A Design Space for Ephemeral User Interfaces

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ABSTRACT
In this paper, we present the novel concept of ephemeral user interfaces. Ephemeral user interfaces contain at least one user interface (UI) element that is intentionally created to last for a limited time only and typically incorporate materials that evoke a rich and multisensory perception, such as water, fire, soap bubbles or plants. We characterize the term "ephemeral user interface" and, based on a review of existing user interfaces that fall into this research area but have not been discussed under one common term before, we present a design space for ephemeral user interfaces providing a terminology for (a) materials for ephemeral UI elements, (b) interaction and (c) aspects of ephemerality. This paper contributes to the ongoing research on materiality of user interfaces as well as on conceptualizing visionary interaction styles with novel materials.

Author Keywords
Tangible user interface, ephemeral user interface, materiality, ephemerality, interaction materials, soap bubbles, water, ice, fog, plants, food, fire, sand, clay, air, smart materials.

ACM Classification Keywords
H.5.2 Information interfaces and presentation (e.g., HCI): User Interfaces – Input devices and strategies, Interaction Styles.

General Terms
Design; Human Factors.

INTRODUCTION
Ephemeral (i.e. transient) phenomena and materials shape our perception of the world: they are part of the rich experiences of life. Experiences are so precious because they are temporally restricted. Nature has designed organisms and things not to last forever. This strong concept of the world around us has yet not been consequently applied to computer technology and user interfaces. Especially if we design human-computer interaction (HCI) from a reality-based interaction point of view, where the "goal is to give up reality only explicitly and only in return for other desired qualities" [13:205], user interface designers should start thinking about integrating ephemeral phenomena into HCI. Humans are used to and value the ephemeral: why should not also digital information be presented transiently? Could we even design systems that naturally grow and age? These aspects get increasingly important as we think about the information overflow and attention problem we face today caused by the ongoing integration of computer technology into all parts of our lives. To address this problem, researchers have developed the concepts of calm computing [39], ambient media (e.g. [11]) and ambient communication (e.g. [6]). When writing about a more human-centered perspective in HCI, Bannon discussed human needs for ephemerality and forgetting versus the prevailing technology-focused persistency of data [1].

It is timely to systematically explore the design space for user interfaces that focus on ephemerality as design concept. Starting from a material perspective, we address this by introducing the concept of ephemeral user interfaces (see figure 1 for examples), a class of user interfaces that contain UI elements that are intentionally created to last for a limited time only. This work is motivated by threefold: first, the ephemeral is a natural phenomenon that yields potential for application in HCI but has yet not consequently been thought of as part of reality-based interaction; second, there is a need to address the cognitive overload due to the huge amount of data that gets represented; and third, this is an important topic for the research field of tangible user interfaces (TUIs) that deal with diverse materials and rich textures for interaction. Taking a material perspective on ephemerality, this paper contributes to the ongoing
research on materiality of user interfaces, that focus on, e.g., a material turn in interaction design [26], computational composites [33], or the visions of organic user interfaces [9] and radical atoms [12].

Quite a number of exploratory prototypes and art installations that use ephemeral materials have been designed, but these efforts have yet not been drawn together or analyzed on a broader scale. The contributions of this paper are the introduction of the novel term "ephemeral user interface" as umbrella term for this group of UIs and the presentation of a design space. This analysis is inspired by the authors' own experiences with self-built ephemeral UIs and based on a review of 50 user interfaces published in HCI research and art contexts. The list of papers and web resources is available from the authors. In the following, we first introduce the concept of the ephemeral as found in nature and applied in art and architecture. Then we adapt it to ephemeral UIs, define their characteristics and explore the design space in further depth. Finally, we discuss future research directions.

