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A SEMIOTIC MODEL FOR SMART HOME AFFORDANCES: TRAJECTING SEMIOTIC COMPONENTS IN A TECHNOLOGICAL LIVING ENVIRONMENT

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INTRODUCTION

Smart home technology is an emergent industry that is revolutionizing what technological advancements can become integrated into household goods for an inhabitant's preexistent or ideal living space. The denotation for smart home technology utilizes the integration of electrical components into objects deemed as mechanistic household goods, such as a door lock or window blinds, which are purely a mechanical object, can now perform functions via a smart phone app or by other technological modes that may exist within a smart home system. The wireless television remote control was developed in 1955, and over half a century later we now have household goods that range from allowing a user to interact remotely with their pet using a robotic pet assistant, command their smart voice assistant to pour exactly one cup of water from the kitchen sink, record security footage of the backyard using facial recognition when the surveillance camera identifies a face in a user-defined area, and the smart home system can signal the smart vacuum to begin cleaning once all inhabitants are out of the home. This thesis focuses on the systems of affordances that exist within the concept of a smart home, affordances are a significant semiotic component to analyze due to their contextual boundaries and their relationship with the creator and user's infinite semiosis. The design process of smart home technology requires the creator to form an interpretation on how a future user will interact with the designed object within the user's home. If a creator does not effectively design characteristics into the object to meet the user's afforded state, then the smart device is limited on what potential meaning-making events can be performed in the user's home. Also, the user of smart home technology requires an interpretative response to understand how to aggregate the smart devices connected to their smart home system to scaffold home automations. Therefore, semiotics is crucial for both the user and the creator on how a smart device will be integrated into a home and for what purpose is the device defined to behave and interact with the other smart devices that are connected to the smart home system.

The thesis constructs a gestalt system of affordances that is applied to cloud-based smart home technologies, while also identifying the interrelations the creator and the user have in the meaning-making process with a smart home environment. Being that smart home technology offers additional functions designed into the product compared to common household devices and appliances means that the creator should have a clear understanding on who the product is designed for and for what purposes will the user utilize the product. With this said, certain characteristics designed into the smart device will lead to the user establishing affordances with the device which can generate to a deeper meaning within the smart home. Constructing a semiotic engineering approach that focuses on the semiotic components defined by Campbell *et al.* (2019) of resources, competence, affordances, and scaffolding provides insight on how the relations between the creator, the user and the smart home system are interconnected during the meaning-making process that exists in a smart home. Therefore, a model to identify the systems of affordances that exist for a smart home offers the framework for product designers and researchers to analyze the four semiotic components that allow for the emergence of the higher-level systems of affordances, such as the user scaffolding home automations through their smart home system.

This thesis is intended to have a wide scope to define who the target reader is, there are three distinct groups that this research is designed for. The first group is creators of smart home technology, because smart objects that are constructed with affordable characteristics can lead to generating a deeper user experience of the product within their home. The second group is researchers interested in semiotic engineering; the thesis is designed to show how analyzing affordances can be beneficial to pinpoint which specific affordance system can be improved within a complex object such as a smart home. The third audience group is the users of smart home technology, the reason for including users is to enhance their understanding on how to analyze their own smart home system within a semiotic spotlight, and this research can be used as a resource that can potentially lead to improving the overall meaning of appropriating smart home technology within their living space. The content of this thesis focuses on the current impact of cloud-based smart home technology in the global market, while, at the same time, bringing to light the implications a designer or end-user may face when interacting with smart home technology.

From the semiotic research perspective, there is not a significant amount of research in semiotics regarding a living environment using smart home technology. Prior research by Umberto Eco in *Function and sign: Semiotics of architecture* (1973) provides detail on the way the construction of an architectural object can be modeled, but the construction of a smart home differs due to the user becoming a quasi-creator within the smart home environment, meaning the smart devices that are connected within the user's home become tools that construct higher-level system of affordances.

