AIS SIGPRAG
Pre-ICIS Workshop 2018
"Practice-based Design
and Innovation of
Digital Artifacts"

Towards Digimaterial Design

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Abstract

We present and discuss four focus points for the design of digimaterial artifacts, i.e., artifacts that combine digital and material aspects. Cars, cameras, ERP systems, and robots are examples of digimaterial artifacts. The four focus points are structures, symbols, actions, and plasticity. The structures of digimaterial artifacts are constituted by connected digital and material components. Digimaterial artifacts can store and process symbolic representations of information. Digimaterial artifacts can perform four types of actions: Move, control, modify, and sense. Digimaterial artifacts are plastic in the sense that their capabilities can be modified by changing their digital aspects. We relate the characteristics of the four focus points to associated affordances.

Keywords: Digimaterial artifacts, capabilities, affordances, design.

1 Introduction

Digital and material aspects are integrated in various types of artifacts like cars, cameras, robots, information systems like ERP systems etc. Such artifacts are characterized by combinations of digital and material aspects.

One of the interesting consequences of this combination is a merge of information processing and material action. As an example, an information system like an ERP system has digital aspects like the information and software and it have material aspects like storage devices, microprocessors, monitors etc. Furthermore, an ERP system may be materially expanded via information from sensors and connections to various types of technological artifacts like robot-based warehouse management systems. As another example, a robot may be composed of various types of data and software. And it may be materially constituted by components like motors and arms.

Sometimes the purpose of the processing of digital information is to provide relevant information to human beings or other artifacts. This is the case, for example, in ERP systems that process customer orders and provide information about these. Sometimes the purpose of the processing of digital information is to control material actions. This is the case, for example, when the actions of a robot are controlled by means of software.

From a design perspective, it is not clear how we can account for the integration of digital and material aspects. There are many aspects of the integration that are still too vaguely understood. The purpose of this paper is to discuss four focus points of within a context of the design of digimaterial artifacts.

Our research method is based on an analysis of concepts and ideas that have been proposed in the literature. In particular, our work is based on notion of digimaterial artifacts. Such artifacts combine digital and material aspects and they can be characterized in terms of structures, symbols, actions, and plasticity. We use these four characteristics as our foundation for a discussion of four related focus points for the design of digimaterial artifacts. We relate the characteristics of digimaterial artifacts to their social and material contexts by means of the concept of affordance.

The paper is organized as follows. In Section 2, we present and discuss the notion of affordance. In Section 3, we present and discuss the notion of technical artifacts. In Section 4, we present and discuss the notion of digimaterial artifacts. In Section 5, we present and discuss four focus points for digimaterial design: Structure, symbols, action, and plasticity. In Section 6, we conclude the paper and suggest potential directions for future research.

2 Affordance

Originally, the concept of affordance has been used to describe and explain relationships between an animal and its environment in terms of what the environment offers the animal (Gibson 1979). In a context of human beings, the concept has been described as a "... relationship between the properties of an object and the capabilities of the agent that determine just how the object could possibly be used." (Norman 2013).

Affordance can be used to express what can be done with artifacts (Maier 2008). It can be used to characterize relationships "... between two subsystems in which a potential behaviour can occur that would not be possible with either subsystem in isolation." (Maier and Fadel 2009). A variety of variants of the concept of affordance can be found in the literature (Gibson 1979, Hutchby 2001, Markus and Silver 2008, Lanamäki, Thapa et al. 2011, Dotov, de Wit et al. 2012, Faraj and Azad 2012, Allen 2013, Norman 2013, Cormier, Olewnik et al. 2014, Grgeric, Holten et al. 2015, Vardouli 2015, Moralez 2016). The affordance of a product can be described in terms of "... what it provides, offers, or furnishes to a user or to another product. Most products have a multitude of affordances." (Maier 2008). Affordances can be positive or negative and that they can be intended or unintended.

In Section 4, we use the notion of affordance to relate digimaterial artifacts to their technical and social contexts. A wide range of potential contexts can be identified (Maier 2008). We focus primarily on contexts related to design processes and the related considerations of use processes (Kroes 2002).

3 Technical Artifacts

Technical artifacts can be characterized as dualities of structures and functions (Kroes 2002, Kroes 2006, Kroes and Meijers 2006, Kroes 2010). A structural characterization focuses on physical and spatial characteristics, materials, shapes, material forms etc. A functional characterization of a technical artifact focuses on what the artifact is for. As an example, a car is composed of elements like wheels, tires, and seats etc. The function of a car can be characterized as driving.