BACKGROUND: THE EPHEMERAL IN NATURE, ART, AND ARCHITECTURE

The word “éphéméros” is originally Greek and literally means "lasting only one day". It is used to specify different phenomena or species in nature, e.g. the mayfly (ephemeroptera), plants with short life cycles, non-permanent waters or the permanently changing positions of planets (ephemerides). Within cultural studies the term ephemeral is used to describe phenomena that arise and disappear again, e.g. in the context of new media or for the triviality of everyday life [41]. The ephemeral can depict a broad variety of time spans - from seconds to years. Ephemeral is an important aspect of human life - on a big scale regarding our own lives (e.g. childhood, youth) and on a small scale regarding all these special moments and experiences we have [2]. People generally love the ephemeral as event and sensation, e.g. in the form of performances or fireworks. Experiencing something that is only there for a limited time makes it a special experience. Natural phenomena like the solar eclipse (see figure 2 middle) and even rainbows, which happen beyond our control, are exceptional and beautiful moments. Ephemeral architecture depicts buildings that are only constructed for a certain event, like pavilions for exhibitions. An example pavilion that took ephemeral architecture to its extremes was the "blur building", a project built by Elisabeth Diller and Ricardo Scofidio for the Swiss national Expo 2002 [4]. This pavilion consisted of a (mainly hidden) metal construction as large as 60 by 100 by 20 meters that sprayed tiny drops of water from high-pressure jets, such that a huge cloud arose, visible from far and floating above the lake (see figure 2 left). The cloud "building" could be reached by a bridge and entered, such that visitors could stay inside and experience the ephemeral building made by ephemeral "material". Integrating ephemeral materials into art started as part of movements like arte povera, land art or pop art, where cheap, natural and industrial materials were used to broach the issue of everyday contexts in art. While in aesthetic theories in western culture material mainly had been the media of form and the materials' history as well as their meaning in everyday contexts were basically eliminated in artworks, this changed in the 20th century [36]. The materials themselves became carrier of meanings. Materials such as earth, trash or clothes became part of artworks, explicitly using the materials' connotations for their meaning. This also included a number of ephemeral materials like ice (e.g., see figure 2 right), food or fire. This looser notion of "material" applied in art differs from definitions of materials used in material science for example. Nevertheless, even in material science the concept of what a material is, is ill-defined [33] and strongly depends on the point of view. For example, every material is a structure at a molecular level, while on a higher level of abstraction a complex structure containing a number of materials can be regarded as material, as e.g. done with smart and sensorial materials, that themselves contain composite or hybrid materials on a microscopic level [17].

Within art, the notion of material is shaped with a perspective from a higher level of abstraction, focusing on dominant materials in artworks from a perception and cultural perspective rather than on its molecular structure. This includes next to pure substrates and natural materials also plants or assembled objects, and even fire, air or light can be regarded as materials of art, if used in a meaningful way for a piece of art [35]. Important for regarding something as an artistic material in this broader context of contemporary art is the existence of certain meanings of the material in a cultural context as well as the evocation of a rich multisensory perception of the material. In our introduction and analysis of ephemeral user interfaces we are following this approach: an interaction material can be any material that is used in a meaningful way for the interaction, that has certain meanings in a cultural context, and that evokes a rich multisensory perception. Here, we are specifically interested in ephemeral interaction materials.

CHARACTERISTICS OF EPHEMERAL USER INTERFACES

Ephemeral user interfaces constitute an approach to bring the described aspects of ephemerality and related aesthetical experiences into human-computer interaction from a material perspective. We define ephemeral user interfaces as follows.

Figure 2. Humans enjoy ephemeral events. Left: Blur Building by Diller and Scofidio [4] (courtesy of Diller Scofidio + Renfro); middle: solar eclipse; right: Minimum Monument by Nêle Azevedo [7], sculptures made from ice (courtesy of Nêle Azevedo, www.neleazevedo.com.br).
Definition: Ephemeral User Interface

Ephemeral user interfaces are a class of user interfaces that contain at least one UI element that is intentionally created to last for a limited time only. The durability of the UI element is determined by its intrinsic material properties in combination with its surrounding ecosystem. While their ephemeral UI element(s) exist(s), ephemeral user interfaces provide a rich and multisensory user experience. They may deliberately be designed to offer only partial or imperfect user control.

In the following, we explain the key characteristics in further depth.

