ORIGINAL ARTICLE

Extensible, Extendable, Expandable, Extractable: The 4E Design Approach for Reconfigurable Displays

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ABSTRACT
We introduce "4E," a new design approach of reconfigurable displays that can change their form factors by capitalizing on four quality properties inspired by applied material: *extensibility*, *extendability*, *expandability*, and *extractability*. This approach is applicable to both fixed and portable displays. We define and exemplify each property, highlighting the key differences in how reconfigurable displays can change their form factors to accommodate more screen real estate for more users, applications, and functionality. To demonstrate the 4E approach, we conduct a targeted literature review and introduce E3Screen, a prototype that enhances any flat screen (*e.g.*, of a tablet, laptop, monitor) with two slidable, rotatable, and foldable lateral displays. We report results from a controlled experiment with N=103 participants, conducted to collect, analyze, and understand end users' preferences for display configurations permitted by the extendability, expandability, and extractability of E3Screen. Our results structure future research and development in reconfigurable displays and multi-display collaborative workspaces.

KEYWORDS
Reconfigurable displays; Desk spaces; Personal and public displays; Territoriality; Prototype; Experiment

1. Introduction

Computer displays, like laptop screens, desktop monitors, and tablets, become "reconfigurable" when their form factor is adapted by user interfaces of interactive applications to fit existing or new contexts of use (Ohta, 2019). The technology enabling *reconfigurable displays* (Schmidt et al., 2004) has accommodated a wide diversity of workplace scenarios (Mandviwalla & Olfman, 1994), from single-screen devices for single users (Gomes & Vertegaal, 2014; Khalilbeigi et al., 2012; Lee et al., 2008; Roudaut et al., 2013) to Multi-Display Environments (MDEs) and workspaces for group meetings and collaborative work (Jokela et al., 2015; Marquardt et al., 2018; Rädle et al., 2014). Even specific application scenarios involve opportunistic configurations of individual displays (Braley et al., 2018; Schwarz et al., 2012). The reconfigurability of displays has been imple-

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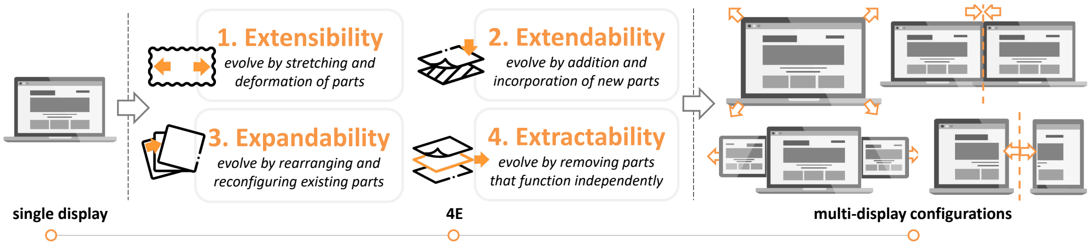

Figure 1. The four quality properties of our 4E design approach inspired by applied material (*i.e.*, extensibility, extendability, expandability, and extractability) for informing and guiding design and prototyping of reconfigurable displays, such as turning a single display system into a multi-display configuration.

mented in various ways, such as by using innovative shape-changing materials (Gomes & Vertegaal, 2014; Roudaut et al., 2013), elastic and foldable surfaces (Gallant et al., 2008; Lee et al., 2008; Troiano et al., 2014; Yun et al., 2013), flexible tile-based and cell-based structures (Goguey et al., 2019; Marquardt et al., 2018; Suzuki et al., 2019), mixed physical and video-projected displays (Jones et al., 2014; Vatavu, 2013), and modular display systems that can be conveniently separated and reassembled (Ohta, 2019; Seyed et al., 2017). Recently, these ideas have moved from research labs into actual consumer products, such as the Samsung, a dynamic display with an articulated spine, and TCL's smartphone featuring a triple foldable display (Cormack, 2019).

In order to reflect this wide variety, Ardito et al. (2015) classified a series of display configurations according to five dimensions: the visualization technology (*e.g.*, projection *vs.* physical display), the display setup (*i.e.*, horizontal, vertical, diagonal, and floor), the interaction modality (*e.g.*, tangible *vs.* touch interaction), the application purpose, and the physical location. Many more dimensions and attributes are useful (Sturdee & Alexander, 2018) to characterize and classify these display configurations (Boring, 2007) such as spatial attributes (*e.g.*, screen real-estate, resolution, mobility), physical relationships (*e.g.*, position, orientation), technological aspects (*e.g.*, type of displays, number of displays, number of input technologies used), and privacy concerns. Among them, the form factor emerges as a pre-eminent dimension since it directly expresses the physical configuration of displays (Hinckley et al., 2004).

This previous work was made possible by the creativity of researchers, designers, and system builders that sought the opportunities offered by the flexibility of new materials, surfaces, circuit boards, and software architectures to reconfigure their form factors, components, and programmable parts in order to present new functionality to their users. However, despite impressive research prototypes (Braley et al., 2018; Goguey et al., 2019; Marquardt et al., 2018; Roudaut et al., 2013; Suzuki et al., 2019), *there is little methodology available for newcomers to the field to support design of new reconfigurable display prototypes, devices, and systems.* The community has focused primarily on exploring prototyping opportunities rather than on consolidating design knowledge in the form of readily applicable design methods.

To this end, we introduce "4E," a new design approach for reconfiguring single displays, *e.g.*, tablets, laptops, PC monitors, into multi-display systems by capitalizing on four distinct capabilities of physical objects to increase their size to accommodate more users, more applications, and more functionality. For example, textile fabrics can be extensible (Williams, 1999), furniture expandable (ExpandFurniture, 2020), and hardware components extractable (Goguey et al., 2019). But how can these subtle semantic differences be thoroughly characterized and then exploited to inform the design of displays that can resize, reshape, and restructure to accommodate various user needs? We describe such capabilities in terms of four quality properties: *extensibility*, *extendability*, *expandability*, and *extractability*; see Figure 1. We insist on the unique distinctiveness of each quality property, *e.g.*, extensibility *vs.* expandability, for which we provide operationalizable definitions and clarifying examples. Our 4E approach capitalizes on these semantic distinctions to provide practitioners with a new design approach for their projects. We make the following contributions in this paper:

(1) We define "4E," a new approach to characterizing, designing, and prototyping *extensible*, *extendable*, *expandable*, and *extractable* multi-display systems for multi-user applications and workspaces.
(2) We illustrate the "4E" design approach by introducing a new prototype, E3Screen, designed to enhance any flat screen (*e.g.*, of a tablet, laptop, PC monitor) with two slidable, rotatable, and foldable lateral displays. We show how E3Screen implements extendability, expandability, and extractability.
(3) We perform an evaluation of E3Screen in the form of a controlled experiment with a large number of participants (N=103) in order to understand end users' preferences for configurations of displays permitted by the extendability, expandability, and extractability features of E3Screen. We use our empirical results and observations to suggest future work on reconfigurable displays, including aspects regarding territoriality, deterritorialization, and reterritorialization.
(4) Lastly, we demonstrate another practical use of our 4E approach by using its four quality properties to characterize previous work on reconfigurable displays, which we identified by conducting a Targeted Literature Review (TLR) (Abraham et al., 2019).

This paper provides practitioners interested in prototyping reconfigurable displays with an actionable design approach to inform and guide their work. We hope that the new perspective provided by the 4E approach will foster more research and development in reconfigurable displays and, overall, lead to improved system designs.

2. Related Work

We discuss in this section multi-display and reconfigurable display systems targeted by our 4E approach. We also discuss "territoriality," an aspect that emerges naturally for multi-display systems, which we equally touch with our controlled experiment.