Artifacts may have functional potentials that have not been foreseen by their designers (Mumford 2006). For example, a parked car may prevent the passage of other cars on a road. Or a knife may be positioned on the top of a stack of papers to prevent these from being moved around by the wind. Likewise, a given function may be realized by a multitude of structures (Baker 2006, Houkes and Meijers 2006). For example, knifes of many different forms may be used for cutting.

Examples of statements about functions my include references to affordances: The function of a hairdryer is to dry hair (Kroes 2006); The function of a boat is to provide transportation on water (Baker 2004). We could just as well state that a hairdryer affords drying of hair. And we could state that a boat affords transportation on water. Clearly, the notion of function goes beyond the mere characteristics of artifacts. It includes assumptions about and references to the contexts of artifacts.

For these reasons, we do not used the term function. We use the term capability to refer to a characteristic of an artifact that do not include references to the context of the artifact. And we use term affordance when we relate one or more capabilities of an artifact to its perceived context. We use the term capability when we to refer to what an isolated artifact can *be* or *do*. We use the term affordance when we to refer to what can be done with an artifact.

4 Digimaterial Artifacts

Artifacts like cars, cameras, robots, and ERP systems are based on a combination of digital and material characteristics. They use material components like hard disks and microprocessors to process digital information. Terms like IT artifacts, digital technology, and digimaterial artifacts have been proposed in order to characterize aspects of artifacts that combine digital and material elements.

IT artifacts can be characterized as combinations of information, software, and technology that can be used to process information and to mediate communication: "An IT artefact is a physical artefact based on technology. Every running IT artefact relies on some hardware. The software and hardware can be seen as an integrated whole. Without the software, the hardware is just an empty shell. Without hardware, the software is just symbolic expressions. But together they are machines with the power to execute intentionally designed information-processing tasks." (Goldkuhl 2013).

Digital technology can be characterized in terms of reprogrammability (malleability), homogenized data (binary representation of all information), and self-reference (software that modifies information). Furthermore, they can be characterized by a combination of modular architectures and layers like content, service, network, and device (Yoo, Henfridsson et al. 2010).

Neither of these approaches offer a sufficient starting point for designing artifacts that combine digital and material aspects. The IT artifact approach can be used to characterize artifacts where the primary purpose of the material elements is to serve as a foundation for information processing (including communication). The material aspects are not a core focus in this approach apart from the fact that hardware is necessary for information processing. The digital technology approach can be used to characterize artifacts where information processing is supplemented by material devices with characteristics that go beyond information processing. However, this approach does not focus explicitly on the capabilities of the material devices.

Digimaterial artifacts can be characterized as material artifacts that combine digital and material aspects. More specifically, a digimaterial artifact is a material artifact that bears one or more digital artifacts (Bækgaard 2016, Bækgaard 2018). We use the term digital artifact to denote information artifacts like binary expressions and bar codes. Digital artifacts can be viewed as non-material artifacts that can be materialized by means of material artifacts that bear them (Faulkner and Runde 2011, Faulkner and Runde 2013). A piece of software may be viewed as a digital artifact that is constituted by a binary expression, i.e., a sequence of zeroes and ones. This sequence is, in itself, a conceptual, linguistic entity. It is non-material. A hard disk or a usb drive may bear a representation of the software. These artifacts are examples of digimaterial artifacts.

Our work is based on the notion of digimaterial artifacts because it provides four aspects that can be used to analyze potentials for digimaterial design: Structures, symbols, actions, and plasticity. In Section 4, we use these four aspects to present and discuss four related focus points for digimaterial design.

5 Focus Points for Digimaterial Design

We discuss four related focus points for digimaterial design: Structures, symbols, actions, and plasticity.

5.1 Focus Point #1 - Structures

Digimaterial artifacts have structures that may be based on a combination of connected components and layering (Bækgaard 2016, Bækgaard 2018).

Components

A digimaterial artifact can be constituted by a set of connected material components. At least one of the connected components must be a digimaterial artifact. Some components may have no digital elements. For example, the front glass plates on many smartphones are purely non-digital. Digimaterial components combine material and digital aspects.

Digital artifacts can be divided into connected components (Parnas 1972, Bækgaard 1990, Henfridsson, Mathiassen et al. 2009, Kallinikos and Mariátegui 2011). The following examples illustrate potential types of digital components.

Data components can be based on media files (Kallinikos and Mariátegui 2011) or databases (Codd 1970, Chen 1976). Media files like images, videos, text etc. can be divided into data components and distributed on a number of digimaterial artifacts. Likewise, databases can be divided into data components and distributed on a number of digimaterial artifacts.