Ephemeral UI Elements

Ephemeral UI elements are characterized by two important features. First of all, they are time-based. This means, that parts of the interface are designed not to last. How long they last varies depending on the used material, their surrounding ecosystem and what determines their disappearance or degradation. Ideally, the disappearance of UI elements fits to the intended interaction with the interface and its user experience. This could be due to the fact that UI elements are only needed for a short time, that users should be engaged to destroy them or create new ones, to simply raise attention, or to limit the users' mental load by presenting information unobtrusively in the background for a limited time span. With ephemeral user interfaces, temporality becomes part of the meaning of the interaction. This distinguishes ephemeral UIs from existing common user interfaces that as well do not last forever but the aspect of its temporality is not used in a meaningful way for the interaction. Furthermore, with ephemeral user interfaces the time restriction and sensitivity of UI elements is explicitly perceived by its users.

A second focus of ephemeral UI elements lies on the qualities and aesthetics of the materials used for interaction. While this generally might be true for any user interface, ephemeral user interfaces contain materials that especially carry embedded meanings from other contexts, often meanings that are deeply inscribed into the cultural context of their users. Most ephemeral materials are perceived as being very poetic. Examples for such materials are many natural materials like the elements (water, air, earth, fire), plants, soap bubbles or food. If these materials are used for input or output or both their original meaning will always shape the perception and thus the overall user experience of the interface. Next to using the semantics of the materials, one central idea of ephemeral UIs is that the intrinsic properties of the used materials are directly applied to the interaction - beyond their use as passive decoration in backgrounds, covers or shells. Ephemeral UI elements can be realized by directly applying ephemeral materials like soap bubbles or fog that disappear by themselves due to their physical properties or by integrating materials with certain properties into an ecosystem that enables ephemerality (e.g., wind blows sand away, ice melts in warm environments, a plant that does not get water withers, food can get eaten or might get rotten).

Multisensory User Experience

Affectiveness and aesthetics play important roles in the design of ephemeral UIs. Our experiences are that an integration of ephemeral materials into user interfaces potentially raises peoples' interest to use a system and motivates the users to engage with the UI. Interface designers can build upon users' experiences of transient phenomena from the real world and the fact that timely restricted moments are often valued as precious. Another central design element of ephemeral user interfaces is that they offer multisensory experiences, simply by integrating materials that naturally address a number of senses. If an ephemeral material is used for input by touching it, it gives natural haptic feedback e.g. evoked by non-flat surfaces, interesting and diverse textures, liquids, fragile structures, temperature, etc. Additionally, many ephemeral UIs allow a playful interaction, giving users many degrees of freedom to interact with the materials, which not necessarily need to be sensed and be part of the interaction with the system, but enrich the overall interaction. All these aspects potentially contribute to a rich user experience. To better address the different aspects of technology as experience McCarthy and Wright have introduced a framework of four threads of experience [20]: the compositional thread, the emotional thread, the sensual thread, and the spatio-temporal thread. We believe that ephemeral user interfaces explicitly address the latter three threads by putting a strong focus on emotional response, sensual experience and effects of temporality.

Limited Control

The French philosopher Buci-Glucksman wrote about the aesthetics of the ephemeral as an aesthetics of fluidity in which the "spirit of the vagueness" plays an important role [2-20]. This spirit can become part of human-computer interaction by integrating ephemeral UI elements that are designed to be not absolutely precisely controllable, e.g. bubbles that burst in an uncontrolled manner after a while, water that freely flows or fog that clears away. The degree of control strongly relies on the material properties and also depends on the environmental conditions (e.g. temperature, wind) as well as on used sensing and actuation technologies and applied algorithms. This offers many opportunities to design for engaging and poetic interactions.

DESIGN SPACE

To get a deeper understanding of the design space for ephemeral UIs, we collected and analyzed 50 user interfaces that we regard falling into this research area. They all incorporate ephemeral materials and as such provide valuable insights for a discussion of our introduced concept as well as further research directions. In our design space, we focus on three aspects of ephemeral UIs: materials for ephemeral UI elements, interaction and ephemerality.
Materials for Ephemeral UI Elements
The example materials for interaction we found in our set of ephemeral user interfaces are water, ice, fog, air, soap bubbles, sand, clay, fire, light, plants, wax, perfume and food. This does not present a comprehensive list of all possible ephemeral interaction materials, but the examined examples highlight a number of interesting aspects and present a basis to discuss the design space of ephemeral UIs that as well could include novel and smart materials in future. We looked at these materials from two points of view: the purpose of their selection for the UI and their states of matter.

