered on the multi-curved surface
of an object

To commercialize the display that has such innovative form factor, the interface technology registration of how users interact through stretchable display is being actively carried out by the companies and research institutes. Here are some examples of the patent registration organized in **Table 1**. (a), (b), and (c) are the expected products to be developed of which the image or the visual output is altered accordingly when the stretchable display is perceived as being transformed, and (d), (e), and (f) are another set of expected products where the actuator is linked to the stretchable display to show and demonstrate the three-dimensional shapes.

Table 1. Registered Patent Related to User Interface Technology of the Stretchable Display

No	Patent Name	Registration Information	Technology Summary	Common Attributes
a	STRETCHABLE DISPLAY APPARATUS AND DISPLAY CONTROL METHOD AND APPARATUS OF THE STRETCHABLE DISPLAY APPARATUS	SAMSUNG DISPLAY US 9804699 B2 2017.10.31	Outputs the image with the equivalent resolution even with either a shrink or an expansion of the display	Technology of the presentation and making changes of the graphics or visual

b	STRETCHABLE DISPLAY DEVICE AND OPERATING METHOD THEREOF	LG ELECTRONICS US 9,928,571 B2 2018.03.27	Adjusts and presents the visual information accordingly by detecting the direction of the forces on X, Y, and Z-axis as well as specific input shape	information according to the shape transformation
c	STRETCHABLE DISPLAY AND METHOD FOR CONTROLLING THE SAME	SAMSUNG DISPLAY KR 2090711 B1 2020.03.12	Detects the shape transformation and generates the appropriate screen accordingly	
d	THREE-DIMENSIONAL TACTILE DISPLAY APPARATUS USING STRETCHABLE LIGHT-EMITTING MATERIAL AND MANUFACTURING METHOD OF THEREOF	University Industry Foundation, Yonsei University KR 2088807 2020.03.09	Stretchable display is linked to an actuator; materializes the three-dimensional shape through the transformation of the actuator by using pneumatic chamber and micro-channel	Technology of the presentation and transformation of the physical freeform three-dimensional shape based on the actuator
e	SOLID CONTENT OUTPUT DEVICE AND METHOD USING STRETCHABLE DISPLAY	University Industry Foundation, Ewha University KR 10-2302498 2021.09.09	Stretchable display is linked to an actuator; presents the protruded or depressed three-dimensional shape through the actuator that moves along on the Z-axis	
f	STRETCHABLE DISPLAY DEVICE AND METHOD FOR PROVIDING INPUT FUNCTION UISNG THE SAME	University Industry Foundation, Ewha Womans University KR 10-2022-0022011 2022.02.21(Registration decision. 2024.07.26)		

2.2 Current state of Home Interior in Home Appliances Industry

With the aftermath of the Fourth Industrial Revolution and the popularization of the ICT technology, the residential environment has been advanced and the development of the IT technology to personalize has risen up the demands of the home appliances that reflect the user's tastes as part of the home interior[8]. In 2022, LG Electronics launched an object collection at the Internationale Funkausstellung 2022, also known as IFA 2022, the biggest European Home Appliances Exhibition, to suggest kitchen appliances that can be customized according to the individual's tastes[9]. The panel on the MoodUp refrigerator can have a combination of 170 thousand colors to be displayed on the four doors by penetrating the RGB LED light through the light guide plate to realize the selected colors. Furthermore, Samsung Electronics introduced a simulation solution with a launch of refrigerator called 'Bespoke AI' which allows consumers to preview the finalized look with recommended color combinations on the home appliances that would suit their own home interior[10]. They have been steadily participating in the Salone del Mobile Milan, and in 2023, they launched 'Bespoke Home, Bespoke Life' that enables the users to materialize the personalized space[11]. Home appliances are smart furniture that reflect individual's tastes when decorating home space; they play an importance role in the home spatial experiences through customizing the color and tone of the products as well as through the IoT functions.

