A DESIGNERLY PERSPECTIVE ON IOT

A Growing Systems Approach (DCM110)

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Figure 1. Final design in context

Introduction

In the ever-evolving landscape of technology, the intersection of human-product interaction and digital systems has become increasingly complex. While technological advancements in the 'Internet of Things' (IoT) are rapidly growing and being employed on a large scale (Miorandi et al., 2012), the current landscape of IoT systems primarily relies on screen-based and voice-based interactions through smartphone applications (Frens et al., 2018). Electronic 'intelligence', an intrinsically complicated phenomenon, enters our living rooms via home IoT. It is suggested in the design realm to leverage rich and embodied interaction to better grasp the concept of IoT (Frens et al., 2018). The concept of rich interaction can be explained as "a paradigm for interactive consumer products that results in a unity of form, interaction, and function and taps all human skills for information-for-use thereby setting the state for aesthetic interaction" (Frens, 2023). Notably, by designing with respect for all human skills—emotional, cognitive, and perceptual-motor skills—embodied interaction is enhanced (Frens, 2006). Despite decades of research in rich and embodied interaction, these principles often fail to extend throughout commercial IoT design practices (Luria et al., 2017). This essay seeks to bridge this gap by advocating for a paradigm shift towards Rich and Embodied Interaction within IoT systems. This essay navigates the challenges and opportunities inherent in this domain, giving rise to answering the question "How can we design for rich and embodied interaction in home IoT?".

To explore this question, we indulged in a design case centred around the concept of two rich interactive 'Loci of Interaction' with distinct core functionalities for living room IoT. This exercise compels us to reimagine conventional paradigms, replacing traditional smartphone applications with a focus on physicality and expressiveness, shifting emphasis from remote control to meaningful, embodied engagement. In doing so, the notions of rich interaction, parameters of use, core vs emergent functionality, distributed vs centralized functionality, and approaches towards growth are taken as fundamental points of reference for exploration. Our first design concept is aimed at enhancing social connectedness—a messaging system (figure 2). In a modern world of continuous availability, being disturbed by incoming calls for communication, we notice a reduction of meaningfulness in digital messaging. Therefore, we aim to not only facilitate communication but also foster social cohesion within young family households through personalized message construction and enhancing the non-intrusiveness of incoming messages.

Embedded within this design exercise is a broader inquiry into systems design, where the scope extends beyond mere functionality to embrace emergent phenomena. As we introduce the second core functionality for entertainment—a media controller—into the system (figure 3), the interface evolves organically. Unlike modern search queries driven by automation, using a physicalized approach for recommendation systems enhances transparency in the generation of personalized suggestions, fostering a sense of control and an exploratory approach to media selection.

This essay serves as a reflective journey, navigating the complexities of designing for rich and embodied Interaction in IoT systems. By reflecting through the lens of five aforementioned theoretical concepts and practical design experiences, we establish an answer to the approaches and viability for designing for rich and embodied interaction in home IoT, exploring a future in which human-device interactions are not just functional but also enriching and meaningful.

Figure 2. Physical messenger. To facilitate incoming messages, side components can be connected to the short ends of a writing display, as shown in the configuration. This display utilizes a stylus and E-ink technology for message construction. Personal tokens placed on the side components indicate sender and receiver functionality: white tokens represent household members, while blue tokens represent individuals in the household's network. By sliding the tab attached to the display from a blue to a white token, incoming messages can be revealed. Conversely, sliding from white to blue sends a message to another person. Group messaging is enabled by increasing the number of tokens on the side components. Moreover, sliding the display tab in the absence of side components allows for discarding or reconstructing messages.

Figure 3. Media controller. Media preferences are set by selecting a movie or a show preference, using singular or combined circular tokens to be positioned in the centre of the media controller panel. This central location illuminates to suggest this action possibility. Once set, hexagonal-shaped lights illuminate in turn, indicating the placement opportunity of similarly shaped criterion tiles denoting genres, minimum/maximum watch length, release date, and show length. Each tile that is placed triggers a new light to illuminate in turn, adjacent to the previous one, indicating a sequence for placement. Presets (e.g., age and nationality) can be uploaded and used in a designated slot on the panel to indicate the viewer's profile. Throughout this engagement, live recommendation filtering is performed on the linked media display, such as a television.

