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Design Methods Review for Smart Product: Objectomy, a New Approach

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Abstract

Digital artefacts call for new design challenges: they enable services, technology-driven and multidisciplinary never ended processes, uncouple form-function, in a social relationship that must be ecosystem-framed. Then, the usual design mindset is not proper and expected vs unexpected outcomes must be equally studied. A framework of methods, in view of the usual design variables and the new ones called by design of smart objects, is here offered. From that the seeds for the future aid to the design process of smart objects result. Then, Objectomy and one real application case are described.

Keywords: smart objects, objectomy, design methods, product design, digital design

1. Introduction

Nowadays, the job of designer is challenging and being a 'good' designer means playing a new game: that is, dealing with digital and smart artefacts. Digital technologies and digitalization not only have consequences on designers, both individually and as part of the team, but also provide challenges to the design process (Porter and Heppelmann, 2014; Bstieler, L., et al., 2018; Cantamessa et al., 2020).
This paper aims at analysing the traditional and new design variables called by the design of digital and smart products. A conceptual framework for highlighting limitations of current design methods and seeds for future research on methodologies aiding the design of digital and smart artefacts is here presented, even if not deepened. Instead through such framework, an alternative design method, called Objectomy, is analysed and an application is described in view of a real case study. In particular, by analysing Objectomy through the framework, the paper analyses 1) what kind of aid such method really provides; 2) if there/what are additional variables that smart products activate, which cannot be covered by traditional methods and that instead Objectomy is able to tackle.
From a methodological point of view, the research has been carried out through a qualitative approach. In particular, three main contributions (Pahl and Beitz, 2007; Ulrich and Eppinger, 2015, Cross, 2005), have constituted the starting point of an extensive literature review of over 50 papers for the state of art in the fields of Engineering Design and Innovation Management (from Design Science, International Journal of Engineering Science, Design Studies, Research in Engineering Design, Journal of Engineering Design, Journal of Mechanic Design, Journal of Artificial Intelligence for Engineering Design, Analysis and Manufacturing, Institute of Electrical and Electronics Engineers Journal of Product Innovation Management Innovation).
The first part of this paper has been dedicated to the state of art. Part of the literature review has been dedicated at identifying relevant design methods and their classification. The rest of the effort has been focused on formalizing the method Objectomy and analysing its application.

2. State of Art

2.1. The peculiar features of Digital and Smart Products

Digital technologies have allowed smart products to become reality and have contributed as building blocks to the disruption of traditional markets in the new era of Internet of Things (Kortuem et al, 2010). Due to their dual nature, digital and smart products interact with users in both a physical and a digital way; this blurs the lines between products, services and the user environment, so that companies need an integrated "end-to-end" design view (Breschi et al., 2018). The artefact becomes a mean of interaction between the user and the company, so that the company can interact directly with users and sometimes the other way around.

Actually, there is still not a consensus on a common definition of 'smart product'. According to (Vitali et al., 2019), it is a cyber-physical device that has software-based digital capabilities, but also a physical nature. To others, it is rather a physical product empowered with digital technologies, which enable programmability, communicability, memorability, sensitivity, traceability, and associability (López et al., 2011). It has therefore 'intelligent capabilities' that allow it to achieve some behaviours, typical of an intelligent being (Wong et al., 2002), such as communication, sensing, processing, and networking capabilities (Kortuem et al., 2010). Sometimes, they can become deliberative, reflectional, experiential, and communicative agents of reflection for behaviour change (Ghajargar et al. 2017). For Raff (2020) 16 capabilities synthesizable in four macro-capabilities characterize such systems: digital, connected, responsive and intelligent. For our purposes, they are *physical objects, which with enhanced digital capabilities can collect and elaborate data, can interact with other objects, humans, environment, as well as possesses an identity and is able to participate in decision making processes.*

2.2. The traditional Design Process and Design Variables

Many models of design processes exist in the literature: Stage-based vs Activity-based Models, Solution-oriented vs Problem-oriented, Abstract vs Procedural vs Analytical approaches (Clarkson and Eckert, 2005; Wynn and Clarkson 2005). In spite of that, generally, the literature agrees that a design process is a sequence of defined activities (Stempflee Badke-Schaub 2002), design objects (Smith e Browne, 1993) and design variables (e.g. Gero and Kannengiesser, 2004). Among these variables, the most common are:

- **Function, which** is probably the most inflated term in design research. From Pahl and Beitz (2007), who propose a functional view of the technical system, function can be defined in general as activities, effects, goals, and constraints. Gero (1990) instead proposes a slightly different perspective, for which functions describe the teleology of the artefact; that is, its purpose.
- **Behaviour** that is how the artefact behave during the use, how he acts. According to Pahl and Beitz, it is consequence of the function while, according to Gero, it leads to determine the structure of the artefact, i.e., it describes the attributes that are derived or expected to be derived from the structure designer chooses and vice versa. From the practical experience observation, part of the behaviour is derivable, part is unexpected.
- **Structure** that describes the components of the artefact and their relationship; the components can be physical or virtual and their relationship can be tangible or intangible. It is related to the **form (**Greenough, 1947**)**, as well as it determines the **architecture** by which the functional elements of a product are arranged into physical chucks and by which chunks interact (Ulrich and Eppinger, 2015).
- **Affordance** (Gibson, 1977) that is the set of properties between the world and an actor (person and animal) to be designed or the relationship between the properties and the capabilities of the agent to determine just how the object could be possibly used Norman (1988).

Digitalization and its enabling technologies heavily affect the design process and these design variables (Jung and Stolterman, 2001). The design process in fact changes in its nature, becoming more complex and losing the conventional separation between ex-ante development and ex-post product use (Montagna and Cantamessa, 2019; Cantamessa et al., 2020). A fundamental separation

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between form and functions occurs (Zittrain et al., 2006), because HW and SW components still do not have the same life cycle as they had for electronic products (Cantamessa, 2021) and because of such uncoupled paradigms that lead to differences in the technological evolutions (Autio et al., 2018) with great implications on product architecture, as displayed by Modular Layered Architecture (Yoo et al., 2012). Traditionally, in fact, function and component trees were entirely coupled, also with respect to system behaviours, so that once system functions are defined, they were related to the set of the behaviours and component (HW by nature). The re-programmability, re-purposing at very low cost of digital components (Faulkner and Runde, 2010), instead, becomes the basis for further improvements and extension, activating combinatorial innovations (Yoo et al., 2012; Marion et al., 2015), such as enabling the addition of behaviours after the product has been designed, produced and sold. This implies that, as a SW platform, the structure and the physical parts must be ex-ante enabled, in order to accept ex-post behaviours, inducing unimagined physical features (i.e., forms). If one finally thinks that a heterogeneous group of smart products are often consumer durables, one can immediately understand that to satisfy all customers, this programmability of digital components calls designer to embrace incompleteness and continuous improvement of tangible open-ended products (Vitali et al., 2019).

To the end of continuously improving products, design modularity and platforms become the key pilots (Porter and Hepplelmann, 2014) and more than ever, become fundamental, given the multiplicity of needs led by product customization and personalization (Mourtzis and Doukas, 2014).

Additionally, digital technologies impose interoperability, virtualization, decentralization, real-time capability, as new guidelines for design (Hermann et al., 2016). In designing electronics products, designers often still consider such artefacts as isolated, instead, when the product is connected, it has social (physical or virtual) relationships with the world and its functions require to be framed and compatible in an ecosystem (Bangle, 2010). It is difficult to define all the affordances only from the artefact, while a broader info-context enabled by agent-agent interactions and must be considered. There is in fact a problem in facing ‘design affordance’ (Oxman, 2006; Yoo et al. 2012) based on features and functionalities of the artefact, especially because, in the case of digital artefacts, the sensory stimuli are generated by the output of the artefact itself.

The design of smart products therefore requires a broader view on the social ecosystem the product will be part of, and a detailed understanding of the interactions of these products with other systems, with humans and with the context, to correctly determine its affordance. It is important that the designer has understanding of the enabling platform and all possible technology enablers, in order to do a first assessment of feasibility in an open-ended system, without being limited by the considered technologies, especially during the concept phase.