Additional semiotic work used in this thesis to help construct the theoretical model consists of Winfried Nöth's *Trajectory: A model of the sign and of semiosis* (2020) which is applicable to how a creator of smart home technology must traject their constructed object towards a future user's ideal living environment, this is also in-line with how a user of smart home technology must traject their current living space towards the conception of their ideal living space, the trajectiveness that emerges from the perspectives of the creator and user relies on semiotic components which leads to meaning-making (semiosis). Research by Kalevi Kull, who was a co-supervisor of this research, has written about the impact of semiotic fitting and semiosis, most notably in the article titled *Semiotic fitting and the nativeness of community* (2020), which is discussed in the third section of the research.

In a narrower scope for this research, James J. Gibson's stance on affordances discussed in his book titled *The Ecological Approach to Visual Perception* (1986) provided implicit means to show how affordances are a semiotic phenomenon. Additionally, research by Cary Campbell, Alin Olteanu and Kalevi Kull, in the work titled *Learning and knowing as semiosis: Extending the conceptual apparatus of semiotics* (2019) highlights that affordances are one of the four semiotic components of semiosis. This thesis extends on their contemporary model of semiosis and focuses on the role of affordances within a smart home environment.

The closest research relative to this thesis is the publication of Younjoo Cho and Anseop Choi (2020) in the paper titled *Application of affordance factors for the user-centered homes: A case study approach*. Their research focused on a case study of three smart homes in South Korea and provided recommendation on how to improve the designing process of human-computer interaction affordances (see section 2.4.). In less than a decade, the amount of smart home technology research has significantly increased and ranges from policymaking, target consumer perception, software engineering, and security protocols, but the topics mentioned above are typically limited to a cultural system or the type of software used within a smart home. This thesis is intended to provide insight on the semiotic construction of a smart home, which is largely influenced on human-computer interactions and the denotative functions designed by the creator and the connotative functions that a user establishes with the smart home technology. Furthermore, a focus on the various affordances that exist between the user and smart devices within the smart home is valuable to understand how a user codifies meaning for lower-level affordance systems that emerge into higher-level affordance systems.

Being that smart homes require a system to process information of the aggregated smart devices, a user must appropriate the individual devices to connect to the smart home system, the core research objective is to semiotically engineer a gestalt model of affordances for a smart home to get a clearer picture on the relations that exist between the subject-object-environment. Then, once the concept of affordances is defined by the five affordance systems that are present for a smart home the research questions for the thesis are designed to fit the four semiotic components of resources, competence, affordances, and scaffolding to get a clearer understanding on how the four components can improve the individual affordance systems of a smart home from the perspectives of the creator, the user, and the smart home system. The four research questions that narrow the focus of the research objective are listed as followed:

RQ1) What are semiotic resources for/in a smart home?

RQ2) How is competence appropriated into a smart home?

RQ3) What do affordances provide for shaping behavior in the smart home's environment?

RQ4) How can semiotic scaffolding improve the design process of smart home technology and user interactions?

The thesis is broken down into five sections and begins with introducing the roles and variations of smart home technology. The first section identifies the current challenges with smart home technology and categorizes smart devices as being active or passive devices that exist within a smart home. The concept of a smart home is explained to provide detail on the technological components necessary for a smart home to operate and a limitation is defined on how the term smart home is used for this research. Then, there are three subsections that focus on the smart home system's information processing, the trajectory of the smart home's environment as an ecological reality that is constructed into the smart home by the creator and user, and the last subsection focuses on the categorization of the potential and actual users of smart home technology.

The second section provides an in-depth view on the concept of affordances and constructs a gestalt model of affordances for a smart home. The section is broken down into five subsections to explain the hierarchical model of the various systems of affordances and include: architecture, product design, perceptual psychology, human-computer interaction, and automated function. Modeling how these five systems of affordances within a smart home construct a larger model gives insight on how the creators and users of smart home technology provide the semiotic components for the smart home system. Architectural theory relies on semiotic scaffolding to construct an 'afforded' level. Product design utilizes relations between two subsystems to reduce potential negative affordances, while increasing the potential for positive affordances to emerge. Perceptual psychology affords possibilities for action and response is embedded in an organism's *umwelt* within an environment. Human-Computer interaction guides interaction by using modes to orientate within the context. Automated function is the codification of affordances from the lower-level systems that are programmed and defined by the user, which allows the smart home system to interact with specific smart devices connected on the home's network in lieu of the user.