2.1. Multi-Display Environments and Foldable Displays

Users employ Multi-Display Environments (MDEs) to present, structure, and consume visual content (Grudin, 2001), *e.g.*, a second-screen is generally used to support the task rendered on a primary display, for peripheral awareness of extra content, or for resource access. Second-screen research has been especially pursued for applications in the field of interactive television (Geerts et al., 2014; Nascimento et al., 2016). For more than two screens, previous work has showed that physical discontinuities between the arrangement of individual displays seem not to affect the efficiency of content understanding, at least for tasks such as those examined by Tan & Czerwinski (2003). MDEs arrange displays in such a way that each individual display can support personal or group interaction as well as transitions between these two modes. However, the configuration of displays implemented by most MDEs is predefined, with limited flexibility to accommodate changing user needs, one of the requirements for groupware (Mandviwalla & Olfman, 1994). Specific MDEs involving virtual (video-projected) displays (Cotting & Gross, 2006; Vatavu, 2012a,b, 2013) are more flexible in this regard.

In particular, tabletops have been extensively studied to inform the design of collaborative interaction for several reasons: a tabletop gathers all collaborators around a same physical space that can be partially shared, a tabletop maintains a high degree of collaboration awareness among people as it mimics a traditional table, a tabletop can adapt its user interface layout (*e.g.*, documents, menus, pictures) depending on the users, their actions, and the interchangeable roles they play in the collaboration. Defining a private interaction area on a tabletop and removing it from the audience awareness is difficult, unless transferred to a separate personal device.

Foldable displays (Gomes et al., 2013; Gomes & Vertegaal, 2014; Lee et al., 2008) are considered a particular group of MDEs since they present content on various sides by folding, bending corners, or squeezing the surface. Foldable displays increase their interaction surface when unfolded in a stationary environment, and minimize visual clutter when mobile. For example, "FoldMe" (Khalilbeigi et al., 2012) consists of a foldable plastic surface with predefined hinges on top of which the user interface is projected. "FlexPad" (Steimle et al., 2013) also projects interactive content on flexible surfaces, such as paper, foam, and other materials; the supporting surface is tracked by a Kinect sensor and its deformations detected with depth sensing techniques. "FlexView" (Burstyn et al., 2013) recognizes bending gestures performed on an E-Ink Bloodhound flexible electrophoretic display.

We pause for now our discussion of the previous work on reconfigurable and multi-display systems, which we resume in Section 7, where we report the results of a targeted literature review on this topic to demonstrate the value of our four quality properties to characterize features of reconfigurable displays. Closer to our work is the concept of *chained displays* (Ten Koppel et al., 2012), where public flat vertical screens are configured together to form a non-flat surface, such as a concave or convex assembly. Unlike chained displays, Takashima et al. (2016) reconfigure three vertical flat displays independently of each other, either combined or separated, co-planar or not, thus leading to a set of frequently used configurations (*e.g.*, concave, concave with separation, offset rows, and zigzags).

2.2. Territoriality for Multi-Display Systems

Tang was probably the first to report that the partitioning of a surface into regions and the orientation of people around it represent two key variables that mediate collaboration. The surface is divided into regions that evolve over time depending on the users, tasks, and the roles played in the collaboration. For example, the members of a design team primarily engage in four types of tasks when involved in a workspace activity: store information, convey ideas, represent ideas, and engage attention; see (Tang & Leifer, 1988; Tang, 1991). Moreover, the location, size, and orientation of the regions delineated on the shared surface determine the boundaries of territoriality (Scott et al., 2004): the *personal territory* contains personal artifacts used in the collaboration; the *group territory* contains public artifacts shared among the members of the same group; and the *storage territory* contains physical artifacts that require persistence during the collaboration. The number of users and their position, *e.g.*, around the table (Tang, 1991), further influence the boundaries of territoriality.

Partitioning and orientation of the display used for collaboration, *e.g.*, a tabletop, are two vital parameters that mediate group interactions. and that delineate the boundaries of the respective territories involved in the collaboration: the personal territory, the group territory, and the storage territory, which all together form the concept of *territoriality* (Scott et al., 2004). Territoriality, the expression of ownership towards an object, can emerge when social actors occupy a shared social space.

The position and orientation of the items placed in the personal, group, and storage territories determine the roles these items play in the collaboration (Kruger et al., 2003), such as for the comprehension of information, coordination of activities, and communication among group members. Items that belong to the personal territory are located close to their owners and oriented towards them, while the shared items from the group territory are located near the center of the workspace.

The physical configuration of these territories is flexible and supports transitions from personal to group and vice versa (Scott et al., 2004). For example, the personal territory is materialized in the "ConnecTables" system (Tandler et al., 2001) by tablet devices, while the group territory by a tabletop. When two members of the group want to create a common space, they bring their personal displays side by side. Several technical mechanisms (Barralon et al., 2007) as well as interaction techniques (Jokela et al., 2015) can support this coupling. So far, territoriality has been studied for large public displays Azad et al. (2012) and interactive tabletops (Scott et al., 2004; Thom-Santelli, 2009; Thom-Santelli et al., 2009) but, to the best of our knowledge, has not been examined in the context of reconfigurable displays. In Section 7, we discuss the first empirical results on this topic.

The AugmentedSurfaces (Rekimoto & Saitoh, 1999) again materialize the personal spaces of group members on adjacent tabletops. The personal territory is integrated in the group territory by including the first on the entire table of the second. The DiamondSpin toolkit (Pinelle et al., 2003) allows deploying tabletop user interfaces around a table with different configurations based on partitioning of the personal territories, their location and their shape: for example, table for two, table for four, and continuous mode for more. Klinkhammer et al. (2018) compared two types of technical settings workspaces on a tabletop supporting a brainstorming task to conclude that different territorial strategies dependent on the role of territoriality and the orientation of digital notes. Therefore, in all these references, territoriality plays a central role and deserves a study to determine which elements could regulate its functioning to better understand how it mediates collaborative interaction.

3. The 4E Approach for Reconfigurable Displays

Quality properties, representing the capability of an entity to fulfill a particular function, provide a convenient basis to structure the design of user interfaces and interactive systems. Thus, we start our discussion of the 4E approach by defining its four quality properties, *i.e.*, *extensibility, extendability, expandability,* and *extractability.* Since there are subtle, yet key differences between these properties, *e.g.*, extensible *vs.* extendable displays, we adopt the following approach:

- We present definitions of the various terms from well established sources: Merriam-Webster, Cambridge, and Oxford's Lexico.
- We report usage of the terms in other disciplines, *e.g.*, extensible architectures in software engineering, extendable networks in computer communications, expandable furniture in interior design, etc.
- We introduce operational definitions for each quality property of reconfigurable displays and accompany the definitions with examples. These definitions and examples are gathered in Figure 2 to serve as a quick reference.

3.1. *Extensibility*

Merriam-Webster defines "extensible" as *"capable of being extended,"* where the extension can take place in either space, time, or in terms of effort.[1,2] Cambridge Dictionary provides a more specific definition that is contextualized in Information Technology, where the adjective is *"used to describe a computer program or language that can be changed by the people who use it in order to make it suitable for what they need to do."*[3] Oxford's Lexico presents both perspectives: in general, extensible means *"able to be extended or stretched,"* while, in computing, it indicates design *"to allow the addition of new capabilities and functionality."*[4]

Starting from these definitions, we explored the use of the terms "extensible" and "extensibility" in the computing. In software engineering, for example, *"extensibility is an important aspect of API (Application Programming Interface) design as it lets users expand base functionality without requiring [..] to support their needs explicitly"* (Reddy, 2011). In constraint programming, *"extensibility is crucial to the success of toolkits and libraries alike,"* constituting into a requirement that is *"vital to easily develop domain specific or application specific constraints and blend them seamlessly with other predefined constraints"* (Fruhwirth et al., 2006).

The Unified Modeling Language (UML) (UML, 2019) implements extensibility mechanisms to extend the language in a controlled way with stereotypes and profiles (Osis & Donins, 2017). The Extensible Markup Language (XML) (XML, 2019) acts as a skeleton to enable anyone to structure and specify data. Lastly, in an application domain more close to our contribution, multi-display UX design, recommendations are that *"extensibility and platform independence must be taken into consideration during the conception,"* while *"a concept should be flexibly designed for cross-media (digital and print), cross-device, and cross-platform information dissemination"* (Nagel, 2016).