2.3. Traditional Design Methods

At the base of all designers' activities there is a decision-making process and a vast number of alternative design methods that can aid such design decisions (Montagna, 2011), even if, we know, design methods are related to cultural tradition. On the one hand, Engineering Design considers design as function driven: it consists of an iterative, systematic, and usually method-aided process aimed to the definition of product’s functionality and, because of that, its form (Pahl and Beitz, 2007). On the other hand, Industrial Design is mainly meaning driven, it focuses on the creative reasoning of determining and defining a product’s mean, form, and features, relatively unpredictably and spontaneously. In other terms, while engineering designer, also in view of systems/artefacts they design, are concerned about actualizing functions, working out performance and architecture; industrial designers are more focused on user experience, aesthetics, ergonomics, user interface, meaning and communication.

Either way, design methodology encompasses all theories, models, approaches and methods that are used to improve the design practices (Cross, 1993), also because “there is no silver bullet” that can be universally applied (Clarkson and Eckert, 2005) and all methods are in any case valuable (Ulrich and Eppinger, 2015), since they allow designers to track the information, to create a record of the decision-making process and to set milestones and monitor the design processes.

Design Task Clarification is aided by methods mainly focused on the identification of the customer's needs and on the problem definition, to obtain a requirements list. The requirements list represents a

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collection of objectives to be achieved by the design process. Since needs are usually expressed in the "language of the customer", they are usually collected by **Questionnaires, Interviews**, **Focus Groups** or indirectly with **Observing the Product in Use**, both online and in-person (Ulrich and Eppinger, 2015) to be finally translated into requirements by **Quality Functional Deployment** (Akao, 1990). The customer's needs can be also identified as product or service purposes, derived from the design brief or mission statement through the **Objectives' tree** method (Cross, 2005) or **Functional Analysis** (Pahl and Beitz, 2007). More recently the tendency to consider the design problem as part of a wider ecosystem, with different stakeholders involved, as in **Meta-Design** (Giaccardi and Fisher, 2008), **Design for Innovation** (Cantamessa et al, 2016), or **Computational Thinking** (Wing, 2006), has allowed to identify a broader need spectrum in the problem definition.

Progressing into the design process, in Concept Generation the main goal is enlarging the exploration space and methods, such as **Morphological Chart** (Cross, 2005), **Brainstorming** (Osborn, 1953), **Synectics** (Gordon, 1961) or **Scamper** (Eberle, 1996), **Lateral Thinking** (De Bono and Zimbalist, 1992), **Role Playing and Scenario** (Díaz et al., 2009) and **Wicked Problem** (Rittel and Webber, 1973), all aim at "thinking outside the box". Mostly, all these are encompassed by **Design Thinking** (Brown, 2008). Similarly, other ways to bring non-conventional design elements into the design space has been explored: **Biomimicry** (Hargroves and Smith, 2006) allows the designer to take inspiration from nature, **Gamification** (Deterding et al., 2011) allows to use game design elements in non-game context and **A-Design** (Campbell et al, 1998) to consider products as adaptive agents, like designers themselves. Finally, other approaches rely on a more systematic exploration of new ideas: the **Theory of Inventive Problem Solving** (Altshuller, 1996), the paradigm of **System Thinking** (Forrester, 1999) than declined into a specific methodological guideline, **Value Analysis & Engineering** (Miles, 1962), **Design for X** and **Classification Tree and Tables** (Ulrich and Eppinger, 2015).

Finally, Concept Selection is usually that delicate activity, structured on a comparison of the generated concepts or solution proposals to the previously defined problem, by the requirements lists and other criteria, with the final aim of synthetize the design proposal. There are a lot of methods to support this phase, such us **Weighted Objectives** (Ulrich and Eppinger, 2015) that make comparison of utility value of different design proposal, **Multi-Voting** that compare the vote of different members of the development team or generally **Multi-criteria** (Belton and Steward, 2002), such as **Decision Matrices** (Pugh, 1981), the **Analytical Hierarchy Process**, **Weighted Rating**, **General Morphological Analysis** (Cross, 1993). Most of the time, the selection is influenced by the experience of designers/decision makers, and therefore various methods such as **Concept Championing, Intuition, Pros and Cons** (Ulrich and Eppinger, 2015) are adopted. When the decision is completely or partially delegated to the user, **External Decision** and **Prototype and Testing occur** and the user together with the development team test the concept.