The third section of the research is dedicated to a semiotic point-of-view to theoretically define the meaning-making components that emerge regarding smart home technology. The first half of section three will explain the role of semiotic and ecological fitting, the mediation of signs, and the user's semiotic freedom. Then, the remaining portion of the section reflects on the four semiotic components (resources, competence, affordances, and scaffolding) from the perspectives of the creator, user, and smart home system, the subsections aim to give details on how to improve the semiotic components that exist in relation to a smart home. The purpose for the subsections of 3.2. is to elaborate and go in detail regarding the research questions.

The remaining two sections are dedicated to a discussion and a conclusion. The discussion section identifies the results of analyzing affordances within a smart home and discusses future semiotic research related to smart home technologies and specific niche industries that can utilize smart home systems. Lastly, the conclusion will review the central research objective and the four research questions and provide a short summary on how semiotically engineering a smart home can improve the concept of smart homes by understanding the semiotic components related to the user, creator, and smart home system.

1. CHALLENGES WITH SMART HOME TECHNOLOGY

Smart home technology currently faces a two-fold dilemma that begins with smart devices' heterogenous language – in this sense the communication system programmed into a device – that leads to a loss of information that is untranslatable from one device to another, and the devices with heterogenous language act as an entry barrier for users who must learn and appropriate the smart device into their living environment. This research aims at the latter dilemma mentioned above and is intended to provide a deeper understanding within a semiotic framework on how creators and users of smart home technology can improve the meaning-making process for the pre-existent heterogenous language of smart devices.

1.1. Smart Device

Smart devices, but more specifically relative to this paper smart appliances, are a type of product in the emergent industries of the Internet of Things (IoT) that can be connected to a system by a network that allows a user to define automated functionality. A smart appliance is an electrical household device able to react to external signals (Paetz *et al.* 2012: 24). From the product design perspective, the term 'smart' is used to differentiate new ways for using old technologies (Katuk *et al.* 2018), these new ways of using a technology rely on sensors, actuators, and the base system that supports the collection and exchange of information (Cho, Choi 2020: 1). Also, as mentioned by Wilson *et al.* (2017: 72) sensors and monitors detect environmental factors including temperature, light, motion, and humidity.

The global industry for smart appliances was valued at $24 billion in 2016 and has a forecasted value of roughly $54 billion by 2022 (Katuk *et al.* 2018: 71). Smart appliances include lights, vacuums, refrigerators, ovens, outlets, laundry machines, toilets, thermostats, and several more household appliances (refer to Katuk *et al.* 2018 for an extensive list of smart appliances). Additionally, devices such as smart voice assistant speakers are making a significant impact in the sector of household goods, voice assistants are integral devices in a smart home which can act as a central hub that allows compatible smart devices and appliances to interact with the voice assistant. At the end of 2016 in the United States alone, about 13 million households have purchased one smart voice assistant[1]. Smart voice assistants provide an alternative mode, similar to utilizing a smart phone app, and interacts with the synchronized smart appliances within the smart home system.

When smart appliances connect with other household smart appliances it becomes a part of the ecosystem for smart home technologies, which are networked using standardized communication protocols (Wilson *et al.* 2017: 72), these protocols are communicated on the home's mesh network with a language from one device to another either by using connection via Wi-Fi, Z-Wave, or Zigbee. With this being said, smart appliances rely on a heterogenous language which refers to the diversity of smart appliances, interconnectivity, and user preferences (Xu *et al.* 2016). Each device has its own semiotic language programmed by the manufacturer that includes a unique set of meanings and representations (Chagas *et al.* 2018), and a devices' language is often constrained due to their heterogenous properties and this is a current major challenge within the smart home ecosystem to share relevant resources (Katuk *et al.* 2018; Patrono *et al.* 2020). Users are required to appropriate the functionality of a smart home, this means that certain actions and affordances must be defined, configured, and adapted for individual appliances to perform user-configured automated scenarios within the home. Users can schedule automated functions to perform in the home by defining specific smart devices to react to various signals (*e.g.*, the time of day, the day of the week, the weather forecast, a movement that is picked up by a sensor, or a user's voice command). For a detailed example, a customized automated scenario can be scheduled to operate each weekday, and includes the smart lights in the bedroom gradually becoming brighter to mimic sunrise at 6 A.M., the smart blinds opening up to let the actual sunlight at a specific time based on the weather forecast information provided by the smart home controller, the smart voice assistant reading what is on the agenda for the day once the smart sensors of the user's bed transmits the information to the home system that user is out of the bed, and the smart coffee machine in the kitchen can begin brewing a pot of coffee using the same signal emitted from the bed's sensors to the home system. Customized scenarios vary depending on the devices within the home and