Other scientific fields are using the term "extensibility" to characterize the properties of their objects of study. In material science, for instance, extensibility represents the *"fundamental ability of a material to extend or elongate upon application of sufficient force"* (Williams, 1999). Extensibility, as the amount a material can deform before breaking, can be measured along an axis by the breaking strain, representing the maximum value of strain supported by the material (Ennos, 2012). In the textile industry, fabric extensibility represents *"the extent of the ability of a textile to stretch when a tensile force is applied to it."*[5]

In conclusion, textile fabrics are extensible in that they fit and adapt to the wearer, software is extensible in that it can be updated to embrace new functionality, data formats are extensible by providing users with freedom when describing their data, and multi-display design is extensible with respect to the various forms and formats of content that can be displayed. The common pattern here is that the "material" from which all these objects are made of can be "stretched" to accommodate new situations and new uses. With this information, we now provide our operational definition in Fig. 2.

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[1] `https://www.merriam-webster.com/dictionary/extensible`
[2] `https://www.merriam-webster.com/dictionary/extended`
[3] `https://dictionary.cambridge.org/dictionary/english/extensible`
[4] `https://www.lexico.com/definition/extensible`
[5] `http://www.textileglossary.com/terms/extensibility.html`

Definition: *Extensibility* is the quality property of a display to increase its physical form factor by deformations of the material from which it was made.

Examples: The elastic display prototypes of Troiano et al. were made out of latex, cotton, elastane fibres, spandex, polyester, and lycra, which users could pinch, stretch, push, grab, and twist. A thin film E-Ink display with integrated bend sensors was used for "PaperPhone" (Lahey et al., 2011), a device enabling interaction using bending gestures involving the margins and corners of the display. "ElaScreen" (Yun et al., 2013) featured an elastic touchpad that, when pushed, enabled force-based input for 3D navigation. "DepthTouch" (Peschke et al., 2012) used an elastic surface to afford a third interaction axis upon depressing or lifting the surface with push and pinch gestures.

Definition: *Extendability* is the quality property of a display to increase its physical form factor through the addition of new components.

Examples: "Phone as pixel" (Schwarz et al., 2012) introduced a scalable platform for creating large, ad-hoc displays from a collection of smaller devices that could join at any time. "Around-TV" (Vatavu, 2013) implemented virtual TV screens video-projected around a physical TV set. "HuddleLamp" (Rädle et al., 2014) was designed to support spatially-aware, multi-user, multi-device applications in the form of a desk lamp system with a depth camera tracking the position and movement of displays on a table. Second-screens for cross-device media consumption for interactive TV (Neate et al., 2017) are another example of extendable MDEs.

Definition: *Expandability* is the quality property of a display to increase its physical form factor through the reuse, restructuring, and reconfiguration of its internal parts, modules, and components.

Examples: Galaxy Fold (Samsung, 2020), a combined phone and tablet device, features an articulated spine for smooth unfolding of the phone into tablet mode. Self-actuated "Morphees" (Roudaut et al., 2013) adapt to the context of use. "Projectagami" (Tan et al., 2015) and "FoldMe" (Khalilbeigi et al., 2012) were designed to be expandable by means of unfolding their constituting parts. "PickCells" (Goguey et al., 2019), a fully reconfigurable device, is composed of cells that enable physical and functional reconfiguration and inter-device connectivity. "Doppio" (Seyed et al., 2016) is an example of a reconfigurable smartwatch display.

Definition: *Extractability* is the quality property of a display to allow removal of its parts to be used independently of the display from which they originated.

Examples: The modular smartphone for lending (Seyed et al., 2017) conceptualizes devices that can be separated into pieces and those pieces lent to other users. "PickCells" (Goguey et al., 2019) enables individual displays (cell-like) to be extracted from a multi-cell system and used independently. Any MDE affording expandability, such as the "phone as a pixel"(Schwarz et al., 2012) or "HuddleLamp" (Rädle et al., 2014), also affords extractability when devices are removed from the multi-display system. In "Attach Me, Detach Me" (Grolaux et al., 2005), parts of the user interface can be detached and reattached: toolbars or palettes can be detached from their home application, moved at run-time to another device such as a tablet while running, and reattached when finished.

Figure 2. Definitions and illustrations of the four 4E quality properties.

3.2. Extendability

The terms "extensible" and "extendable" can be employed as synonyms[6] in regular language. However, while extensibility is generally associated to stretching functionality (*e.g.*, in materials, software libraries, data formats), extendability brings a subtly distinctive semantic perspective on how a display increases its form factor other than by stretching of the material from which it was made.

Upon dictionary search of the word "extendable," Merriam-Webster falls back on the definition for the verb "to extend."[7] The Cambridge Dictionary defines the term by means of an example: *"something that is extendable can be made longer"* or *"can be made to last longer."*[8] Similarly, Oxford's Lexico defines the term as *"able to be made longer or larger."*[9] Since these definitions are too general, far from capturing the subtlety and semantic finesse that we require, we turned our attention to applications where objects or systems increase in size to accommodate new functionality. In Computer Networking, a network grows by adding more routers, switches, and computers, *e.g.*, *"in EWN [Emerging Wireless Networks], overlay networks and extendable networks, the management plane must be easy to maintain and remain coherent, even when the ad-hoc network size is growing, when the network is merging with another one"* (Ding et al., 2011); consequently, computer networks are designed to be extendable for scalability purposes. In swarm robotics (Rubenstein et al., 2014), the swarm grows by adding more members to it. Coordinated flocks of drones (Tahir et al., 2019) are extendable by welcoming more drones to the flock, including drones that make up mid-air displays (Braley et al., 2018). Modular display systems are extendable by integrating more individual displays (Rossmy & Wiethoff, 2018; Suzuki et al., 2019).

So far, we know that computer networks are extendable to be able to incorporate new nodes, robotic swarms are extendable to permit new members, and large displays are extendable to include more surfaces on which content can be presented. The common pattern is that systems become larger by addition as new pieces are integrated within. With this insight, we can define *extendability* for reconfigurable displays:

3.3. Expandability

Merriam-Webster defines "expandable" as the property to *"open up (unfold); increase the extent, number, volume, or scope (enlarge); to express at length or in greater detail."*[10] Cambridge Dictionary defines it as *"able to increase in size,"*[11] and Oxford's Lexico as *"able to be made larger or more extensive."*[12]. Again, these definitions are too general for our purpose, so we must reorient our attention to applied

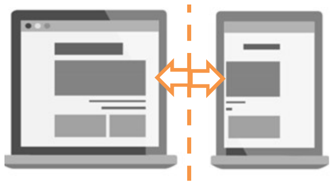
[6] https://www.lexico.com/definition/extensible
[7] https://www.merriam-webster.com/dictionary/extendable
[8] https://dictionary.cambridge.org/dictionary/english/extendable
[9] https://www.lexico.com/definition/extendable
[10] https://www.merriam-webster.com/dictionary/expandable
[11] https://dictionary.cambridge.org/dictionary/english/expandable
[12] https://www.lexico.com/definition/expandable

fields to get the subtlety that we need. Probably the best example is expandable hardware, where RAM memory or hard drives can be expanded to larger amounts. The difference with respect to software extensibility is that hardware can only be expanded as permitted by its original design, *i.e.*, the number of memory slots that are available on the circuit board.

Actually, the term expandable hardware is used frequently for work describing reconfigurable architectures, such as field-programmable gate arrays (FPGA) (Martinez et al., 2013). In economics, businesses expand by means of four strategies, according to the Ansoff Matrix (Ansoff, 1957): market penetration, market development, product development, and diversification; the first three strategies capitalize on something that the company already has, either products or an existing market. In interior design, expandable furniture can increase in length, height, or volume, *e.g.*, from a box coffee to a table dinning set (ExpandFurniture, 2020).