Figure 4. Show and movie tokens with identical form

Rich Interaction

Designing electronic products for IoT systems offers designers increased freedom in shaping components and controls, since microelectronics do not necessitate direct mappings between components, unlike their mechanical counterparts (Djajadiningrat, 1998). This relates to the trend of dematerialization (figure 5), where physical objects are augmented or replaced by digital representations. Consequentially, interactions are abstracted, causing high reliance on human cognition (Van Campenhout et al., 2013).

However, the field of embodied cognition shows that humans make sense of the world and its complexity through physicality and the situatedness of our actions (Frens, 2017). Therefore, our approach prioritizes rich and embodied interactions, drawing from cognitive, emotional, and perceptual-motor skills to integrate interaction, form, and function, and the interplay between these concepts (Frens, 2006), allowing users to better comprehend the complexity of IoT products and their growing systems.

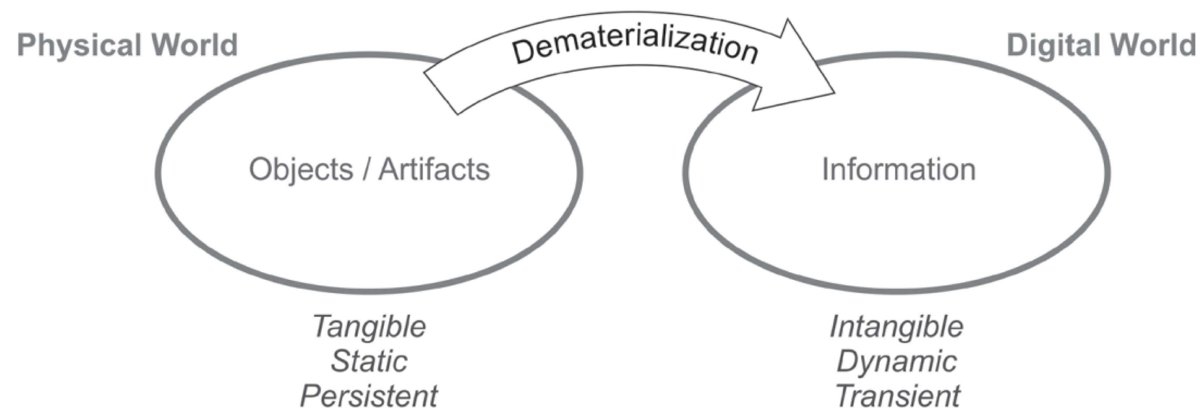

Figure 5. The concept of dematerialization (Van Campenhout et al., 2013).

Rich interaction in our design

In designing the physical messenger, we focussed on implementing the framework for interaction by van Campenhout et al. (2023), where couplings between time, location, direction, and expression play a central role in rich interaction (Van Campenhout et al., 2023). While the initial design showed couplings in all four aspects (figure 6), revealing how physical embodiment concretizes abstract message transmission and enables tangibly preserving messages, in line with the design objectives, reliance on metaphors—the traditional mailbox—raised limitations for the functional expandability of the design, as this necessitates breaking the metaphor.

Nevertheless, employing the framework revealed the significance of these couplings and improved the sensitivity for designing for rich interaction in subsequent iterations. A pivotal subsequent design choice was the introduction of a slider interaction (figure 7), aligned with the framework by van Campenhout et al. (2023), where the direction of sliding determines the control's functionality, such as indicating data transfer on the display—a feature fundamental for the design for emergent functionalities later.

Whilst designing for a second core functionality—entertainment—the materialization of filtering criteria and abstract phenomena such as genre and season length played a central role, fostering transparent and experiential filtering. The tokenized means of filtering offer richer, more inherent feedback, taking advantage of multiple senses and the multi-modality of human interactions (Ishii & Ullmer, 1997), providing more opportunities for meaningful couplings between interaction, form, and function (Djajadiningrat et. al., 2004). However, for an interaction to inform the function it triggers, we need to move away from all controls looking similar (Djajadiningrat et. al., 2004).