[1] https://www.researchandmarkets.com/reports/4399216/smart-voice-assistant-speaker-market-global

by the user's programmed responses for a smart device in relation to a certain system command, which is structurally associated with the Boolean logic of "if this, then that" – the website IFTTT[2] is dedicated to help the user configure automated functions. Smart devices must be compatible with the controller to the home's system, this is usually achieved through a voice assistant, smart phone, or tablet. Then, the user can edit and program certain devices to respond to defined cues within the environment, this allows for the user to appropriate a defined future behavior for a device.

There are two types of smart devices within a home's technological ecosystem, active devices which control and generate an output of signals, and passive devices that monitor and measure physical characteristics in the environment and converts the data as electrical signals that is inputted into the smart home system – the following two subsections are to elaborate on how the two categories of smart devices (active and passive) relate to a smart home system, and sections 2.2. and 2.4. provide insight on affordances regarding product design and human-computer interaction.

1.1.1. Active Device

Active devices are smart objects that a user directly or indirectly uses. Research by Younjoo Cho and Anseop Choi focused on the affordance factors for user-centered smart homes and noted that users interact directly with active devices within the smart home "by inputting commands and receiving output for the commands" (2020: 5). A user relies on the active device's interface, as well as the user interface (UI) designed in the active device, to understand the meaning-making process regarding the input and output functions. Active devices have a variety of interfaces that range from gesture, graphical, physical, and voice interfaces, additionally, to improve the usability of smart homes, active devices and their user interfaces should appropriate affordances in terms of physical, visual, auditory, and tactile aspects (*ibid*., 5).

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[2] https://ifttt.com

An active device affording multimodality provides the user with the choice on how to perform a function on a smart device. An example of multimodality of an active device is a smart door lock, various modes can be engineered into the product design for a smart lock, integrating different modalities could range anywhere from allowing a user to unlock the door remotely on a smart phone application, facial recognition, a fingerprint, a door combination, and by a card or key. Incorporating multimodality into an active device generates new subsystems of affordances within the device such as remote (application) interface, physical interface, and a tactile interface.

Designers of smart appliances can improve the usability of active devices and the user interfaces with which the user directly interacts in the command input and output process (Cho, Choi 2020: 2). This means that active devices and user interfaces should provide users the ability to make internal changes for the system of the smart home rather than purely relying on a smart home controller to assign and define home automations. Also, smart devices that introduce a new technology will require more appropriation since the technology has to be learned from the bottom-up, because the user must semiotically scaffold the substances of knowing, learning and memory. As Umberto Eco mentions, "an architect or designer cannot make a new form functional (and cannot give form to a new function) without the support of existing process of codification" (1973: 178). Therefore, designers should integrate well-established conventions that transfer the semiotic substances from the 'old' technology into the newly designed smart device, this specific codification is related within the system of human-computer interaction affordances (section 2.4. of the thesis).

1.1.2. Passive Device

Passive devices rely on their sensors to collect data that signal information to the controller. The data of a passive device is an output that is sent to the home's control system and creates an interaction with the user (Cho, Choi 2020). These devices send the collected information to an active device, which is where a user can view, analyze, and alter the functions of the passive device. Examples of passive devices range from temperature sensors, carbon monoxide and fire detectors, water detection sensors, and smart vent filters.