Fig. 2. (Left) 2023 Milan Design Week features the collaboration between the Italian creative studio
brand TOILETPAPER and the domestic brand Samsung's Bespoke Gallery Zone,
(Right) IFA 2022(the largest home appliances exhibition in Europe) features LG Electronics' the
collections of objects-MoodUP Zone

The home appliances that have been studied and developed so far mainly use flat displays
where only the color, pattern and lighting of the panel can be modified. However, with the
ability of producing a vivid image as well as the flexibility and transformability of stretchable
display, it can be applied to any object in all shapes without limitations, not only within home
appliances but also in any furniture or objects that can be found in home space. This will
effectively bring up the satisfaction of the user's expectations.

2.3 New Technology-based Design Related Research

It is difficult to verify and confirm how the users will respond to the new technology-based
near-future designs until they are actually launched in the market. Since the user's acceptance
on the product determines the success of the business, it is now important to define the future
user's expectations on the products or services. In turn, the user's expected experience plays
an important role in the designing process for innovative products[12],[13]. Expected
experience refers to desires, required experiences, and positive expectations that the users can
get from the products or services[14].

When conducting advanced design process for the next-generation product development
with a focus on the technology roadmap, companies discover new products based on the future
user's expectations and required experiences. The application of future user's experience value
to future user's experience scenario was found to be very useful in Sin and Pan(2016)'s research
on corporation's task on new smart home appliances discovery[15]. As proven in "Self-Driving
Step-by-Step Service Scenario Research" by Jung, Gao, Choe, Cheon, and Park(2020)[16],
"Scenario-based Self-Driving Car UX Design Concept Research" by Pak(2021) [17], and
"Flexible Display Scenario Research" by Jung and Ryoo(2016)[18], user experiences, as a key
scenario development criteria, are utilized to elaborate the design, and the developed scenarios
are used to convey the design concepts that suffice user's expected experiences. However, the
evaluation and decisions on the derived design are executed by the stakeholders in many
cases[15], and in fact, the user-expected experience factors, used in the important design
criteria for market acceptance, are not efficiently utilized in the verification process of the
design.

Investigating the factors that influence the user's acceptance and its impact should be
verified in the beginning of the introduction phase when new innovative technology and media
are starting to spread. In the research from the social science field, the cause-and-effect
relationship between the suggested concepts and behavior intention to use are explored in the
form of hypothesis test. The concepts of the expected experience from a product are being

studied as important influencing factors. In "Virtual Reality Device Acceptance Factor Research" by Choi, Kang, and Choi (2017)[19], "Smart Speaker Research" by McCloskey and Bennett (2020)[20], and "Robot Taxi Service with Self-Driving Function Research" by Kim, Jang, and Kim (2023)[21], the user's expectations for meeting their various needs by using the applicable products are studied, and the relationship between the expected experience factors and the behavior intention to use are explored. Since this research was conducted through a survey on innovative technology that has not been commercialized yet, the introduction materials and videos of the applicable products and services were provided to the participants[15],[22]. These studies are focusing on the influential relationship through the statistical analysis and yet, how the proven factors are reflected on the products and being designed is to be further studied.

Thus, in this research, scenarios are to be developed based on the expected experience factors in the home appliances field in order to derive the product design with a stretchable display. Then, the expected experience factors that affect the behavior intention to use are to be verified through the derived scenario design. Lastly, the product designs are to be presented by organizing the embodied functions and interface designs reflecting the expected experience factors whose influential relationship has been verified.

3. Scenario Development Based on User's Expected Experience

3.1 Scenario Development Criteria

Stretchable display's vivid image presentation and transformability to freeform are expected to be effectively utilized in the home interior appliances field. In this research, innovative home appliance product designs are to be suggested by applying stretchable displays. One of the user-centered design methodologies that Cooper(2014) suggested has been used[23], which is a design method where scenarios are used to imagine and explain the functions and usage directions of a product that satisfy the user's required experiences and expected experiences. Therefore, it is necessary to investigate the user's expected experiences and analyze them in the early stage of the scenario design process.