Now many of these methods, and others not mentioned above, have been used over time in system-centered design processes, as well as (especially since the 1990s) harmonized into more human-centered perspectives. In this latter scenario, since then, the intent was of guaranteeing the user the best possible experience from interacting with the product and the study of the artifact's affordance was central. However, because of the increasing penetration of digitalization and the advent of digital artefacts in consumers houses, those traditional approaches have been becoming dated. Both schools of Engineering and Industrial Design, in fact, are starting focusing on-demand use (Moggridge, 2007), as well as on the need of interpreting system behaviors in digital contexts. With digital artefacts, the affordance should consider a wider information environment (Hartson, 2003) and several different interaction aspects (Sun, 2014; Rapp, 2015). Nested affordances (Faulkner et al. 2010; Yoo, 2010), or a cluster of affordances, to be hierarchically defined (Maier, 2003, Chen, 2014), are required.

Some methods, specifically developed in the SW industry, consider such multiple interactions between artefacts and systems: in many cases, simplified models of the system are created, in order to run simulations and observe as the different system elements interact with each other. Accordingly, designers observe the behaviour of the model, the possible structure, as well as the expected and unexpected functions. The purpose is to see how this might be carried over into contexts where the physicality of what is designed can be a constraint. Objectomy might be a first attempt in this direction.

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3. Objectomy

Objectomy is a design approach who's roots can be found outside the processes central to the industrial design tradition, specifically in the emotionally charged aesthetics of an Car Design; but it has been applied in various advanced design projects of diverse industries. In the automotive sector, it was proved to be useful in designing the experience for new concept of vehicles, i.e. through the concept of "moving space". In the consumer good sector, robotics and automation, it aided the conception of new ways of interaction between human and artefacts leading to innovative products.

Objectomy enables the designer to create a mindset to put him/herself in the soul of the object (Bangle, 2020), i.e., giving a 'character' to the object itself. The object is represented as an agent that acts in the environment, interacting with other agents or with the environment itself. Inside Objectomy, 'object' represents an abstraction of a product, service, or system and 'function' is "what the object aims to do". An object, according to the functional design tradition, can perform many functions, part of them is expected, part unexpected. The 'behaviour' is all the working principles which allow the object to perform in the desired way, i.e., the way by which the object accomplishes its functions. The structure, tangible or intangible (HW/SW) is the set of components the object can rely on to behave and enable the function. Re-elaborating some hypothesis of A-Design, objects are a) animate or alive; b) able to interact; c) able to adapt and evolve. This applies in all the selected objects that are considered in the design process. Objectomy leads to systems that work through a model of interaction with a multitude of agents. In other terms objects are "living creatures", which act following their purpose, aspirations, feelings, etc. generating a socio-technical system, in which the interactions and the purpose of the objects 'shape' (physically and digitally) the artefact in the same way as humans define themselves by interacting in society.

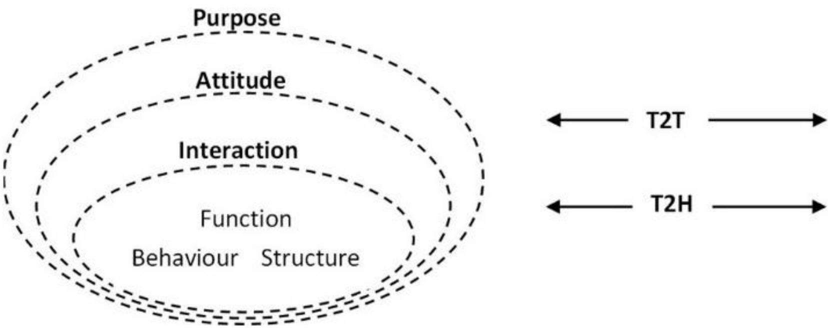

Figure 1. Objectomy approach framework

As in Figure 1, traditional functional frameworks result enriched and encompassed by a 'purpose of an inner life', i.e., the meaning behind the interacting object during its lifecycle, since the question "what does it have to do?" is addressed through the 'interactions' that it puts in place. This is done in view of the objects' 'attitudes', which answer the question "how does it act?". The attitude represents object's temperament and viewpoint concerning external conditions; defining them means knowing how the temperament may influence the way in which it acts. The interaction can occur with the object itself, with another object, or with a human and vice versa: Thing-to-Thing (T2T) or Thing-to-Human (T2H). Both type of interaction can be tangible and intangible. The interaction, for instance, can result in an exchange of data (intangible) or in a physical actuation (tangible). Of course, the interaction can happen one or more times and between one or more objects and humans, and they can be repeated.