Looking at the relation between user and a smart motion sensor as an example, the active device is the smart phone that serves as a controller for the outdoor motion sensors, and the individual smart outdoor motion sensors are passive devices. Interacting with the smart phone to control the outdoor motion sensors allows a user to define when the sensor's light and video recording begins once the device identifies a moving object above the user-specified weight – giving the user the ability to define when the smart sensor is active will alleviate any unnecessary recording, such as the neighbor's cat strolling through the yard at night.

Future generations of passive devices can be designed to reduce the impact of a device's heterogenous language. This approach will allow passive devices to be configured to share data with various active devices on the home's network rather than just being compatible for certain active devices on the home's network (*e.g.*, the smart phone app designed for a smart vent filter). Additionally, passive devices can integrate the affordances mentioned active devices subsection of physical, visual, auditory, and tactile aspects, this would lead the passive device to generate more 'activeness' within the smart home, while also improving the functionality of the passive device.

1.2. Smart Home

There are several variations for the definition of what a smart home is, to thoroughly explore the capabilities of a smart home, I define this as a home with a technological network and system that is capable of perceiving environmental stimuli which can influence automatic or controlled functionality. Researchers have defined smart homes as a generic descriptor for the introduction of enhanced monitoring and control functionality into homes (Wilson *et al.* 2017: 73); linking separate devices of a household to a network (Paetz *et al.* 2012: 24); a residence that improves quality of life by providing various services based on information and communication technologies (Cho, Choi 2020: 1); a combination of the demand for variable electricity tariffs, smart metering, smart appliances and home automation (Paetz *et al.* 2011:

24); lastly, a system that consists of three main components: home network[3], intelligent controller[4] and gateway[5] that control home automation through wired/wireless access (Katuk *et al.* 2018: 74). Thus, the concept of a smart home requires individual artifacts to collect and transmit information, which is quantified data that is signaled to other artifacts connected on the home's network. It is important to reiterate the broadness on the definition of a smart home, but there is a semiosic distinction for smart homes in this research that focuses on the three semiotic substances of learning, memory and knowing.

The focus of this research is to model the system of affordances that can exist within a person's inhabited space with the inclusion of smart home technology. The term smart home is ambiguous since a person does not necessarily require a house or a home to integrate smart home technology. Smart home technology can be integrated into an inhabited space if and only if the shelter or dwelling contains the architectural affordances to attain a higher-level system of affordances – this can range from having access to electricity and Wi-Fi to connect smart devices to the cloud to perform functions with the smart device, having a window to afford the potential of integrating smart blinds, or even possessing a water pump to afford a smart leak detector. An individual can live in an apartment, a houseboat, a cardboard box, a cave, or any other form of shelter that is used as a living space, but the living space requires vital architectural affordances to appropriate smart home technology. Additionally, the term smart home is implicit to the household goods that exist within a shelter. So, the various technologically advanced (smart) household goods integrated into a place of living assimilate the notion of having a smart home.

Owners of smart appliances orient and define the behavior of the smart object on the home network, meaning that the user must input syntactic commands into the system's program, which David Mick mentions that syntactics are "sign-sign relations" (1986: 200). This syntactic command allows one device, whether it is a passive or active device, to transmit information for the function of another device within the system, such as a smart home user programming

[3] A communication network that connects smart appliances or sensors and the intelligent controller seamlessly.
[4] Software that can manage appliances and services including auto-discovery and auto-deletion of the appliances and services, auto-transformation of data between different appliances, and auto-switching tasks.
[5] A bridge to link cloud server and home network.

the smart lights behind the television to change hue depending on what is shown on the television screen to generate a more cinematic experience.