To collect the potential expected experiences of the home interior appliances products, the experiences of using products related to decorating the home space and revealing tastes were investigated through preliminary studies. Not only the existing home appliances but also home furniture and small home devices were all analyzed, especially considering the stretchable display's applicability to objects with its freeform transformability. The derived expected experience factors are Environmental Aesthetics to expect the product's design, material, and color to aesthetically blend well with the surrounding environment, Customization of Emotions to be able to change the ambiance and feel refreshed, Presentation of Preferences to match individual's tastes and differentiate from others, and Functionality of Space and Life support to be provided with functional usefulness to support the limited space and the context of use[24].

In Cooper's scenario-based design, a scenario is laid out where the user's expectation is achieved by a certain idea. Similarly, in this research, stretchable display's technical characteristics are set as the key variables to meet the user's expectations, and scenarios are to be developed where the derived expected experience factors are resolved through the products with stretchable displays. For example, Environmental Aesthetics factors can be design, material, and color of the stretchable display products. To utilize it as scenario development criteria, 'products' such as home appliances, furniture, and small home devices are rephrased

to 'SD products' with a stretchable display under home interior product expected experiences so that the expectations are reorganized in terms of SD product usage. Based on the results of in-depth user interviews conducted in the previous research, four expected experience factors and 15 attributes are organized in **Table 2** below.

Table 2. Expected Experience Factor and Attributes Based on Scenario Development Criteria

Expected Experience Factor	No.	Expected Experience Attributes
Environmental Aesthetics	EX1_01	Expect to have SD products with aesthetic designs or that are effective for aesthetic production
	EX1_02	Expect to have SD products that will harmonize with the surrounding environment, achieving unity in home interior design
	EX1_03	Expect to have SD products that are suitable for the changing weather and seasons in terms of design, material, and color
	EX1_04	Expect the SD products to blend well with the atmosphere of the space
Customization of Emotions	EX2_01	Expect that SD products can be used to create a specific atmosphere
	EX2_02	Expect that SD product variations will refresh one's emotions
	EX2_03	Expect that SD product variations will create a fresh and new ambiance
Presentation of Preferences	EX3_01	Expect that one's SD product designs can be shared with others
	EX3_02	Expect that SD products will have unique designs that can be differentiated from others
	EX3_03	Expect that SD products will satisfy personal preferences and/or characteristics
Functionality of Space and Life support	EX4_01	Expect to have SD products that are functionally useful, thereby assisting users in their specific situations and actions
	EX4_02	Expect to have SD products that are functionally useful, thereby supporting the characteristics of the space
	EX4_03	Expect to have SD products that will enable efficient use of limited space
	EX4_04	Expect to have SD products whose appearance can be altered, thereby offering economic benefit
	EX4_05	Expect to have SD products that maintain their functional excellence even when their appearance is altered

3.2 Home Appliances/Home Furniture/Interior Materials Usage Scenario Development

In future-assuming scenarios, certain situations are predetermined and preset based on the future variations that are highly likely to occur[25]. When developing a new product using new technology, the technology variations are defined according to the key technical characteristics, and then the situations where the solutions are provided to satisfy the user's expectations can be supposed. The stretchable display that is being developed at the moment can produce a full-color image with over 100ppi. Also, with its elasticity, it has a distinctive technical advantage over other types of displays, being able to freely transform as well as to cover an object with multi-angled surface. Based on this innovative form factor, it was confirmed that the interface technology is being studied. This technology allows to provide image or visual information appropriately adjusted by detecting the stretchable display's transformation or to provide a three-dimensional shaped image, protruded or depressed, by

linking an actuator, either soft or hard. Thus, the first attribute of the stretchable display to apply to this scenario development is the high-resolution image and information representation properties, "SD1", and the second attribute is the physical freeform three-dimensional shape representation properties, "SD2". The attribute of presenting physical freeform shapes (SD 2) differentiates itself from traditional flat and flexible displays by materializing multi-curved surface user interface design examples in the context of home appliance use alongside GUI.

Considering the applicability of the freeform transformable stretchable display to objects, ideas to apply the stretchable displays to various products that are commonly used in home space are brainstormed. Assumptions were made to have the products commercialized with the stretchable display applied to small devices, furniture, and interior in home space, and detailed situations were outlined. Within the context where SD home appliances are used, task details were identified to fulfill the user's expected experiences, and the product interface and interaction context were explained.