Software components can be procedures based on procedural programming languages (Yourdon and Constantine 1979, Yourdon 1989, Yourdon 2003), parts of software applications based on the principle of information hiding (Parnas and Clements 1986), objects based on object-programming languages (Mathiassen, Munk-Madsen et al. 2000) etc. Also, software components can be parameters that represent software properties in a way that can be used to change selected software properties without changing the source code itself (Bækgaard 1990).

Connectivity

Digimaterial components can be connected in a number of ways as illustrated by the following examples.

Material components may be connected by means of mechanical connections. For example, car components like doors and car bodies may be connected be means of mechanical connections between the components.

Digimaterial components may be connected by means of a combination of mechanical and electrical connections. For example, car components like steering wheels and driving wheels may be connected by means of a combination of material and electrical connections between components.

Electrical connections can be used to establish digital connections by interpreting binary electrical signals as binary information. This makes digimaterial artifacts communicable (Yoo 2010) by facilitating sharing of binary information across digimaterial artifacts. Individual digimaterial artifacts of groups of digimaterial artifacts can be selected as targets because they are addressable (Yoo 2010).

Digital components may be associated by means of relationships between data elements (Codd 1970, Chen 1976) or by means of hyperlinks in, say, Web 2.0 structures. Digital components may be related to and identified with other entities (such as other artifacts, places, and people) based on certain commonly shared attributes. Digital associativity is enabled by tags, keywords, or affiliation patterns (Yoo 2010).

Layers

Digimaterial artifacts can be layered. We view a layer as an aspect of a component that can be found on more than one component in a digimaterial structure. Digital artifacts like information systems can be divided into layers like interface, model, and function (Jackson 1983, Mathiassen, Munk-Madsen et al. 2000). Digimaterial artifacts can be divided into layers like content, service, network, and device (Yoo, Henfridsson et al. 2010). Each component in a layered architecture can contain aspects of one or more layers.

Affordance

The following examples illustrate potential affordance related to structures. A car can keep driver and passengers in fixed positions on seats while the car is driving. A robot can grab an object and keep it in a fixed position. An elevator system can keep a car at a fixed position in a hoistway. The spatial distribution of a digimaterial artifact distributes access to the artifact.

Affordance related to componentization are targeted to both design processes and use processes. For example, componentization can make it easier to design subsystems and to manage division of labor in development projects. For users, componentization may facilitate stepwise acquisition of product modules.

Connectivity enables the distribution of digimaterial components on a variety of locations and distribution of digital artifacts across a variety of digimaterial artifacts (Kallinikos, Aaltonen et al. 2013). Also, affordance related to connectivity include the ability to facilitate control and monitoring of such artifacts across long distances.

Affordances related to layering are primarily targeted towards designers and their ability to manage, say content and software, across a set of digimaterial artifacts.

5.2 Focus Point #2 - Symbols

Digimaterial artifacts can store and process symbols (Bækgaard 2016, Bækgaard 2018). Often, the symbolic capabilities of digimaterial artifacts are based on the digital artifacts they bear. Binary information stored on hard disks can represent sound, text, imagers, movies etc. The information can be presented on, say, displays in ways that are relevant for human beings.

Storage and processing of symbols are the basis of information systems that capture, store, manipulate and present information (Checkland and Holwell 1998, Avison and Fitzgerald 2006, Alter 2008). A digimaterial artifact can use action capabilities like move, control, modify, and sense to process digital artifacts with the intention of manipulating their symbolic capabilities.

Affordance

Basically, information has two related types of affordance: Decision and action. In traditional business information systems, the information content support human being's decisions and actions. For example, information contained in a customer order can support decisions and actions related to packing and shipping. Increasingly, business decisions and actions are executed by digimaterial artifacts like robots.

5.3 Focus Point #3 - Actions

Digimaterial artifacts can perform actions (Bækgaard 2016, Bækgaard 2018). Below, we focus on four action types: Move, Control, Modify, and Sense.

Move is a type of action that makes it possible for a digimaterial artifact to change the location of a material target object (Bækgaard 2016, Bækgaard 2018). For example, robots can move material objects. Digimaterial objects like drones and cars can move themselves. Digital artifacts cannot be moved. They can be copied and deleted. Apparent movement of digital artifacts can be immitated by means of a combination of copy and delete.

Control is a type of action that makes it possible for a digimaterial artifact to request that a target object executes a specified action. Digimaterial artifacts can control (digi)material artifacts. For example, a smartphone with suitable apps can be used to control heating devices and drones.