Therefore, the tokens representing movie or show (figure 4), only differentiated in terms of colour, leave room for improvement. Nonetheless, feedforward has been carefully incorporated by light, guiding the user through a sequence of action possibilities, made apparent by the respective spaces on the media controller being illuminated (figure 8).

However, when giving rise to cross-functionalities of the writing display with the media controller, complexities are recognized in the aforementioned sliding interactions, such as the misconception that opposite interactions always yield opposite functionalities—a notion disproven by scenarios like sliding from the display to the media controller, which does not transmit saved settings, highlighting the nuanced interplay between interaction, form, and function.

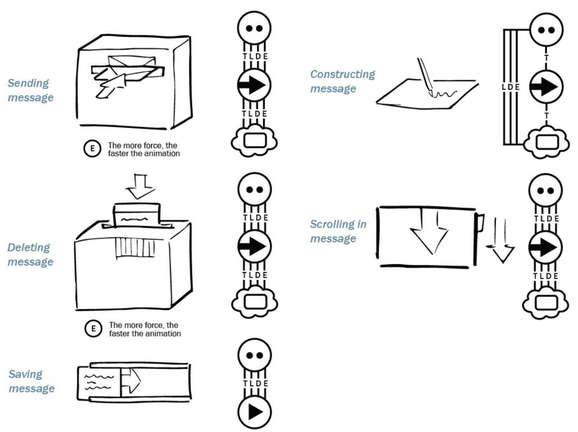

Figure 6. Initial physical messenger design based on the traditional mailbox, showing couplings on the aspects of time (T), location (L), direction (D) and expression (E).

Figure 7. An earlier iteration of physical messenger: sliding for transferring a displayed message to an external module

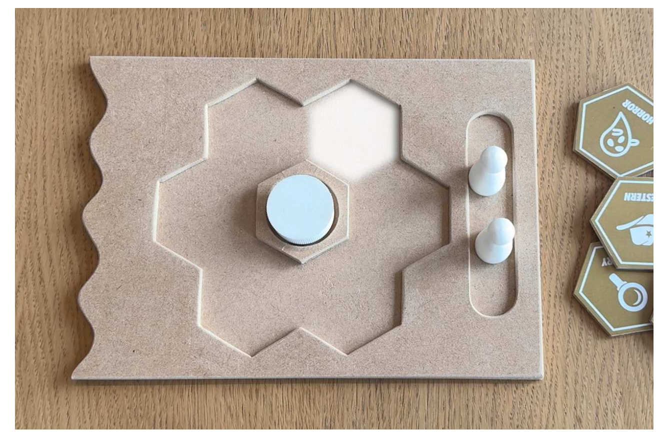

Figure 8. Feedforward in media controller, making the (sequence of) possibilities for interaction apparent.

Figure 9. Connecting the personal token figure to a laptop to set presets

Parameters of Use

When designing technical systems, many technology parameters can be manipulated. They determine the functionality of the system. However, this is not necessarily identical to the functionality made available to the user; the parameters of use (Frens, 2006). If these two sets of parameters are directly mapped, a system quickly becomes overcomplicated, thus harming usability. Therefore, in interaction design, a re-mapping between parameters is suggested to strike a balance between interaction and automation (Klapperich et al, 2020). How to do this re-mapping is also relevant to consider when designing for growth. On the one hand, increasing the parameters of use potentially creates more interactions and more “start-points” for emergent functionalities. However, it makes a system more specific and closed, limiting its growth potential (Frens, 2017).

Mapping the parameters of use was not consciously considered when designing the physical messenger. However, in the context of query filters for the media controller, this mapping played a more crucial role. As the system was designed for exploration and transparency, we initially opted for a rather direct mapping, where users could interact with a myriad of filters. In this sense, the parameters of use increased compared to traditional filtering queries in streaming services.