Among the ideations based on SD2, a differentiating attribute from existing display technologies, those that could be addressed with traditional flat, bendable, foldable, or rollable forms were removed. Similar ideas among the generated concepts were integrated or grouped and then modified and further developed into scenarios suitable for the product line. The summary of the derived scenarios is described in **Table 3**.

Table 3. Context-based Details of the Product Usage Scenario Summary

Product	Scenario	Experience Factor	SD Attributes	Scene Setting	Product Usage
SD Product applied to Home Appliances	A scenario where friends are invited to a home party and preparing the food at home with the built-in multi-ovens. This is an example where a SD is applied to home appliances with multi-functions	EX 1	SD 1	SD cannot be distinguished and well blended into the home interior before using the home appliances	SD is flat in the synchronized color and pattern around it when not in use
		EX 4	SD 2	SD control buttons are generated to be used to support cooking	- Summon the physical three-dimensional button by user's touch - Based on the cooking instructions, function buttons and/or handles will pop out
		EX 4	SD 1	Online recipes can be displayed and/or a video can be played through SD	- An online video can be played on a flat screen without any buttons - Screen will be expanded by connecting to another display

					screen next to it
		EX 2	SD 1	Appropriate atmosphere generation through SD for the meeting	Color and pattern, motion design changes according to the party theme
SD Product applied to Home Furniture	A scenario where on a sofa, that the family members share, the user can modify its design and also can control the home devices such as TV and/or air conditioning in the user's preferred setting	EX 3	SD 1	Personalized Design changes	Design application based on personal preferences
		EX 3	SD 2	Personalized shape changes	Application of the Sofa's shape changes
		EX 4	SD 2	Controller usage to watch TV	- Control interface appears where the hand sits - Engraged button generation that does not affect the action of the user's arm being laid on a sofa's arm - Accurate button manipulation while watching TV through tactile sensation
		EX 4	SD 2	Multi-controller to control several home furniture like air conditioning, etc.	- Physical buttons per home furniture function and visual information change
		EX 4	SD 2	Link to newly purchased personal devices such as bluetooth, earphones, speaker, etc.	- Select the new device and additional linkage - Provide personalized controller
SD Product applied to Interior Materials	A scenario where a smart tile is installed partially on a wall to control the home IOT services such as interphone, lighting, and heating system	EX 1	SD 2	Smart Wall Construction	- Custom order the smart wall with interior tile texture - Installation on the wall in the living room

		EX 4	SD 1	Interphone control panel pops up when doorbell rings	- Function screen appears when the context of use occurs - When user is perceived to have moved away, the screen will disappear and turn into the wall
		EX 4	SD 2	Home IoT Service screen appears as the user approaches	- Control panel and function buttons pop out by recognizing the distance with the user to control interphone system, lighting, heating system, etc. - Home IOT services linkage by user's settings
		EX 1	SD 1	Not being able to distinguish with the surrounded interior wall tiles when not in use	Interior wall tile

User scenarios for home appliances with stretchable displays were created into videos, each 30 seconds long, totaling approximately 1 minute and 30 seconds. The scenario videos were visualized to highlight the functional services and interface features in the context of using SD-applied products, and these videos were used for the user survey in the following chapter.

4. User Research and Analysis

4.1 Data Collection and Measurement

In this chapter, user research was conducted to verify which expected experience factors affect the behavior intention to use of the home appliances with stretchable display. A group of 200 participants with a mix of male and female adults had taken an online survey, and the demographic characteristics of the samples are summarized in **Table 4**. Before the survey, they were instructed to watch stretchable display introduction videos as well as the pre-produced scenario-based videos where the stretchable displays are applied to home appliances as described in chapter 3. Participants were instructed to answer the survey questions after watching the videos to fully understand unique technological attributes of SD. The evaluation method based on watching videos has been widely used in previous research to assess the behavior intention to use of technology that has not been commercialized yet because it enables the viewers to experience a certain situation indirectly[14],[26]. The questionnaire was composed of questions to measure the expected experiences, behavior intention to use, and demographic characteristics.