In conclusion, hardware is expandable to upgrade memory or processing resources, businesses expand by capitalizing on their potential, and furniture is expandable to new form factors to accommodate new functionality. The common pattern in all these examples is that growth is achieved by something that is *internal*, already existing in the object that grows. Expansion comes from using potential that was already there in the first place. Based on this perspective, we adopt the following definition for *expandability* for reconfigurable displays:

3.4. Extractability



Merriam-Webster defines "extractable" (adjective) as the property *"to draw forth; pull or take out forcibly; to withdraw; to separate,"* among other meanings of the term.[13] Cambridge Dictionary does not contain a definition for "extractable," but defines "extract" as *"to remove or take out something."*[14] And Oxford's Lexico lists the definition *"remove or take out, especially by effort or force."*[15] Based on these explanations, we adopt the following definition for *extractability* in the context of reconfigurable displays:

3.5. Summary

In this section, we defined four quality properties for reconfigurable displays by drawing from and analyzing many sources. These properties capitalize on subtle, yet key differences regarding how displays can change their form factors to accommodate more screen real estate for more users, more applications, and more functionality. We found that extensibility implies stretchability, where forces acting upon the material make the display larger, wider, taller. Extendability is about increasing screen real estate by having systems that integrate individual displays. Expandability means reusing, rearranging, restructuring, and reconfiguring parts of a display system toward a new form factor. Thus, expandability is different from extendability in that the capacity for expansion is "built-in," as opposed to the situation where parts are "added in" for extendability. Even when a mechanism for adding a display is installed, the property of concern remains extensibility, not expandability. Expandability is also different

[13] `https://www.merriam-webster.com/dictionary/extractable`
[14] `https://dictionary.cambridge.org/dictionary/english/extract`
[15] `https://www.lexico.com/definition/extract`

from extensibility in that no deformation needs to be applied to the display. Lastly, extractability is the capability of a multi-display system to be taken apart, resulting into smaller devices that can be used independently. Since extensibility always increases the screen real estate, its inverse property is contraction. Similarly, expandability also increases the real estate, but its inverse property of reduction. From this perspective, extendability and extractability are opposites. A reconfigurable display can implement one or multiple of these quality properties. These four properties are in principle applicable to any type of display, fixed or portable, private or public, whatever the size of the display is. For a portable display, these properties are particularly important in order to maximize the screen space while being stationary, while minimizing the size of the display when carrying out or keeping a reasonable surface while being mobile. The rationale is to apply these properties to reduce the cluttering of the display when unused and to increase the surface depending on its usage. While these properties are applicable to any display, we instantiate them on a laptop in the next section.

4. Prototype

To exemplify the 4E quality properties, we rely on a prototype of Le Slide, a reconfigurable display prototype in the form of an overlay containing two identical display panels, acting as secondary and tertiary displays, respectively, that can be attached to the backside of any tablet, laptop, or PC screen representing the main or primary display; see Figure 3. In the remainder of this paper, we will refer to this prototype as the“E3Screen”. The two panels are attached to the primary display using two Aluminum hinges, and are connected and powered via USB 3.0/USB-C. Each panel slides laterally and can be rotated up to 180°. Our specific implementation targeted a Sony laptop with a 15-inch screen diagonal, but the overlay can be engineered for any display size. The overlay is 0.7-inch (18 mm) thick and weighs 1.8 kg, and an optional stabilizing leg can be added to support the extra weight, if needed; see Figure 3. In our case, each display has 1920×1080 resolution, 60 Hz frequency, 5 ms response time, and luminosity of 350 cd/m^2. The power consumption of each panel is about 5 Wh, but the USB connection is sufficient to power up both displays. A driver was developed to extend the resolution of the primary device on the secondary and tertiary displays.

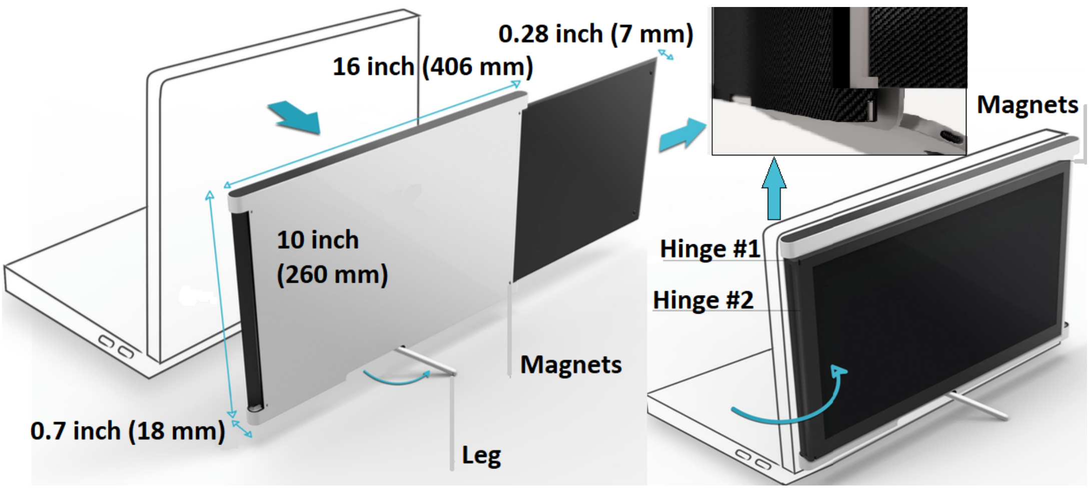


Figure 3. Illustration of the E3Screen, a reconfigurable display featuring extendability, expandability, and extractability.

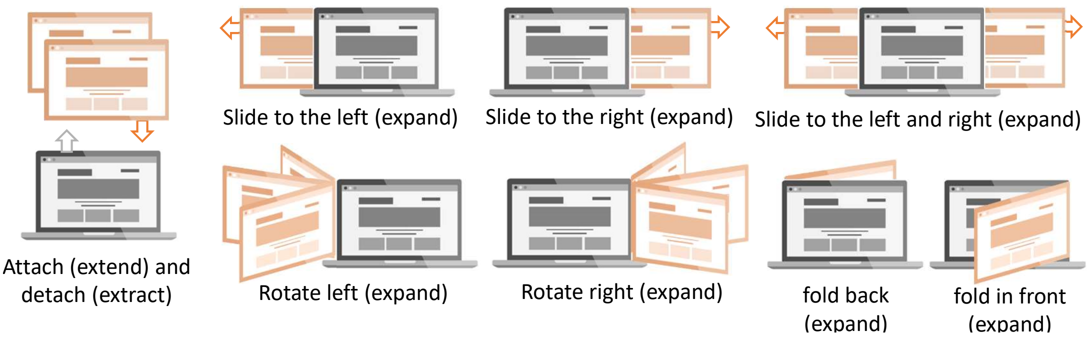


Figure 4. Extendability, extractability, and expandability properties of the E3Screen.

Unlike a double- or triple-monitor setup, E3Screen is reconfigurable by ensuring extendability (*i.e.*, the two panels are added to the primary display), expandability (each panel can be slided, rotated, and folded), and extractability (the panels can be removed from the overlay and used independently). Figure 4 exemplifies these quality properties and Figure 5 illustrates some of them for our implementation. Next, we discuss use cases and display configurations for E3Screen.

The prototype enlarges the user's visual field (Bi & Balakrishnan, 2009) by doubling or tripling the interaction surface to form an adjustable and rotatable panoramic view. Unlike creating a setup with three fixed screens with real bezels (*e.g.*, with a triple monitor) or virtual bezels (Lee et al., 2011) and unlike a monitor stand with table mount for three monitors or more, the E3Screen combines a wide and flexible interaction surface with a minimal cluttering while offering two foldable displays, which is an unprecedented combination of displays.

4.1. Display Configurations for E3Screen

E3Screen supports several use cases, from enlarging the user's field of view to accommodating several users in a collaborative workspace. Next, we identify display configurations for E3Screen based on the following parameters and corresponding references from the literature on multi-display systems:

(1) The number of displays (*i.e.*, one, two, or three) used simultaneously, following Truemper *et al.*'s (Truemper et al., 2008) treatment of usability aspects for multiple monitor displays.
(2) The orientation of the two rotatable displays (from $-180°$ to $+180°$) with respect to the primary display (Scott et al., 2004; Thom-Santelli, 2009).
(3) The number of users accommodated by the multi-display system (from one to seven users) (Mandviwalla & Olfman, 1994; Tse et al., 2004).