Direct mapping was also common in earlier mechanical and electrical products (Frens, 2006), but less in newer electronic (digital) products because of the aforementioned usability concerns. However, in our context and the design’s values, we believed increasing control made sense.

A crucial pivot in our understanding of the concept of parameters of use was learning to leverage layering. Until that point, we differentiated between direct mapping, re-mapping, and automation. However, we could also account for the frequency of use in our parameter selection. An example from the design is setting your language preferences; a user is likely to desire control over this but no desire is assumed to manipulate it every session. Hence, presets have been introduced within the user's personal token, allowing changes when the token is connected to their device (figure 9). This approach introduced an additional layer to the parameters of use; one for daily use and another for sporadic use. To further minimize the parameters of use, we rid the design of other media filtering options, such as the release region of a movie. Additionally, we constrained the possible configurations for search filters and guided users in placing the next criterion tile (figure 8). With this, a balance was struck between exploration, transparency, and usability. However, in doing so, the system’s potential for future growth was also constrained.

Figure 10. Compatibility opportunities (emergent functionality) between the physical messenger and media controller.

Core and Emergent Functionality

As new devices with distinct functionalities and control elements—core functionalities—are introduced to a home IoT system, a core challenge is designing for the openness needed to satisfy the changing demands of users. Core functionalities gradually become available over time as new IoT artefacts are introduced to the system. Between core functionalities, emergent functionalities may arise based on user needs (Frens et al., 2018). Four approaches to designing for embodied interaction in growing IoT systems include a Hybrid Approach, combining screen-based and physical interactions, a Modular Approach utilizing inter-connectable modules for remote control growth, a Shape-changing Approach employing remote controls that change shape, and a Service Approach updating interactive nodes for hyper-personalization through surface replacement (Frens, 2017). Modularity has been further explored by Frens et al. (2018) in the IoT Sandbox, utilizing a modular tray with controls for various functionalities. However, conceptual and technical issues arose in combining physical interfaces with contextual representations of space (Frens et al., 2018). Therefore, we opted to explore an alternative approach in this design case which does not rely on a remote alternative mapping of space but employs the modular approach directly within the form of devices (figure 11).

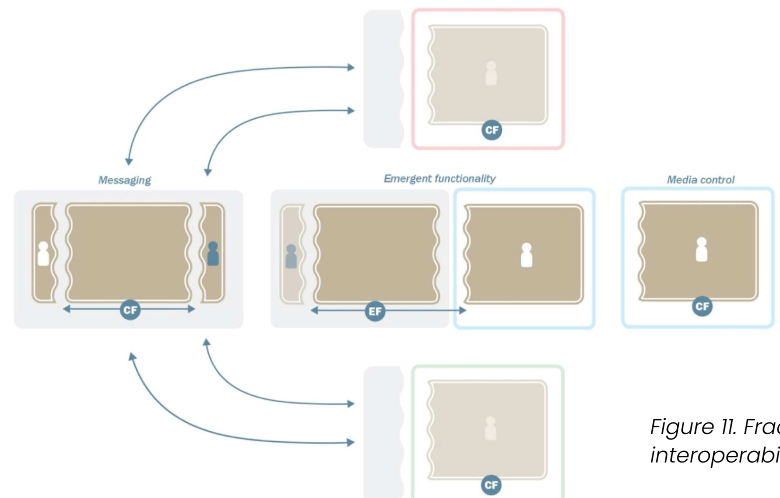

Figure 11. Fracturing approach for interoperability in the growing system.

We define two core functionalities in our design case: messaging and media control. These features are the system's core pillars. To enable modularity and give rise to emergent functionality, we have taken the fracturing of core functionalities as an alternative approach. The messaging module, initially consisting of a non-fractured design (figure 12), is fractured into a multitude of modules (figure 13): (1) a writing display and (2) two side handles for placing personal tokens, indicating the sender and receiver of messages. The slider attached to the writing display is central to interaction between the fractured modules for the core functionality of messaging, fostering enriched and non-obtrusive communication experiences. The core functionality of the media controller is a more experiential approach to media selection and transparent recommendation generation.