Table 4. Respondents' Profiles

Demographic Characteristics		N	%	Demographic Characteristics		N	%
Gender	Male	100	50	Location	Gyeonggi	92	46
	Female	100	50		Seoul	90	45
Age	19-29 years	60	30		Incheon	18	9
	30-39 years	60	30	Monthly Income	Less than 2 million won	43	21.5
	40-49 years	50	25		2 million won or more but less than 3 million won	60	30
					3 million won or more but less than 4 million won	41	20.5
	50-59 years	30	15		4 million won or more but less than 5 million won	19	9.5
					5 million won or more	37	18.5

In this research, user's expected experience factors related to home interior are presumed to have an impact on the behavior intention to use of home appliances with stretchable display in the near future. The four user's expected experience factors organized in **Table 2** are set as the independent variables and 15 attributes were used as measurement criteria. Behavior intention to use was set as the dependent variable, for which eight measurement items were selected from the previous studies on home appliances and innovative products[19],[27],[28] and they were modified suitable for this research. The reliability of each item constituting the five variables used in this study was verified through an internal consistency review using the Cronbach's alpha coefficient. The alpha values are 0.840, 0.806, 0.691, 0.843, and 0.931 for Environmental Aesthetics, Customization of Emotions, Presentation of Preferences, Functionality of Space and Life Support, and behavior intention to use respectively. In general, the values above 0.6 are considered that there is no problem with reliability, so it was determined that all are internally consistent[29].

Table 5. Items and Reliability

Factors	# of Items	Cronbach's α
Environmental Aesthetics	4	0.840
Customization of Emotions	3	0.806
Presentation of Preference	3	0.691
Functionality of Space and Life support	5	0.843
Behavior Intention to Use	8	0.931

Table 6. Descriptive Statistics

factors	Items#	M	SD
Environmental Aesthetics	EX1-01	4.10	.628
	EX1-02		
	EX1-03		
	EX1-04		
Customization of Emotions	EX2-01	4.08	.641
	EX2-02		
	EX2-03		
Presentation of Preferences	EX3-01	4.12	.597
	EX3-02		
	EX3-03		

Functionality of Space and Life support	EX4-01	3.97	.631
	EX4-02		
	EX4-03		
	EX4-04		
	EX4-05		
Behavior Intention to Use	DV-01	3.73	.729
	DV-02		
	DV-03		
	DV-04		
	DV-05		
	DV-06		
	DV-07		
	DV-08		

4.2 Data Analysis and Results

First, to measure the correlation between the four factors and the behavior intention to use, the Pearson correlation analysis was conducted. As summarized in **Table 7**, Environmental Aesthetics (r=.596, p<.01), Customization of Emotions(r=.592, p<.01), Presentation of Preferences(r=.589, p<.01), and Functionality of Space and Life Support(r=.640, p<.01) were all proven to have positive correlation with the behavior intention to use.

Table 7. Correlations of Analysis between the Variables

	Environmental Aesthetics	Customization of Emotion	Presentation of Preferences	Functionality of Space and Life support	Behavior Intention to Use
Environmental Aesthetics	1.000				
Customization of Emotions	.799**	1.000			
Presentation of Preferences	.778**	.748**	1.000		
Functionality of Space and Life support	.730**	.717**	.707**	1.000	
Behavior Intention to Use	.596**	.592**	.589**	.640**	1.000

**p <0.01

In order to determine the association between each factor and the user's behavior intention to use, multiple regression analysis was used. Using stepwise regression, Environmental Aesthetics factor has been removed while Functionality of Space and Life support (β=.378, p<.001), Presentation of Preferences (β=.185, p<.05), and Customization of Emotions (β=.183, p<.05) are found to have a statistically significant positive effect on the behavior intention to use. This model was verified to have 45% accuracy of explanation, and the strongest relative influence on the behavior intention to use of the SD products was in the order of Functionality of Space and Life Support, Presentation of Preferences, and Customization of Emotions.