Figure 6, left illustrates display configurations suitable for one user, which we represented along the orientation and number of displays dimensions. Although the panels are fully rotatable, suitable rotation angles for comfortable visualization in the single-user scenario are between $-45°$ and $0°$, such as when displays are rotated towards the user (top-left drawing).

Figure 6, middle highlights configurations accommodating two users. For example, when only one display is used, two people can sit in front of it; when one or both panels are fully slided, a maximum angle of $45°$ preserves the visibility of colors (Harrison & Hudson, 2011). The two panels deployed in a non-coplanar and concave manner

Figure 5. E3Screen demonstrating (a) both panels fully expanded and (b) the "U-shape" and (c) "triangle" configurations.

to either left or right would enable two users sitting side by side to view the content presented on all the displays. When panels are unfolded convexly at angles of 90° or 180°, users can work from different sides of the table.

Figure 6, right shows configurations suitable for three users. When the number of displays is less that the number of users, all the configurations previously illustrated still apply, but one or two users are excluded. Two configurations of three displays are interesting to note: the "triangle" that distributes the visualization and interaction surface equally among users sitting on different table sides, and the "U-shape" configuration, representative of setups for follow-up meetings (Mandviwalla & Olfman, 1994). Usage scenarios for more than three users are equally permitted by E3Screen, such as all users sitting around the table in the "triangle" configuration. Figure 7 illustrates a few examples of configurations accommodating four to seven users. Note that for some scenarios, some users are excluded.

The resulting classification defines a total number of 14 (for 1 user) + 19 (for 2 users) + 14 (for 3 users) + 7 (for 4 users) + 5 (for 5 users) + 5 (for 6 users) + 3 (for 7 users) = 67 configurations, which will be used to univokely identify configurations.

These surfaces could accommodate a wide range of tasks, such as showing a presentation to a close audience, making a (public) demo of a software without actually showing the (private) code, showing a (public) product to a customer while keeping an eye on the (private) price list, broadcasting different (public) views of a blueprint (one for the customer and one for the builder) while manipulating a (private) source drawing. Or even prototyping a Graphical User Interface with a (private) visual editor on the main screen and showing a real rendering to end users and a design view to designers or marketing people. In these ways, a personal device can be augmented with

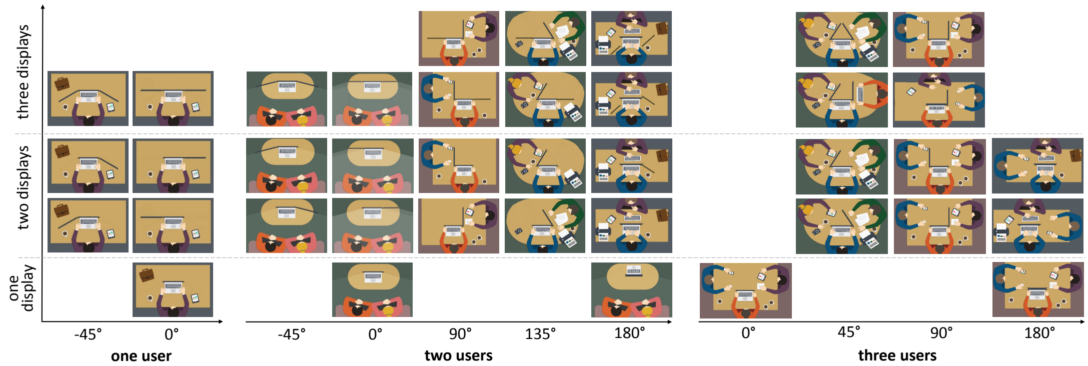


Figure 6. A selection of display configurations for our prototype to accommodate one, two, and three users.

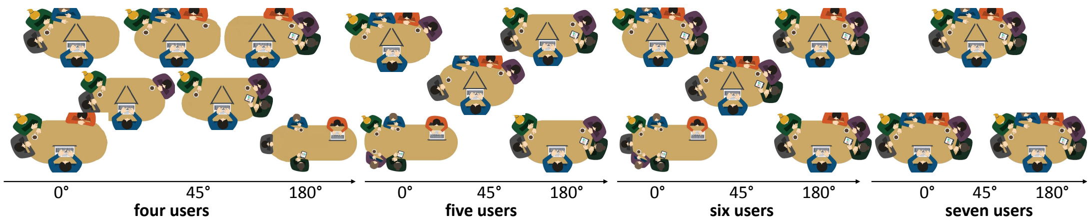


Figure 7. A selection of possible display configurations for our prototype to accommodate from 4 to 7 users.

a foldable display on the left and/or on the right to become either an extension of the personal space or a new support for collaboration with transition between the personal (private) space and the group (public) space.

5. Experiment

We conducted an experiment to understand preferences for display configurations and use cases supported by E3Screen.

5.1. Participants

A total number of N=103 participants (34 female), between 15 and 65 years (M=28.9, SD=12.3 years), were recruited via contact lists. Their professional occupations included secretary, teacher, psychologist, self-employed, unemployed, retired, and students from Engineering, Law, Economics, Physiotherapy, Management, and Criminology. All participants reported frequent use of computers and smartphones for various purposes, such as email (83.5%), social networks (68.9%), watching videos on YouTube (79.6%), web browsing (88.3%), document writing (78.6%), video games (31.1%), and online press (48.5%). About 75% of the participants were already using at least two displays (*e.g.*, laptop and smartphone) on a current basis. A percentage of 62% was aware of the fact that using at least one additional screen would help increase their productivity in the workplace (Grudin, 2001) and reduce workload (Su & Bailey, 2005). 94 participants (91%) were right-handed and 9 (9%) were left-handed. and no dexterity problems We grouped participants in four groups: students (29.1%), lower executive and administrative people (30.1%), and senior executive up to top managers (17.5%), the rest of respondents being independent, retired, and unemployed people. None of the participant has used or seen the E3Screen before; almost one out of two people was ready to invest in this extra device.

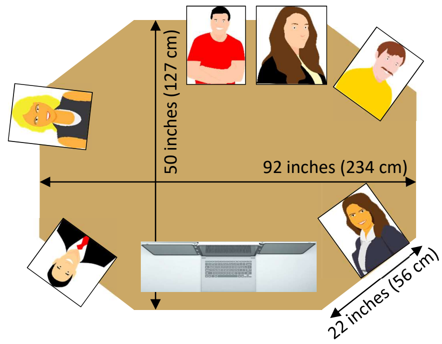
5.2. Apparatus

Participants were presented E3Screen, for which the primary display was a Sony VAIO FIT E laptop (Core i3, 4 GB RAM, Windows 10). E3Screen was placed on a table that could accommodate a maximum of ten people sitting comfortably, and positioned so that the physical distance from the participants was between 18-24 inches (46-61 cm).[16] E3Screen was functional and switched on, showing a typical Windows desktop with folders and applications that could be launched.

5.3. Procedure and Task

Participants were briefed about the purpose of the experiment and, upon agreeing to participate, signed the informed consent form and completed a socio-demographic questionnaire (age, gender, handedness, use of technology). Then, they were presented with a demonstrative video of E3Screen, which we preferred instead of delivering instructions directly in order to maintain control over the information given to all participants since the experiment was conducted over multiple weeks.

After watching the video, participants were asked to propose seven display configurations corresponding to use cases accommodating from one user (the participants themselves) to seven users. The six additional users were represented by cartoon avatars (three female, three male), printed on US-letter sheets of paper; see the aside figure.[17] Participants were encouraged to interact with E3Screen during this process, *e.g.*, launch applications, move icons on the Windows desktop from one display to another, rotate and slide the panels, etc. Also, in order to observe and report aspects of territoriality (Thom-Santelli et al., 2010), we asked participants to place any personal belongings they had on them on the table (*e.g.*, documents, folders, bags, coffee mugs, wallets), just like they would normally do when using a computer.