Modify is a type of action that makes it possible for a digimaterial artifact to modify the state of a target object. For example, 3D printers can transform ink into 3-dimensional objects. And programmers can modify software. Many digimaterial artifacts can process binary expressions. Binary expressions can be used to control the manipulation and transformation of binary expressions.

Sense is a type of action that makes it possible for a digimaterial artifact to sense aspects of the states of target objects. Digital cameras can sense light waves. Digital watches can sense movement.

Combined actions. Digital artifacts cannot be copied but they cannot be moved in the same manner as physical objects. For example, an action that resembles moving a digital artifact can be represented by a combination of modify and sense.

Affordance

The action potentials of digimaterial artifacts can be utilized to replace or supplement the actions of human beings. Digimaterial artifacts can be designed to perform move actions, control actions, modify actions, and sense in socio-technical systems.

5.4 Focus Point #4 - Plasticity

Digimaterial artifacts are plastic in these sense that they can be modified (Bækgaard 1990, Yoo, Henfridsson et al. 2010, Kallinikos, Aaltonen et al. 2013). The plasticity of a digimaterial artifact is to a large extent enabled by the flexibility and modifiability of the digital artifacts it bears.

Digital artifacts like Internet pages (Kallinikos, Aaltonen et al. 2013), image files (Kessler 2009), and search engines (Orlikowski 2007) are modifiable. Digital artifacts are expandable (Kallinikos, Aaltonen et al. 2013) within the limits of the storage capabilities of the bearing digimaterial artifacts.

Programmed rules can be expressed as a combination of software and parameters (Bækgaard 1990). If the software or the parameters are changed, the programmed rules and thereby the logic of the computer is changed and its behaviour is changed correspondingly.

Traditional digimaterial artifacts like computers can be viewed as implementations of Turing machines. A Turing machine is a conceptual model of a programmable machine (Turing 1936). A specific instance of a Turing machine uses a set of programmed rules to transform numbers to numbers. Likewise, a computer uses programmed rules to transform bit sequences to bit sequences.

Usually, the programmed rules are expressed by means of a combination of software (expressed by means of programming languages) and parameters (Bækgaard 1990). If the software or the parameters are changed, the programmed rules and thereby the logic of the computer is changed and its behavior is changed correspondingly.

The plasticity of digimaterial artifacts that is rooted in the flexibility and modifiability of the beared digital artifacts has a number of important implications as illustrated by the following examples.

Programmability. Digimaterial artifacts are partially programmable (Yoo 2010). They can accept new logic to modify their structures and the enabled capabilities.

Weak coupling. The structures of digimaterial artifacts are plastic and the coupling between form and function is weakened (Autio, Nambisan et al. 2018).

Flexible use. Digimaterial artifacts possess use plasticity in the sense that there are multiple ways of activating functions and exploring information (Kallinikos, Aaltonen et al. 2013). For example, there are multiple ways to explore the content of databases.

Affordance

Digimaterial plasticity support late binding of properties (Hylving, Henfridsson et al. 2012) and de-coupling between form and function (Autio, Nambisan et al. 2018).

Digimaterial plasticity support flexible re-configuration. Digimaterial artifacts can be designed as flexible assemblages, i.e. "... arrangements of different entities linked together to form a new whole ..." (Müller 2015). Typically, the digimaterial artifacts that constitute an assemblage are autonomous and their connections are flexible.

Digimaterial plasticity may be utilized to support flexible design of generative systems. The term generativity points towards the space of opportunities that is enabled by some system (Zittrain 2006, Allen 2013, Henfridsson and Bygstad 2013). Generativity "... denotes a technology's overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences." (Zittrain 2006).

6 Conclusion

We have presented and discussed four focus points for digimaterial design. We have based our work on the notion of digimaterial artifacts. Such artifacts can be viewed as material artifacts that combine digital and material aspects (Bækgaard 2016, Bækgaard 2018). And they can be characterized by means of four related aspects: Structures, symbols, actions, and plasticity.

We have discussed the potential roles of digimaterial structures, digimaterial symbols, digimaterial actions, and digimaterial plasticity. And we have related these digimaterial to potential affordances.

Viewed as a whole, digimaterial structures, symbols, actions, and plasticity may form the basis of design and analysis of artifacts and systems that combine processing of digital information and material actions. Such artifacts and systems occur frequently in areas like consumer products, the Internet of Things, and Industry 4.0. We are not aware of design theories or design approaches that span the design space that is covered by a combination of structures, symbols, actins, and plasticity.

Future work includes further identification and elaboration of design potentials related to the integration of digital and material aspects. Also, the relations between digimaterial artifacts and sociomateriality is an interested topic that needs exporation.

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