Table 8. Multiple Regression Analysis Results

Variables	B	SE	β	t	VIF	F	R²	Adjusted R²
Functionality of Space and Life support	.436	.094	.378	4.654***	2.383	55.375***	.459	.450
Presentation of Preferences	.226	.104	.185	2.170*	2.627			
Customization of Emotion	.208	.098	.183	2.120*	2.705			

*p<.05, *** p<.01

5. SD Product Design Derivation

Analysis results show that the expected experience factors that significantly affect user's behavior intention to use of the products incorporating SD technological attributes are Functionality of Space and Life Support, Presentation of Preferences, and Customization of Emotions. The most influence that the stretchable display products has is the Functionality of Space and Life Support, meaning that the users expect the functional usefulness out of the products the most to support the characteristics and usage of living space. 'Presentation of Preferences' refers to the user's expectations to be able to express their own tastes and preferences and to differentiate from others, while 'Customization of Emotions' refers to the expectations to be able to create the atmosphere that the users want and feel refreshed.

Considering the influence of expected experience factors on the behavior intention to use, the features of the products that have been developed in the scenario are organized. Each expected experience factor was derived into specific functions and services and transformation interface designs to suit the particular properties of each product. The stretchable display designs for the functions and services were suggested in control pad mode, content screen mode, and interior mode, and as for the differentiated transformation interface, sotf-physical button designs for multi-curve shaped furniture were suggested which can be attachable flexible designs.

First, SD built-in multi oven design was suggested as an example of multifunctional home appliances with stretchable display. This is a kitchen appliances product placed in the kitchen area for cooking and dining and its design was developed with a focus on the Functionality of Space and Life Support and Customization of Emotions factors. With the multi-functions of oven, microwave, and air fryer, this SD product provides 3D soft-physical buttons to support all its functions within the control pad mode. It not only allows flexible functional changes depending on the cooking context, but also provides improved physical operability. The form of the control may appear as a button type, a dial knob type, or a door handle type and its GUI will match. In the content screen mode, the users can watch informative video content by synchronizing to another device or expanding the interface. The atmosphere of the dining area can be shifted in the interior mode appropriate to the occasions, parties, or seasons by displaying videos or graphics.

Differentiated from the transformation interface on the existing products, the three-dimensional soft buttons are designed on the control pad. According to the selected functions from the multifunctional home appliances, the physical 3D buttons are to be generated and switched. When the product is in the content screen mode or in the interior mode, these buttons are hidden away so that the visual content is only displayed. They can also be generated

through the transformation of the actuator that moves along on the Z-axis and thus produces a hidden interface.

Fig. 3. SD Built-in Multi Oven Design Image

Table 9. SD Built-in Multi Oven

Product	SD Built-in Multi Oven	
SD Application Area	Control Panel Area	
Key Functions and Services	Control Pad Mode	Multifunctional 3D Control Pad Displays soft keys such as a button, a dial knob, or a door handle type
	Content Screen Mode	Provides video content to view cooking instructions Expands the screen through synchronizing to the nearby display devices
	Interior Mode	Mood design: Provides videos and graphics for parties, seasons or window lighting
Transformable Interface	Soft-physical Button Design	Generates 3D buttons when summoned by user and/or switches the button types according to the cooking context
		Hides away the buttons when content screen mode or interior mode activated

Next SD product to suggest is SD Smart Sofa, which is an example of digital transformation of analog furniture. A stretchable display is partially covered over existing analog furniture at the armrest area; with digitalization, it provides a personalized service based on the user profile recognition for each family member. The design factor of this product has been developed with a focus on Functionality of Space and Life Support and Presentation of Preferences factors. Customized personal device sync or design patterns will be automatically switched and provided. Also, when seated on the sofa, profile recognition will be revealed through personalized patterns in the interior mode. In the control pad mode, users can connect and manipulate the functions of not only home appliances like TV, air conditioner or washing but also personal devices such as smartphones or wireless Bluetooth earphones. Moreover, in the content screen mode, users can mirror or cast the content that they were watching on the personal devices or even expand the screen on multi-monitors.

Different from the existing products, this SD smart sofa has a transformable interface which can be applied to a soft material-based furniture and the stretchable display can be attached or detached. Also, three-dimensional soft-physical buttons are provided on the control pad on the armrest, and this makes it easy for users to manipulate the functions while watching TV or without even looking. As the display is applied to furniture with flexible surface, buttons can be generated or concealed through the transformation of the actuator like pneumatic chamber.