Once ready, each participant configured E3Screen to demonstrate each configuration, positioned their belongings on the table and the cartoon avatars around the table to mimic a real-world meeting. The experimenter noted the configuration (the entire experiment was video recorded, including the Windows desktop), after which the participant moved to the next condition represented by a different number of users. The order of the conditions was randomized across participants. At the end, the experimenter encouraged free comments about the device. Participation time varied between 21 and 37 minutes.

5.4. Design

Our experiment was a within-subject design with one independent factor: the number of users (one to seven) for which display configurations were elicited from participants. Overall, this design resulted in 103 (participants) $\times$ 7 (display configurations) = 721 proposals to analyze.

[16] The distance between the user and the screen should be at least 3 inches (7.6 cm)-25 inches (63.5 cm) according to the device control perspective (O'Hara et al., 2002). Moreover, displays should not be positioned above 75°from the horizontal line of sight and at a maximum angle of 45°, according to (O'Hara et al., 2002; Harrison & Hudson, 2011).
[17] Vector graphics available from `http://www.pixabay.com`.

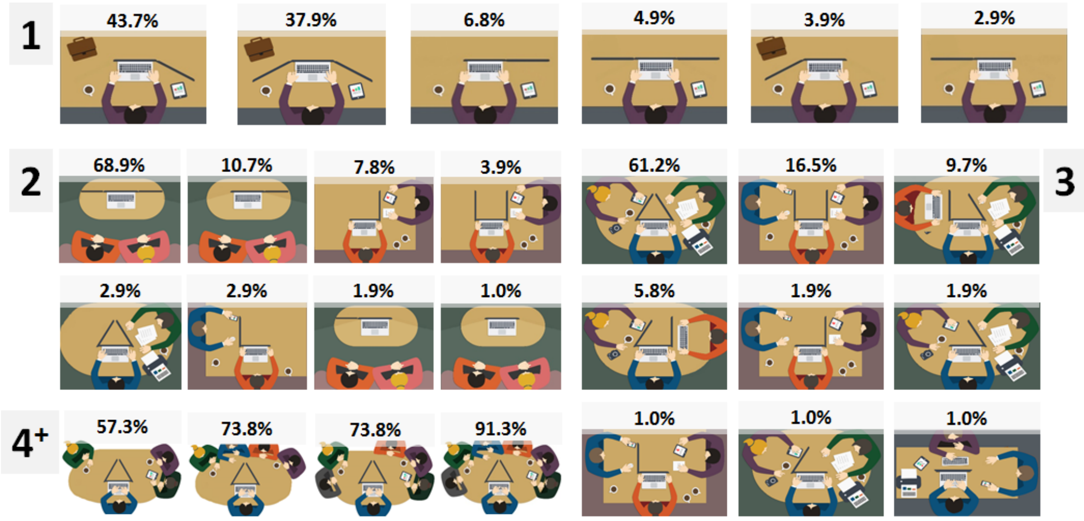


Figure 8. Proposed configurations accommodating one to seven users.

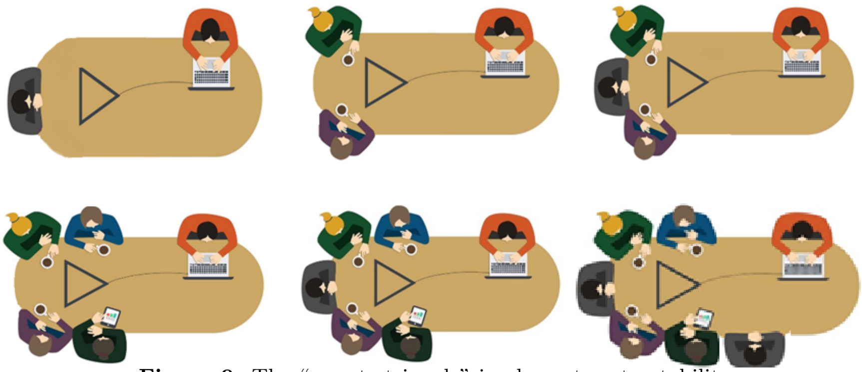


Figure 9. The “remote triangle” implements extractability.

6. Results

We discuss in this section participants’ preferences for the display configurations of E3Screen as well as aspects of territoriality that we were able to observe during the experiment.

6.1. Preferences for Display Configurations

Figure 8 illustrates the display configurations proposed by our participants in decreasing order of their frequency (popularity).

The most frequent configuration observed for the single-user condition involved the right display fully expanded and rotated at 45° toward the user. The large preference for this configuration (43.6%) compared to the others proposed in the single-user condition (see Figure 8, top) is probably due to the fact that the majority of our participants (91.2%) were right handed and, consequently, favored sliding the display they could more easily reach to and manipulate with their dominant hand (Grudin, 2001). In contrast, the symmetric configuration with the left-side display expanded was proposed by just 4 participants (3.8%). Another popular configuration was both displays rotated at 45° toward the user (39/103=38%), a configuration that maximizes viewing comfort and minimizes parallax. Flat (0°) display configurations were less preferred, achieving just 6.8%, 4.9%, and 2.9% popularity, respectively (Figure 8, top). The most popular configuration proposed for two users was full flat (71/103=68.9%), followed by lateral flat to the right (11/103=11%) to accommodate both users sitting side by side; see Figure 8, left for an illustration. Next came the "L-shape" (8/103=7.8%), "U-shape" (4/103=3.9%), and "triangle" (3/103=2.9%) configurations. A single-screen configuration was proposed by one participant.

The most frequent configuration for three users was "triangle" (63/103=61.2%) followed by "U-shape" (17/103=16.5%); see Figure 8, right. The third most frequent proposal was right angle for one display and an obtuse angle for the other (10/103 = 9.7% and 6/103 = 5.8%, respectively). Participants expressed preference toward displays oriented at a right angle when collaborating with someone close and at an obtuse angle for everyone else. We also observed configurations where one user was excluded. Not expanding all the displays was associated with the assumption or use case that the third person played a role that did not require a display, such as a moderator for the collaboration between the first two users. The "L-shape" and "V-shaped" configurations were ranked equally, 2/103=1.9% and 1/103=1%, respectively. One participant proposed one panel fully rotated; see Figure 8, bottom-right.

For conditions involving four to seven users, the "triangle" configuration was always proposed, but with different distributions of the users around the table; see Figure 8, bottom-left. For example, in the four-user condition, "one person left and two persons right" was the most frequent configuration (59/103=57.3%), followed by the asymmetrical "two left and one right" (41/103=39.8%), and the group "all at once" (3/103=2.9%). Note that we clustered all position variations by configuration (see Figure 10): for instance, the most frequent configuration "one person left and two persons right" covers various positions of the person left, such as top left, top, and bottom left. Figure 8 always keeps the most frequent configuration of its cluster.

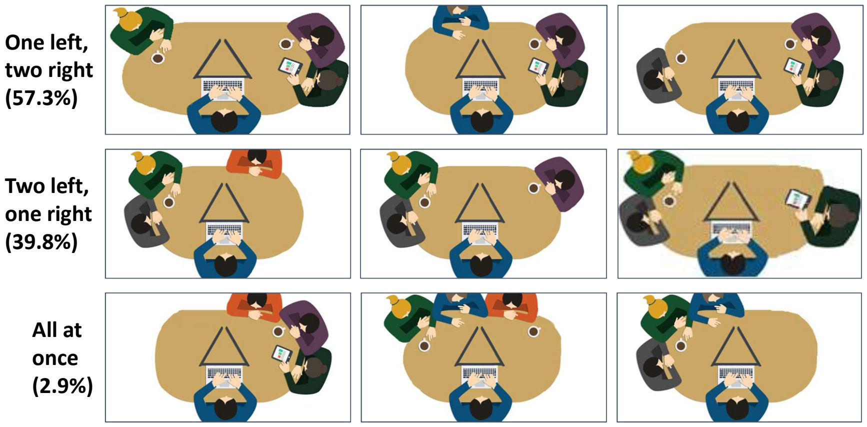


Figure 10. Position variations clustered by configuration.