While the core functionalities provide essential features, our design enables the emergence of new functionality as a result of the interplay of these fractured core modules. In this approach, form—a zigzag edge—is used to inform opportunities for compatibility between fractured modules and thus opportunities for emergent functionality (figure 10). In addition, the personal tokens may be used multi-purposely—as sender/receiver, or viewer—depending on the core functionality interacted with and changing functionality consequentially. In addition, positioning the messaging module and media controller module—the two core functionalities—adjacent to one another, gives rise to opportunities for saving set media criteria to the messaging display, improving the user experience by increasing efficiency. As a result of the fractured modules' synergistic placement, the ultimate functionality of the sliding interaction is determined by the direction, placement of personal tokens, and whether modules are applied to one, both, or none of the sides.

Exploring the fractured approach to designing emergent functionality presents certain challenges. Designing for new core functionality in an open system proves difficult in a design case limited to just two core functionalities. This leads to biased design, rooted in designing for scenarios tailored to compatibility opportunities of core functionalities—social connectedness and entertainment. Fragmenting the messaging system's display has offered a physical alternative for data exchange, making the display central to emergent functionalities. However, this dependency may constrain system openness.

Figure 12. Physical messenger iteration in advance to designing for a growing system.

Figure 13. Physical messenger iteration after designing for a growing system.

Figure 14. Centralized functionality (user experience)

Distributed and Centralized Functionality

Evidence suggests a rapid pace of technological advancements in IoT networks, particularly within the household domain. Innovations such as the shift from cable TV to online streaming services like Netflix signify this advancement (Netflix, 2024). Predictions from experts in Ambient Intelligence (Aarts & Marzano, 2003), Pervasive Computing (Satyanarayanan, 2001), and Ubiquitous Computing (Weiser, 1991) suggest this trend will persist, guiding humanity toward a future where daily routines will be enriched with interactive devices (Peeters et al., 2012). As a result, we consider it vital within the scope of a designer's responsibility to comprehend how connections in a network environment can be established, from both a technical and user experience point of view, which diverge significantly.

Firstly, networks within the technical IoT domain are globally identified as either centralized, decentralized, or distributed (Truong, 2016). In centralized networks, a single server or master node manages the system's operations, whereas decentralized and distributed networks feature multiple independent nodes capable of functioning autonomously (figure 15) (Cryptopedia, 2021). On the contrary, the terms 'centralized' and 'distributed' can also be applied to describe the user experience in tangible design based on the geographic location of interaction (Peeters et al., 2012). For instance, a centralized user experience may involve interaction with a single device in a fixed location, while a distributed experience may span across multiple devices or locations.

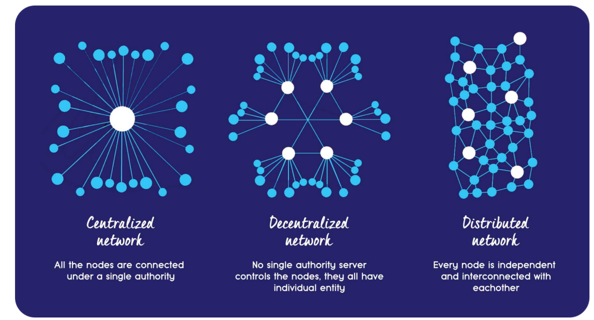

Figure 15. Centralized, decentralized, and distributed technical network (Marlín, 2021)

Research conducted by Peeters et al., revealed that implementing either a centralized or distributed approach in user experience resulted in varied mental models among users regarding the inner workings of a system (Peeters et al., 2012). Inspired by this conclusion, a close correlation between the visually arranged model in tangible form and the actual technical network has been implemented in each functionality of the design (figures 16, 17, 18).

From a technical standpoint, the media controller application operates similarly to a remote control: placing a criterion tile on the base plate triggers the transmission of a code that Netflix understands (figure 16) (Ahmed, 2024). Accordingly, this centralized technical network of the media controller is mapped to the physicalization of the media controller, allowing for the emergence of a correct mental model of the IoT system (figure 15). Subsequently, this close alignment allows for a shift in focus from the design to the digital streaming device, resonating with the user-friendly experience of the Philips Living Colors Hue lamp and its tactile colour remote control (Philips, 2023).