Fig. 4. SD Smart Sofa Design Image

Table 10. SD Smart Sofa

Product		SD Smart Sofa
SD Application Area		Armrest Area
Key Functions and Services	Control Pad Mode	Multifunctional 3D Control Pad
		Syncs to home appliances such as TV, air conditioner, and washing machine, etc.
		Provides personalized control pad
	Content Screen Mode	Provides mirroring, casting, and multi-screen options by synchronizing to personal mobile devices
	Interior Mode	Provides user-individualized preferred design pattern
Transformable Interface	Soft-physical Button Design	Generates and conceals the physical buttons to be manipulated by touch while watching TV
	Attachable Design	Covers different shapes of furniture flexibly which can be also attached or detached

Lastly, SD smart home wall tile design has been developed to materialize a smart wall with the stretchable display applied to the home space interior materials. The display is embedded in one of the wall tiles and this product has been developed with a focus on the Functionality of Space and Life Support factor. In the control pad mode, 3D soft-physical buttons are provided to support the multifunction of home IoT services, such as interphone, lighting, and heating systems and in the content screen mode, the settings will be displayed to control the applicable services.

The stretchable displays that are currently in the development phase use film-type substrates made from special silicon material[30]. With the higher moldability of silicon materials, harmonious designs can be presented through injection molding or over-molding methods to add interior texture to it. However, since how the Environmental Aesthetics factors will affect the behavior intention to use has not been yet verified, the texture or pattern designs will be selectively provided.
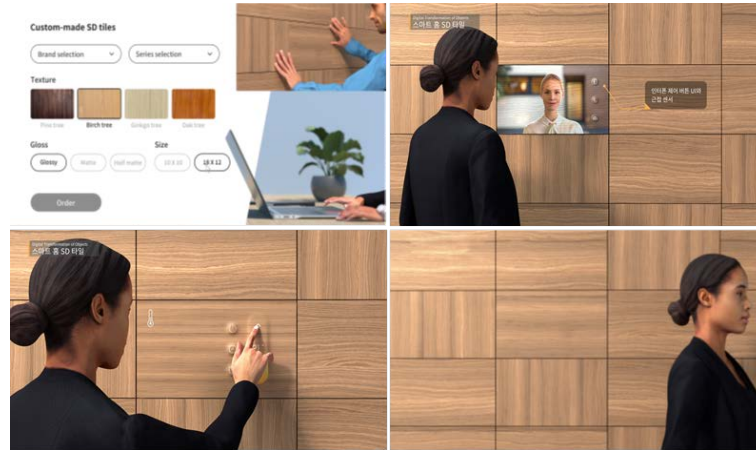

Fig. 5. SD Smart Home Wall Tile Design Image

Table 11. SD Smart Home Wall Tile

Product	SD Smart Home Wall Tile	
SD Application Area	One of the wall tiles	
Key Functions and Services	Control Pad Mode	Multifunctional 3D Control Pad Syncs to home IoT services such as interphone, lighting, and heating systems
	Content Screen Mode	Provides interphone system screen
		Provides miscellaneous IoT service screen
Transformable Interface	Soft-physical Button Design	Generates and hides away 3D buttons when detected user's distance and/or switches the button types

6. Conclusion

In this research, we conducted design development based on user experience expectations related to intention to use, to ensure the effective market acceptance of near-future technology such as stretchable displays. To achieve this, we first developed product usage scenarios that address the expected experiences for home products with the technological features of stretchable displays. We visualized these scenarios to highlight the functional services and interface features in the context of using SD-applied products. Based on this foundation, we conducted user surveys to identify specific expected experience factors that positively influence the intention to use SD home appliances, which were found to Functionality of Space and Life support, Presentation of Preferences, and Customization of Emotions. Considering the influence of each expected experience factor, we organized design elements according to

the characteristics of each product and derived design cases for multifunctional kitchen appliances, smart furniture with flexible surfaces, and smart interior wall tiles. To provide the identified expected experience factors, the common design features in home appliances with stretchable displays are as follows.