The five-user condition fostered more variation in the distribution of the users around the displays: "four users on one side" (76/103=73.8%), "two and two" (13/103=12.6%), "three and one" (9/103=8.7%), and "one and three" (5/103=4.9%). For six users, frequent configurations were "two and three" (39/103=37.9%), "three and two" (33/103=32.0%), and "four and one" (31/103=30.1%). Only two configurations emerged for seven users: "six on one side" (94/103=91.3%) and "three and three" (9/103=8.7%), respectively. Besides these configurations, some participants also suggested a "remote triangle:" the three displays form a triangle, but are positioned at the opposite side of the table with a connecting cable to another computer; see Figure 9.

6.2. Aspects of Territoriality

We report on territoriality aspects regarding E3Screen for each of the personal, group, and storage spaces identified by Scott et al. (2004), and we connect to the concepts of deterritorialization and reterritorialization (Guattari, 1984; Lefebvre, 1974) from anthropology and social geography, which we discuss for multi-display systems. Note that the experiment involved only one participant at a time to capture their configuration independently of each other. Therefore, their engagement in territoriality is limited to the following considerations.

Personal space. This space was delineated by most of our participants (74/103=71.8%) as the region in front of E3Screen, a finding that replicates similar results reported in the literature (Kruger et al., 2003; Scott et al., 2004; Tang, 1991). The personal space could be shared with other users for display configurations involving more people sitting next to each other; see Figure 8. Larger groups could still be accommodated, but without all users having access to the displays, *e.g.*, the rightmost column of Figure 8 shows six people attending a presentation delivered by one speaker.

Group space. This space was specified by the physical configuration of the panels of E3Screen. For example, when the panels were slided laterally and not rotated, they impacted just the primary user's personal space. Centerfold configurations with co-planar panels indicated the intention of sharing a portion of the personal space with the rest of the group, as follows: when the two panels were oriented toward the user, they delineated a small personal space; when the panels were oriented backward, they defined a new group space.

Storage space. This space was delineated by most of our participants (59/103=57.2%) as the region specified by the boundaries of the personal and group spaces. Task-dependent objects, such as documents and folders, were located on the side corresponding to the participant's dominant hand, while task-independent items, such as coffee mugs, bags, or packages, were placed on the other side, as well as calculators and printers (see Figure 11).

Figure 11. Various items delineating the storage space.

Deterritorialization and reterritorialization. During the experiment, participants explored several display configurations, such as by changing the orientation of the displays and relocating personal objects accordingly, until they decided on a specific configuration to propose for the current condition of the experiment. During this process, the boundaries between the personal and the group space were readjusted in a continuous, transitional manner. We hypothesize that these transitions can be interpreted as a manifestation of the "deterritorialization" and "reterritorialization" concepts from from anthropology and social geography (Guattari, 1984; Lefebvre, 1974). For example, Lefebvre (1974) saw the space around a collaborator being divided into three subspaces: a *conceived space* representing the person's mental or conceptual model; a *perceived space* representing tangible space for discussion; and a *lived space*. The identity of any person is structured according to their positioning in these spaces. When the person leaves their territory, deterritorialization occurs, immediately followed by reterritorialization (Guattari, 1984) when there is reinvestment in a new situation. People apply various strategies for marking these evolving spaces, such as via body movements or by using physical objects. We believe that our experiment revealed such a process, which will be interesting to address in more detail in future work.

7. The 4E Quality Properties as a tool to Characterize and Classify Reconfigurable Displays

Our 4E approach based on the four quality properties identified for reconfigurable displays has other practical uses besides informing and guiding design of new prototypes, as demonstrated with E3Screen in the previous sections. In the following, we show the utility of the "4E" quality properties to structure and characterize previous work. To this end, we conducted a Targeted Literature Review (TLR) (Abraham et al., 2019), representing a non-systematic, in-depth, and informative survey of the scientific literature on reconfigurable displays. Indeed, we consider that the "4E" properties represent a first approach for a design considerations of reconfigurable displays and not instead a taxonomy of the research space, since more properties could be imagined, in particular outside the field of the form factor (Sturdee & Alexander, 2018). For example, extensibility hints at other aspects than form and space, such as time, effort, motor/cognitive space, range of functions, and not just the form factor and its stretching capability, as inspired from applied material (Vyalov, 1986). Table 1 illustrates the results of our TLR for various forms of reconfigurable displays, such as deformable, modular, foldable, elastic, and flexible MDEs. In the following, we discuss our findings by grouping prior work into two categories: (i) reconfigurable displays that fulfill only one property and (i) displays that fulfill at least two quality properties.

7.1. Focused, Single-Quality Reconfigurable Displays

In the following, we focus on previous work that implemented reconfigurable displays that fulfill just one of our four quality properties. The top part of Table 1 enumerates this prior work, from which we illustrate in the following just a few examples for each quality property.

Extensibility. The "Scroll Interactive Display" (Lee et al., 2008) consists of a printed material band that can be rolled and unrolled to expose more or less surface and aspect ratio for video-projected content. The band can be exposed or reduced, supporting extensibility. Another example is "Illuminating Clay" (Piper et al., 2002) that allows the user to shape a landscape model from clay.

Extendability. The "Dual Monitor" system (Grudin, 2001; Tan & Czerwinski , 2003) is a representative example of extendability, where a second display is connected to the primary one. This operation can be repeated and, thus, more displays integrated.

Expandability. The "Folding Fan" (Lee et al., 2008) can be expanded to offer maximal display surface and can be collapsed for purposes of transportation and storage. Since all fan triangles already exist and are deployed only when needed, the Folding Fan implements expandability. The same criterion applies for the parabolic/planar umbrella, the parasol, and the folding newspaper discussed by (Lee et al., 2008). Foldable displays are expandable by unfolding their constituting parts. Hence, they are *all* expandable (no parts can be added or removed) and could become extensible if made up of elastic material. This is related to the three physicality properties in applied material: elasticity, plasticity, and viscosity, and their combination (Fig. 4 in (Pérez-Medina et al., 2019)).

Prototype / Reference	Extensi-bility	Extend-ability	Expand-ability	Extract-ability
Focused, Single-Quality Reconfigurable Displays:				
Scroll Interactive Display (Lee et al., 2008), Illuminating Clay (Piper et al., 2002), "ClaytricSurface" (Sato et al., 2014), elastic display prototypes (Troiano et al., 2014), "PaperPhone" (Lahey et al., 2011), "ElaScreen" (Yun et al., 2013), "DepthTouch" (Peschke et al., 2012), "Khronos projector" (Cassinelli & Ishikawa, 2005), the "DeformableWorkSpace" (Watanabe et al., 2008), "BendableSound" (Cibrian et al., 2017)	✓	X	X	X
Dual Monitor (Grudin, 2001; Tan & Czerwinski , 2003) and its variant for TV (Neate et al., 2017), "Phone as pixel" (Schwarz et al., 2012), "Around-TV" (Vatavu, 2013), "Stitching" Hinckley et al. (2004), ´´Codex" (Hinckley et al., 2009)	X	✓	X	X
Folding fan (Lee et al., 2008), umbrella/parasol (Lee et al., 2008), folding newspaper (Lee et al., 2008), Foldable displays (Gomes et al., 2013; Gomes & Vertegaal, 2014), FoldMe (Khalilbeigi et al., 2012), FlexPad (Steimle et al., 2013), Galaxy Fold (Samsung, 2020), "Morphees" (Roudaut et al., 2013), "Projectagami" (Tan et al., 2015), "PickCells" (Goguey et al., 2019), "Doppio" (Seyed et al., 2016), "DeforMe" (Punpongsanon et al., 2013), workspace activity of Tang & Leifer (1988)	X	X	✓	X
Modular smartphone for lending (Seyed et al., 2017), "PickCells" (Goguey et al., 2019), "Phone as a pixel" (Schwarz et al., 2012)	X	X	X	✓
Multi-Quality Reconfigurable Displays:				
FlexView (Burstyn et al., 2013)	✓	✓	X	X
Emergeables (Robinson et al., 2016), Fog Screen (Rakkolainen et al., 2005), Gushed Light Field (Suzuki et al., 2017)	✓	X	✓	X
HuddleLamp (Rädle et al., 2014), SurfaceConstellations (Marquardt et al., 2018), AttachMe/DetachMe (Grolaux et al., 2005)	X	✓	X	✓
Common Virtual Workspace (CVW) (Maciel et al., 2010), I-AM (Barralon et al., 2007)	X	X	✓	✓
ConnecTables (Tandler et al., 2001), AudioCubes (Schiettecatte & Vanderdonckt, 2008), DUI (Melchior et al., 2011), 4C (Demeure et al., 2008), E3Screen	X	✓	✓	✓
3D/VR Rain Screen (Rakkolainen & Jumisko-Pyykko, 2012)	✓	✓	✓	X

Table 1. Characterization of previous work on reconfigurable displays using our 4E quality properties.