Purpose of Material Selection
One relevant aspect regarding materials for user interfaces is the purpose of their selection. Analyzing the set of UIs and their descriptions and design rationales, we found that, on the one end of a continuous spectrum, the properties of a certain material led to its usage within a user interface, e.g. a material's physical, mechanical, electrical, optical, eco-, thermal or acoustic properties. On the other end of this spectrum is the material semantics, i.e. a material's meaning, history and typical ways of uses in a certain cultural context or environment (see figure 3).

An example prototype, where the used material for interaction has a very strong meaning in the used cultural and application context, is ThanatoFenestra [32]. ThanatoFenestra is a Japanese Buddhist family altar designed for people to remember passed away family members. Users first need to light a candle in order to let a photograph of the family members appear as projection on a small round screen. The photograph slowly fades in as the candle's flame emits more heat and finally is clearly visible. If the candle flame is moving or flickering, the next picture is shown. In case the candle is blown out, the picture is slowly faded out again. In this prototype the candle's flame is used as material for interaction. Candles very well fit into traditional Buddhist practices, so the material selection clearly was motivated by the semantics that candles have in this cultural context. An example prototype, where the material semantics also is more important for the selection than the material properties, is PlantDisplay [16], a prototype that uses a houseplant as ambient display for information. Plants are typically integrated into living rooms and as such suited as elements representing ambient information in the home context. An example prototype where the material properties presumably are more important than the semantics of the selected material is Noisy Jelly [42], an electronic music instrument that uses different shapes of jelly with variations of salt concentrations to play music. The jelly was most likely selected on the basis of its varying conductivity due to different shapes and salt concentrations rather than the semantics as food. So, in this case, physical and electronic properties played a big role for the material selection. In some cases both aspects, the material properties and the semantics, seem to have played an important role for a material selection and are well integrated. An example that falls into this category is Ice Wall [34], an interactive multi-touch wall built from pure ice in an outdoor environment in winter in Finland. On the one hand, the properties of ice as material allow frustrated total internal reflection, which was needed to realize vision based multi-touch tracking, on the other hand, the ice wall stands in the tradition of ice buildings like igloos or ice hotels (c.f. [26]). In other cases it might be hard to say, how much exactly the semantics and how much the properties of a material have influenced a selection, as, for example, some established ways of usage of a material in a certain context have only evolved due to material properties, e.g. clay as a material for modeling in design and architecture. Nevertheless, often a design evolves from either end of the spectrum: either starting from the properties or starting from the semantics. This continuum helps to reflect this aspect and to discuss design alternatives.

States of matter
States of matter are the distinct forms that different phases of matter take on. We distinguish between the three classical states solid, liquid and gas and use them as a structure to discuss one aspect of the design space for ephemeral user interfaces (see figure 4). As we are looking at interaction materials that are not necessarily pure matter, we apply these three states not in a strict physical or chemical manner but rather look at the dominating materials' state of matter. This yields the potentials to cluster interaction techniques based on the states of matter and leads to a special attention of the phase transformation between different states. Next to other approaches, transformations (e.g., solids can transform into liquids by melting or can even be changed into gases through sublimation) could play an important role to realize and design ephemerality of interface parts. While we have found a number of examples where water in its different phases was used as interaction material, the phase changes of a material itself have been rarely used for interaction purposes.

In a solid state matter maintains a fixed volume. Solid materials for ephemeral user interfaces can for example be sand, clay, plants, or food. Depending on the form and the deformability, the typical interaction techniques for solid materials are touching or pressing them, kneading or moving granules. An example is Botanicus Interacticus [23], a
Ephemeral Materials for Output Only

Almost half of the prototypes we analyzed use ephemeral materials for output only. Many ambient displays fall into this category for example. These UIs receive their input either from a computer or from a user. If the input comes from a computer system, it can either involve no interaction by users, e.g. when displaying digital information, or include implicit interaction - input based on tracked human behavior often without the users realizing this.