The physical messaging application provides a centralized user experience, where all interactions revolve around an interactive display (figure 16). Drawing insights from Peeters et al.'s research, the physicalization of the physical messenger corresponds with a scaled-down version of the technological network (figures 17, 18) (Peeters et al., 2012). Consequently, this setup offers a clear physical representation of data transfer, which would be unachievable in a distributed framework. Furthermore, while the system remains technically centralized (figure 17), the user experience incorporates distributed functionality due to the geographically distributed messaging screens across multiple households (figure 18). This miniature network remains effective when giving rise to emergent functionality, resulting in a similar centralized approach (figure 18).

In conclusion, the two networks, from a technological and user experience perspective, are mapped onto each other, resulting in a comprehensible and intuitive mental model of the workings of the system. However, technical networks within the scope of IoT can be constructed in multiple ways. Therefore, it is argued that a designer should prioritize evaluating and responsibly constructing the technical network distinctly, enabling the utilization of gathered insights to assess how rich interaction could enhance a seamless user experience in the IoT context.

Figure 16. Media controller: centralized technical network

Figure 17. Physical messenger: centralized technical network

Figure 18. Distributed vs centralized (user experience)

Figure 19. Final prototype

Approaches to Growth

The inherent complexity of IoT (Frens et al., 2018) is illustrated by the 'one person – one product' concept being left in favour of complex systems consisting of many 'nodes', raising design challenges for enabling systems to grow (Frens et al., 2009). Our approach to growing systems emphasizes modularity, interoperability, and adaptability. Each core functionality is fractured into different modules, allowing for the introduction of emergent functionalities.

Currently, the most popular interfaces for IoT systems are touchscreens and voice control (Frens, 2017). While still embracing the advantages of a display, and recognizing this to be fundamental to enabling emergent phenomena in our design, facilitating better use of resources as it is interoperable between core functionalities (Frens et al., 2009), a shift has been explored towards a more physicalized user experience. This has raised a more nuanced vision of the advantages and disadvantages of screens, which are predominantly considered disadvantageous in the realm of designing for rich interaction (Djajadiningrat et al., 2004) as screens do not address all senses, while physical objects offer more room for expressivity. Remarkably, a discussion was raised on whether the application of a display as incorporated in our design was even considered a digital or physical I nteraction, emphasizing the ambiguity of the notion of displays in rich interaction, dependent on the context of application.

interaction, emphasizing the ambiguity of the notion of displays in rich interaction, dependent on the context of application. This positions the design in a modular approach to growth with notions of a hybrid approach (Frens, 2017), as it uses a screen to handle aspects of growth while employing physical interactions for other interface components.

A challenge in designing for growing systems is the requirement for loci of interaction, both for control and also to perceive what a system is capable of (Frens et al., 2009). A locus of interaction refers to the central point or interface through which users interact with and control various connected devices within their home. Reflecting on this, and the alternative approach employed in the design which does not rely on an alternative representation of space, gives rise to meaningful yet non-collocated interaction in contrast to the collocated approach of modularity as employed by the IoT Sandbox (Frens et al., 2018), tackling challenges identified for the latter in addressing conceptual issues in combining physical interfaces with contextual representations of space (Frens et al., 2018). However, employing a non-collocated approach where core functionalities (e.g., messaging) are operated directly rather than remotely, they may no longer be considered loci of interaction in the traditional sense. This fosters a discussion point on whether loci of interaction are truly requirements in designing for growing systems as stated by Frens et al., (2009).

Discussion

IIn this discussion, we will reflect on thought-provoking topics that emerged from designing with the aforementioned themes. In doing so, we aim to answer the question of how to design for rich and embodied interaction in home IoT.