Extractability. The "PickCells" system (Goguey et al., 2019) enables individual displays to be extracted from a MDE and used independently. Samsung filled a patent[18] for an expandable smartphone with one fixed display unit and two slidable ones which, once expanded, offer three times the initial surface. Our E3Screen prototype is a more complex implementation, since the lateral displays can also be rotated, extended, and extracted.

7.2. Multi-Quality Reconfigurable Displays

Our 4E quality properties do not exclude each other and, thus, several can be implemented by the same reconfigurable display system. For example, a deformable display made from an elastic material is extensible, but if another display can be added, it also becomes extendable. A multi-display system of several individual displays with reconfigurable parts is expandable, but also extractable if it resumes to its initial operation when the individual displays have been removed.

[18]`https://www.techeblog.com/samsung-galaxy-smartphone-with-expandable-display/`

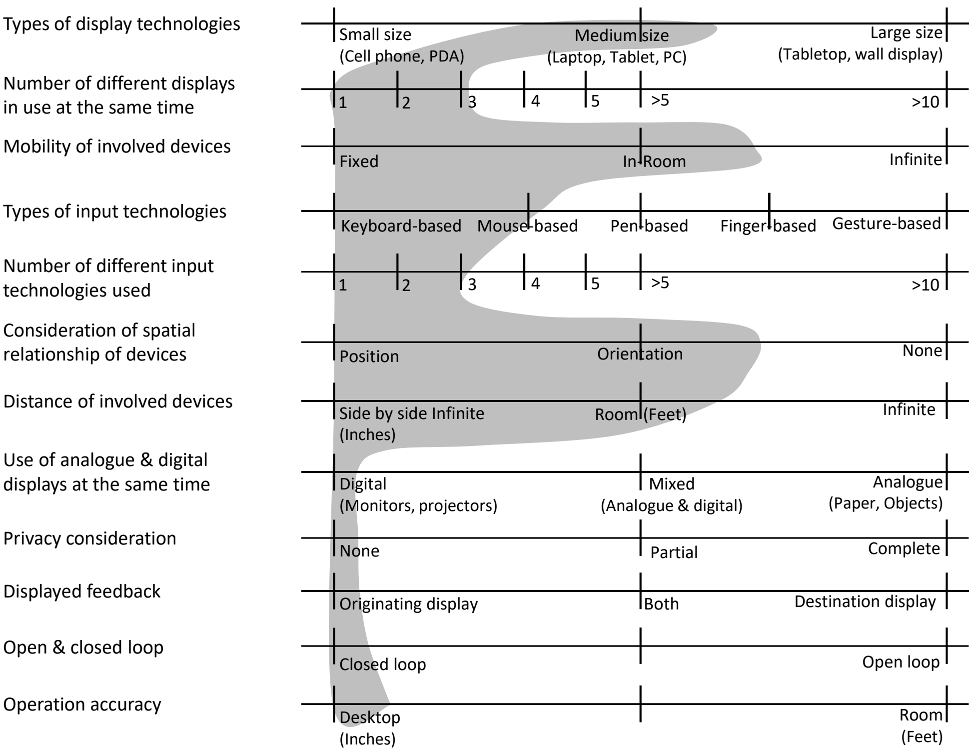


Figure 12. Positioning of E3Screen in Boring's framework (Boring, 2007).

In our TLR, we identified prior work that fulfills more than one of our quality properties; see the bottom part of Table 1. For example, the electrophoretic display of the "FlexView" prototype (Burstyn et al., 2013) can be bent and leafed through (expandability) and is slightly deformable (extensibility). "Emergeables" (Robinson et al., 2016) are mobile surfaces that can deform (extensibility) and morph (expandability) to provide fully-actuated, tangible controls. "HuddleLamp" (Rädle et al., 2014) detects whenever a new display is placed on the table (extendability) or removed (extractability); "HuddleLamp" could also be made extensible if it incorporated an elastic display. "SurfaceConstellations" (Marquardt et al., 2018) feature a comprehensive library of 3D-printed brackets to assemble tablet devices in a cross-device workspace: tablets can be added (extendability) or removed (extractability), but not rearranged; if a malleable bracket were invented, the platform would become expandable as far as the tablet devices could be rearranged. The size and resolution of the "Common Virtual Workspace" of Maciel et al. (2010) change by tiling tablet PCs close to each other (extendability) and also by removing them (extractability). More generically, the "Interaction Abstract Machine" of Barralon et al. (2007) supports the dynamic coupling of screens, keyboards, and mice to form a unified interactive space, from which devices can be removed at any time (extractability). The "Interactive Fog Screen" described by Rakkolainen et al. (2005) is suspended from a truss producing drops that deliver the substratum to render a video-projected image. The truss can be elevated or lowered as needed (extensibility) and its frame reconfigured (expandability). More recently, mid-air technology added 3-D and VR capabilities (extendability) to such installations. Sturdee & Alexander (2018) identified 22 foldable displays among the 79 shape-changing prototypes that they analyzed in their work, which they characterized as *"physically geometric dynamic systems with additional inputs/outputs."*. They correspond to the focused, single-quality reconfigurabale displays in the "4E" design space. Boem & Troiano (2019) surveyed an outlet of 131 papers dealing with deformable interfaces and input, thus covering also shape-changing user interfaces with different shapes, material, and components. Our "4E" design space focuses on reconfigurable displays, which correspond to flat deformable displays in their classification (top right of Figure 2, (Boem & Troiano, 2019), p. 888). We further refine this category according to the four properties. While they distinguish two forms of deformable material, *i.e.*, shape-retaining and non-shape-retaining, we suggest to investigate classical properties of applied material (Vyalov, 1986): elasticity, plasticity, and viscosity. These three fundamental properties could be combined.

If we come back to our introduction where we pointed out the numerous dimensions and attributes to be used to characterize reconfigurable displays, we have to position our E3Screen with respect to these dimensions. Figure 12 depicts the E3Screen positioning in Boring's framework (Boring, 2007): other steps on these dimensions require further studies.

8. Conclusion

We introduced in this paper the 4E design approach to structure, inform, and guide new research and development in reconfigurable multi-display systems. 4E design means accepting that not all application use cases for either single-screen or multi-display workspaces can be designed in advance, and change is inevitable and even unpredictable in how end users may choose to collaborate and share screen real estate. From this perspective, embracing 4E design is essential for those use cases in which reconfiguration of the screen real estate is continual, reprioritization of the display takes place on a regular basis in order to accommodate multiple perspectives and applications, and reusability of the screen is key functionality to accommodate a varying number of users. We showed how the 4E quality properties were used to design and engineer E3Screen, a new prototype of a foldable, rotatable, multi-display system. Our evaluation results identified user preferred configurations of displays for E3Screen, and highlighted aspects of territoriality, which we connected to the concepts of deterritorialization and reterritorialization. It will be interesting to examine these aspects more closely in future work. We also showed how to use the 4E quality properties to structure and characterize prior work on reconfigurable displays, demonstrating another practical utility of these properties. It is our hope that the 4E approach will foster more research and development in reconfigurable displays and, overall, lead to improved designs and better value to users.

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