From the design practices point of view, Objectomy can be resumed in a three-stages process:

- **Meta-analysis** that is pursued through a deep exploration of the design problem, with the aim of defining its boundaries and the list of the agents involved. The participants of the development team, led by a moderator, are asked to apply a set of abstraction techniques (mainly sematic based);
- **Interaction Simulation**, by which participants must identify themselves in the various agents, by role-playing and a simulation of a multiple-agents interaction world. The outcome is a

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collection of interactions undertaken by the different agents (humans or objects), it can be expressed as a collection of storyboarding, sketching, animation, video, text, etc.;

- **Character Definition** that consists in the analysis of the outcome of the previous stage to define a series of events in which the agents are involved and a series of agent's 'attitudes'. At this point, an Event-Attitude matrix is created, and each cell represents the relationship between the two, the way by which the object acts in the row-event and with a column-attitude.

4. The use case: "The kitchen of the future"

The project presented here was carried out in a appliances multinational company. There, the design challenge was represented by creating a new user experience inside the kitchen environment, new unique ideas for the product/service, as well as an understanding of the potential of the new design process for the participants. The Marketing, the Engineering and the Design departments were involved in a collaborative design activity.

During Meta-Analysis, the boundaries of the design problem were defined, i.e., the kitchen environment and the agents involved in the problem as described in Table 1.

Table 1. Agent's list

Thing	**Human**
Fridge (and freezer)	Mam
Stove (and oven)	Dad
Dishwasher	Child
Washing machine	Friend
…	…

Then Interaction Simulation was conducted as role playing acting: each participant was asked to think and act as one agent (human or thing), based on personal feelings about a specific object, and to interact with each other and take note of such interactions as sketch, text, storyboarding, animation etc. The outcome of this simulation resulted in a collection of interactions (Table 2):

Table 2. Agent's list

Thing-to-Thing (T2T)	
1	The dishwasher recognizes objects, and it suggests the best place for it
2	The stove communicates with the hood, that is turning on, the hood is ready to fan
3	The fridge cleans itself
4	The fridge adjusts the temperature according to the food inside
n	….
Thing-to-Human (T2H)	
1	The dishwasher communicates to the user that it needs to be opened after the washing cycle
2	The open fridge communicates to the user that someone left it open
3	The fridge communicates that inside the fridge some frequently used food/drink is missing
4	Dad wants to open the fridge door without using hands
n	…

During Character Definition, from the lists of interactions, the role of the various agents and a series of situations in which the agents are involved is determined. The roles allow the participants to build the character of the agents, that need to be coherent with the purpose of the objects, and, from that, their attitude. This means the participants are asked to list the desired 'personality traits' of the object-agent. Situations are classified in terms of frequency in which they happen (everyday, sometimes, rarely, and special). Finally, the Event-Attitude Matrix is created, showing the way by which, the object acts in the row-event and with a column-attitude (Table 3).

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Table 3. Event-Attitude Matrix

EVENT-ATTITUDE	Silent Servant	Personal Assistant	Helping Friend
Default functioning	Silent mode	Standard Mode	Vocal advice
Opening/Closing door	Soft-close door	Self-close door	Proportional control
Cooking support	-	Ingredient suggestion	Recipe suggestion
…			
Dirty fridge exterior **Dirty fridge interior**	Ext/Int. self-cleaning material (active mat.)	Ext. surface cleaning reminder	Easy washable ext. surface
Shopping list	Automatic buying	Auto-shopping list	
Door left open	Auto-close door	User notifies	User notifies
…			
User/s need ice	Auto-fill ice box	Fast-ice features	-
Freezer empty	Automatic turn off	Reminder for turn off	-
…			
User's birthday			Celebration mode
SW upgrade release	Auto-installation	Reminder SW upgrade	Celebration mode