An example ephemeral user interface for output involving no interaction is BitFall [37], an art installation that uses waterdrops to display words in a water curtain. By controlling water nozzles in a horizontal array, letters are formed and are visible for about a second while the waterdrops are falling to the ground. The displayed words are selected by an algorithm from news found on the Internet. Implicit interaction with an ephemeral user interface that uses transient materials for output only is realized by the PlantDisplay for example that presents information about the user’s communication behavior (e.g. the amount of recent e-mail and phone communication) with the plant’s condition. If a user communicates a lot, the plant gets light and water to grow, if there is not much communication, the plant only gets a little light and water and its condition gets worse.

In a further category, ephemeral materials are solely used for output and the system allows user input, but input and output spaces are not the same (indirect interaction). Examples for this type of ephemeral UI are WaterGames [22], an outdoor game that uses the movements of a group of kids around a water fountain to control the fountain, or Satan’s Calliope [15], a vehicle with a fire music instrument that translates key movements on a MIDI keyboard into flames that emerge from metal organ pipes.

Ephemeral Materials for Input Only

A number of user interfaces use ephemeral materials for input only. In case of Noisy Jelly, the music instrument using the changing conductivity of jelly forms when a person touches them, the ephemeral material jelly is only used for input, the output is sound. We found quite a number of further examples that use ephemeral materials for generating and controlling sound, e.g. tangible sound [40] and the hy-
draulophone [18], which use water movement, or ephemeral melody [30], a soap bubble instrument. A different application context for using ephemeral materials for input is the control of 3D virtual environments, as for example applied in a prototype that maps stirring in real water to the interaction with a virtual pond [3].

Ephemeral Materials for Input and Output

UIs that use ephemeral materials for input and output form the smallest group in our set of analyzed user interfaces. Examples are the Soap Bubble Interface [31] that uses floating fog-filled soap bubbles as handles for input and as projection surfaces for output or the Ice Wall [34] that was used as a projection screen and at the same time allowed input via multi-touch tracking. While these examples show how to unify input and output space, this is hard to realize with some of the materials. Nevertheless, we think a unified input and output space should be part of an ideal ephemeral UI. Fishkin [5] already proposed embodiment, the degree to which the input focus is tied to the output focus, as one important design factor for TUs and suggested increasing the embodiment in order to reduce "cognitive distance" between the input mechanism and resulting output.

Ephemerality

One of the characteristics of ephemeral user interfaces is, that parts of the UIs are not designed to last. This leads to two design parameters: first, the type of determination of disappearing or degradation of ephemeral UI elements and second, the class of durability of ephemeral UI elements.

Determination of Disappearing

Depending on the material, different mechanisms can be used that determine the disappearing of the ephemeral UI element. We identified three different mechanisms: natural phenomena, user interaction, and system trigger (see figure 6).

A wealth of natural phenomena can be used within ephemeral user interfaces. Examples are gravitation as used in Bit.Fall, phase transformation between different states of matters (e.g. melting ice), disappearing sunlight (e.g. used in SolaColar [8]), fog that clears away, or soap bubbles that naturally burst as the surface gets too thin to be stable amongst many others. Many of these effects would be complicated to design artificially with a system. Starting from the nature around us, these rich textures and natural phenomena offer many opportunities for designing interaction.

In some cases a determination of the disappearing of the ephemeral user interface element by user interaction can make sense. The soap bubble installation Bubble Cosmos [21] offers this mechanism as destroying soap bubbles is mapped to sound output. Food as part of ephemeral UIs forms a further class of examples that allows user interaction to determine its disappearing: the users can eat it.

As not all effects and materials needed for user interfaces can be found in nature and not always an elimination of part of the UI by the user is wanted, a third category exists, where the determination of disappearing happens through system trigger. This could be part of a future research area addressing the interaction with smart and sensorial materials that can be fully or partly controlled by computer systems. A step into this direction is done by projects using ferrofluid as interaction material, e.g. [14]. As we regard air as an interaction material, wind could be used as ephemeral interface element. This is realized in Murmur [27], a sculpture containing a matrix of fans that give feedback by generating wind of a certain intensity and duration. In this example, the system can determine the end of the airflow.