- For Functionality of Space and Life Support factor, first, using the SD's high resolution image presentation attributes, the interface where the product's key functions and related information services can be provided has been designed. Next, using the SD's three-dimensional form demonstration attributes, the interface with soft-physical buttons has been designed. Just like the virtual soft keys on the touchscreen interface, the buttons will be dynamically transformed depending on the software application in use, and they will effectively support functional manipulation as they have a three-dimensional shape that the users can feel a physical tactile sense.

- For Presentation of Preferences factor, first, using the SD's high-resolution image presentation attributes, a personalized interface has been designed to provide design patterns and services based on individual preferences. Next, using the SD's three-dimensional form demonstration attributes, multi-curve shaped interface has been designed. Secondly, using the SD's three-dimensional form demonstration attributes, multi-curve shaped furniture interface has been designed. Variable designs to support individual preferences and designs that can be attached and applied in various shapes of products have been suggested.

- For Customization of Emotions factor, first, using the SD's high-resolution image presentation attributes, the interface where the design patterns can be changed to modify the atmosphere has been designed. With a rather low influence on the behavior intention to use, SD's transformation based on the actuator may not be provided as a design for atmosphere change. To change up the ambiance of the space for parties and seasons, visual images or patterns can be offered to be displayed instead.

Stretchable display's key differentiating attribute compared to flat, rollable, or foldable displays is that it is transformable into freeform shapes. Therefore, the transformable interface that the existing products were not able to satisfy user's expectations can play as an innovative design characteristic. Developed through an innovative product design process, the differentiated transformable interface designs have been suggested as 3D soft-physical button design and attachable design for multi-curved soft furniture.

- Soft-physical buttons are the buttons that allow users to manipulate the applicable software and they provide users physical tactile sense in three-dimensional shapes. Such designs will fulfill user's expectations by projecting 3D buttons to manipulate or by concealing them to display informative content depending on the usage context. They can also innovatively support the situations where physical operability affect the use of the function as well as the situations where the operating pad is being used without being looked at.

- Attachable interface design for multi-curved soft furniture covers a part of the furniture in various shapes so that the analog furniture can provide digital services. The stretchable display can be embedded and fixed within the product to provide digital transformation services, or it can increase the effectiveness in the form of attachable pad. Flexible stretchable display can be applied to furniture with soft materials so that its shape may be altered when in use, as well as to the products that require comfort.

This research is meaningful in that it was conducted with a user-centered design so that it can be accepted and spread in the market when a new technology called stretchable display is commercialized. In order to apply the innovative design characteristics released in this study,

the following technical limitations must be overcome, and the research tasks for this purpose are not limited as follows.

- In order for the physical three-dimensional buttons to protrude or be hidden depending on the product usage situation, the reliability of repeated transformation must be strengthened. The foldable smartphone that is currently commercialized uses the hinge mechanism to strengthen the reliability of repeated transformation by reducing the stress caused by repeatedly folding and unfolding the display[31]. Stretchable displays also have buttons that pop up or are flattened, and the studies on mechanism or the shape and variable level of buttons are needed to minimize the stress. In the early stages of the technology, it may be provided in a static form in which no pop-up or down movement occurs, or in a form in which the level of dynamic change is minimized.

- The price of products based on state-of-the-art technology is bound to be high in the early stages of commercialization due to the low economic feasibility of the manufacturing process; thus, if the cost that the users have to pay is too high, it will be not able to be competitive in the market. The stretchable display provided on the surface of furniture or objects can be used as an interface for digital services, and it is necessary to provide a business model that lowers the burden on consumers. Companies like Amazon and Google offer subscription-based services and content ecosystems on AI speaker devices, making the devices more affordable for consumers. Research is needed to develop innovative business models to lower the burden on the hardware cost of SD products in the early stages of technology.

- As an alternative way to increase the economic feasibility of stretchable display products, they can be provided in the form of attachable pads to be attached and detached from various home products. The display structure may be changed depending on the shape of various objects, and for this purpose, an interface that adapts to the shape must be provided. It is necessary to study user interface guidelines that take into account the division of the surface as the display is bent or folded, the definition of the use of the surface, and the angle or direction.

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