In this case, the fridge has played the role of protagonist most of time, indicating the humans give it priority in the interaction with respect to other appliances. This perspective had important influence in the way in which the hardware (shape, technical etc.) and the software (programming logic, network protocol etc.) were designed and the object's attitude implied the set of possible configurations it could assume during its lifecycle.
According to the attitude chosen, for instance, the same object could accomplish same or similar functions in different ways. For instance, as for the agent 'fridge', the primary function of refrigerating can function in 'silent mode' if it is night-time, or if the user is in a work meeting, while it can work in 'normal mode' if there is no need for low noise. When the door is left open, most of the current models on the market communicate the problem to the user (via sound, text etc.), while, asking the participants to be in the mind of the object/agent and be helpful to the user, a solution may be found in the 'self-close' door function. From the same intuition the door can close like a luxury car door, with the 'soft-close' function. Additionally, for instance, the fridge can be designed with a self-cleaning function with an internal washing system.
These easy (rather obvious) examples snow that, as it happens for instance with Lateral Thinking, Objectomy allows us to explore unexpected features, non-obvious aspects of the design research and project. Adopting such point of view, designer is allowed to temporary detach his/her mind from the technical functionalism of the object, to enlarge his/her searching space to find new idea/concepts and to better discover the object's perspective in its interaction with the humans.
In order to understand the real potentialities of such approach, therefore, we decided to frame Objectomy together with other frequently adopted methods in Engineering Design, to understand: 1) what kind of aid is really provided with respect to those design variables that traditionally must be set during designing an object?; 2) are there/what are additional variables that smart products activate, which cannot be covered by traditional methods and that instead Objectomy is able to tackle?

5. Framework analysis

The state of art of Design Methods was framed in view of the design phases these methods are aimed to (in rows) and the most relevant design variables for smart objects derived from the Engineering Design literature in Section 3 (in columns). This is just an excerpt of a much bigger table where all the traditional methods are classified is shown in Table 4. Objectomy was added to the table to perform the comparison.
On the basis of practical applications of Objectomy and from the analysis done for the paper, Objectomy resulted aimed at concept generation, aiding mainly exploration and divergent thinking since it allows to explore a broader spectrum of aspects. It covers the traditional design variables and highlights its own value especially in the study of the architectural and affordance issues in the design problem.

Table 4. Activity-Variable Framework (excerpt)

Design Methods	Design Variables				
	Function (F)	Behaviour (B)	Structure (S)	Architecture	Affordance
TRIZ	(F) are the purposes of the system, the tool is the enabler	(B) are the way by which the system transform input in output	Engine, transmission and the tool represent the (S) elements	How engine, tool and transmission work together	
Biomimicry	…	…	…	…	…
Objectomy*	After the definition of attitude and actions, (F) are defined	(B) refers to the desired behaviour to accomplish (F)	(S) is the working principle or group of that, enabling (B)	The system architecture are simulated in the inter-action simulation	Affordance are evaluated from the observation of the human to object inter-action
…	…	…	…	…	…

This mainly because: 1) it makes explicit the interactions within the socio-technical system (that affect both architecture and affordance); 2) it explores the all the possible declinations of affordance in such interactions, also the ones activated by the object's behaviours.
Consequently, Objectomy can be seen as a complement to the current conceptual design approaches, even offering a better understanding on how the object can assist, support, and help the human.

6. Conclusion

Digital artefacts have features that make traditional methods slightly reductive in supporting the design action. More recent methods consider the multiple interactions between artefacts and systems digital artefacts pose, focusing on on-demand user experience and on interpreting system behaviours in digital contexts (i.e., digital affordance). These methods are mainly developed in the SW industry and are not intended for physical artefacts. Some exception apart, there is a lack of methods that aid the design of a particular class of digital artefacts, characterized by both physical and digital nature. As such, new, dedicated methods may be relevant for future design in the field.
Objectomy approach seems to be a helpful aid in designing smart products. By assuming the object is not 'static', but 'dynamic', and by considering the object as a 'living creature', with an evolution coherent with its purpose, Objectomy allows to explore all the design variables typical of the conceptual phase. Meanwhile, it allows designers to explore unexpected features of a system and to consider a broader spectrum of aspects. As such, Objectomy can be seen as a complement to the current design approaches, a new aid to creative thinking in the design of smart product, as well as in other fields of Design.

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