Durability of the Ephemeral User Interface Elements

Different ephemeral materials offer different time spans of durations. Looking at the natural materials used in user interfaces, we distinguish six classes of durability that can be used for the design of ephemeral user interfaces (see figure 7). UIs with ultrashort durability include elements that only last up to seconds, an example is Bit.Fall where letters are only visible for a second. The short durability class describes UIs with elements that last up to minutes. This includes systems using soap bubbles for interaction. The third class contains UI materials that last up to hours (semi-short durability). Examples include ThanatoFenestra that use a burning candle for interaction or Noisy Jelly, the jelly-based music instrument. The semi-long durability class describes UIs with elements lasting up to days. Some of the food interfaces fall into this class, e.g. Pumpektis - a Tetris game carved and built into a real pumpkin. Ephemeral UIs with long durability contain elements that can last up to months or even years. Examples are plants as applied in PlantDisplay or food like Jelly Beans as part of the BeanCounter [19], an "edible" display. Finally, many materials do not have a self-determined durability, but depend in their durability on other conditions, like temperature for example or their amount. These fall into a sixth group: flexible durability. Ice is an example for a material that can last forever, given the temperature is low enough, but can also melt from one moment to another. Also fire, if used for output, can

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<th>Natural Phenomena</th>
<th>User Interaction</th>
<th>System Trigger</th>
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Figure 6. Three types of determinations of disappearing of the ephemeral UI elements.
DISCUSSION AND CONCLUSION
Based on a review of 50 prototypes that fall into this field, we defined the characteristics of ephemeral user interfaces and outlined a design space focusing on materials for ephemeral UI elements, interaction and aspects of ephemerality. This design space leads to a number of areas for future research. Here, we briefly highlight three of them: first, design tools for material-focused user interfaces; second, ephemeral smart materials, and third, nature and ephemerality as metaphor for hard- and software design.

Design Tools for Material-Focused User Interfaces
In our design space, we have started to structure the aspects of material selection for ephemeral user interfaces. This process could be further supported by a catalogue of example materials and prototypes as well as their material properties and semantics in certain cultural contexts. Additionally, the design space for interaction techniques with ephemeral UIs starting from gas, liquid, and solid materials should be further explored and could be developed into a material-focused interaction vocabulary for ephemeral UIs. An early research work that introduces a structured set of interaction techniques for fluids is given by [38]. Finally, an important area of future work will be toolkits that support the integration of a variety of different materials for interaction. Here, recently some examples have been developed, e.g., Touché [28] and Makey Makey [29] that both use capacitive sensing technology to allow interaction with liquids and other natural materials. Furthermore, our approach to talk about ephemeral UIs from a material perspective could be extended to TUIs in general. If we design UIs starting from material semantics and properties this would most likely lead to much richer textures for interaction and an integration of the fascinating phenomena nature offers.

Ephemeral Smart Materials
Thinking about all the qualities natural materials have and how they can be used for interaction, leads to the question, how we could design materials with exactly the properties we want for a user interface. Current activities in nano- and material sciences already focus on the invention of materials with novel features. In future, a typical UI design task might rather focus on the design and invention of a new material instead of selecting an existing one. Ephemeral natural materials could provide a valuable starting point to think about the features and possible interaction techniques. Future smart materials should provide from a user experience point of view (rather than a technical definition of requirements). E.g., one focus could be on the aspects of ephemerality as introduced in our design space: how could we design an ephemeral smart material with a certain durability span, maybe computationally controlled? Could a material be reactivated, as e.g. already possible with ferrofluid sculptures (c.f. [14])? What interaction techniques are possible for a certain set of novel materials? These open questions are related to current research programs like radical atoms [12] or shape-changing interfaces [25].

Nature and Ephemerality as Metaphor for Hard- and Software Design
Analyzing the values that the integration of natural and ephemeral physical materials have for UI design can also help to improve the design of digital systems. This is in line with the framework of reality-based interaction that suggests starting to think from real world phenomena when designing interaction. The designers' challenge lies in balancing computational power and reality. Taking the nature only as model and transfer insights back to the digital domain can be useful in some cases. A few examples for such nature-inspired UIs have already been designed (e.g. robotic plants [10]), but the potentials have not been fully utilized: how could hard- and software elements grow, get older, degrade or even decay as things in nature do? In this sense, ephemerality could also be a strong concept for software design, as e.g. also discussed by Bannon [1]. We believe that these ideas fit the human nature.

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