Designing for rich interaction in growing systems

As suggested by Ross & Wensveen (2010) and Klemmer et al. (2006), designing for embodied interaction should involve an embodied design process. We reaffirm this necessity through our experience in this design case. Specifically, the use of mid-to high-fidelity prototyping enabled a better comprehension of the complex and otherwise abstract concept of growing systems. The quote “If you think in abstraction, your design will keep having abstract features” by Frens resonated throughout the design case. Only after physicalizing ideas were we able to experience where the design narrative started to fall apart, emphasizing the value of embodied cognition (Frens, 2017). We advocate for this design approach to make rich and embodied interaction in home IoT viable. Otherwise, we believe that a growing system with rich interaction will inevitably break.

Furthermore, one of the constraints encountered in this exploration of designing for growing systems was the limited scope of design, centred around two core functionalities that promoted emergence. This led to biases, favouring design choices that promoted compatibility between the designs. In the real world, potential forms, functions, and interactions within a system are not always evident. Acknowledging this bias raised questions regarding what to design for: a future where rich and embodied interaction in IoT becomes standard, or one where such products coexist alongside existing IoT devices within a single system? This differentiation is crucial in determining how rich and embodied products should be designed for growth. For instance, the current zigzag-shaped edges of the proposed design allow for growth, but only when replicating this in future functionalities in a system. However, in a future where rich and embodied designs coexist with pre-existing IoT products, growth could be facilitated through more generic designs or shape-changing capabilities. Therefore, the future vision for growth within the IoT network should be established before making definitive design decisions.

Viability of rich interaction: context is key

Achieving rich interaction in design goes beyond mere consideration of shape; designs must effectively convey functionality through form and interaction (Frens, 2017). In this context, physical messaging, while more meaningful, may lack the convenience of digital alternatives. Although rich interaction fosters meaningful design, it also introduces complexity that can challenge viability. Nonetheless, it offers user experiences that generic interactions are less likely to match. In addition, despite the existence of methods for designing for rich interaction, there is no one-size-fits-all solution to facilitate rich interaction and rather requires a sensitivity fuelled by exploring existing approaches.

Furthermore, it has become evident that context is pivotal when designing for rich interaction. This can be exemplified by considering the practicality of rich interaction in different scenarios, such as a payment application used in a luxury hotel versus one used in supermarkets, where efficiency is prioritized. Consequently, we recognize that the ultimate design objective takes precedence, determining how qualities of rich interaction may be integrated appropriately. In addition, the viability of rich interaction in commercial IoT products is significantly impacted by demonstrating its meaningfulness to the design objective, thus revolving around convincing storytelling. This design case centred around realizing rich and embodied interaction to its full potential. However, we recognize that design decisions should be made responsibly. While rich and embodied interaction creates meaning, it also influences other factors, such as cost efficiency, and thus viability.

Conclusion

By reflecting through the lens of five theoretical concepts—rich interaction, parameters of use, core vs emergent functionality, distributed vs centralized functionality, and approaches towards growth—related to a practical design case on designing a physical messenger and a media controller, the ultimate question has been explored: “How can we design for rich and embodied interaction in home IoT?”. In short, this is highly dependent on the context of use, desired functionality, and driving values.

Firstly, achieving rich interaction requires navigating the delicate balance between immersive experiences and practicality. To establish meaningful connections and foster design growth without compromising core values, it is encouraged for designers to assess a design's adaptability towards anticipated growth directions, even if this necessitates a redesign of the entire existing IoT product landscape. In addition, context plays a pivotal role in design. Tailored approaches are necessary to ensure the effectiveness and relevance of rich interaction features in diverse contexts. Furthermore, demonstrating the meaningfulness of rich and embodied interaction is essential for its viability. Compelling storytelling that communicates the value of rich and embodied interaction is crucial in the multi-stakeholder development of IoT products. Lastly, responsible design decisions are paramount. Considering factors like cost efficiency and long-term sustainability ensures that home IoT products are rich but also viable in the long run. In doing so, we recognize that no matter what context, functionality, and values are being designed for, it is essential to employ an embodied design approach when designing for rich interaction, especially when designing for the complexity that is growing IoT. To conclude, there is no fixed recipe for designing for rich interaction in any context. Instead, an understanding of and a sensitivity to designing for rich and embodied interaction is suggested to realize this.

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