1.2.1. Information processing of a smart home system

The concept of a smart home has two different methods of information processing and storage, one method is to rely on cloud-based processing to access functionality and store information, while the other method is to process and store information on internal servers. This research focuses on cloud-based smart homes since this type of smart home technology is currently more prominent from the industry perspective, and there is a wider range of products offered which can lead to analyzing various types of affordances in a smart home. A cloud-based smart home can be accessed remotely, by a computer or smartphone software, anywhere in the world that can enable functionalities such as turning up the heat before arriving home or checking the security cameras remotely (Zimmermann *et al.* 2019: 200). However, cloud-based homes pose a high risk of vulnerability to security and data leaks, an attacker can infiltrate one device on the home's network which would allow them to access the entire smart home technological ecosystem (see Patrono *et al.* 2020 for an example of a smart home security breach). On the other hand, a smart home with an internal server for data processing and storage lacks remote accessibility, decreased functionality amongst the smart appliances, and potentially an increased cost in setting up the smart home (Zimmermann *et al.* 2019). Internal server smart homes do not offer a wide range of smart appliances and are also limited to what information is translated from one device to another, although this type of smart home does possess a higher level of affordance for security as opposed to a cloud-based smart home.

There are smart home software platforms, such as Control4[6], that allow the smart home to operate homogeneously through their cloud, while also having the ability to integrate various smart devices manufactured by other companies to create an open platform. Using this sort of platform may be ideal for an inhabitant who wants to have one central system to control their home, but to also integrate additional smart devices that are not designed specifically for this

[6] https://www.control4.com

platform. This type of smart home provided by Control4 greatly differs compared to the smart home system designed by Savant[7], which is a personalized smart home system that is incompatible with smart devices not within their product line. Both types of smart homes have their own advantages and disadvantages, but a smart home with an internal server can rely only on one metalanguage for the smart home's modeling system as opposed to a cloud-based smart home which would typically require multiple data networks to store and transmit information back to the home's system.

Research (Alper *et al.* 2016) has shown that smart home users are more interested in what the system does rather than how it is achieved, additionally, users require a feeling of personal control over the system to be essential, which requires the programming language to include a visual representation a user can access within the system's interface (Zimmermann *et al.* 2019). So, the interrelations between smart appliances in a home should utilize user experience (UX) and user interface (UI) so inhabitants can get a clearer understanding on the various affordances and appropriations within the smart home, this can include knowing how much energy consumption is being used for the entire house or even for a specific room. A smart home's system utilizing memory can track how frequent a device is used, and the system knowing what devices are connected to the network can potentially lead to learning of the potential relations that may be beneficial for the users to appropriate into their smart home system. As Clarisse de Souza *et al.* point out, software artifacts are metacommunication artifacts that send a message from the designer to the user "about the range of messages users can exchange with the systems in order to achieve certain effects" (2001: 462). For example, the open-source software for home automation provided by OpenHAB[8] is a UX resource that a user can integrate into their home system to afford customizable home automations, this software can provide the user with rich visual data and more control over what automated functions are defined, but the user must afford competence in computer programming to integrate this software into their preexistent smart home system.

A user's intention for appropriating smart home technology into their living space is a crucial component when deciding which type of smart home system best suits their needs. As

[7] https://www.savant.com
[8] https://www.openhab.org

mentioned in the paragraphs above, there are smart home systems that can be integrated into a living space that solely operate on one cloud-based platform and are incompatible with third-party devices. Also, there are smart home systems that operate on a central platform and do have the ability to integrate third-party devices, but this type of system may require the proper competence to effectively integrate the third-party devices into the home automation protocols. Depending on which type of smart home platform is suitable for the user is related to their consumer needs, but one critical notion that a potential user of smart home technology should keep in mind is that a smart home that operates on several cloud-based platforms requires much more competence to thoroughly understand each interface, which is predominately related to smart home devices that can be purchased through e-commerce or in retail stores. The distinction on which type of system best fits the user's intention for having a smart home relates to the metacommunication that emerges from within the smart home system. Meaning, the more systems that exist within the smart home require the user to learn how to interact with the specific programming. Therefore, a smart home system that operates on one central homogenous language, while also having the accessibility to integrate heterogenous third-party devices may serve as a suitable type of system to learn how to construct a smart home system in a way that is scaffolded around the user's future intentions or goals.

1.2.2. Trajecting an ecological reality within a smart home

Analyzing a smart home through an ecosemiotic lens shows how the construct of a smart home is created by a trajectory from the perception and implementation of the creator who designed the smart home technology and by the user who interacts with the smart devices in a living space. As Winfried Nöth states, "ecosemiotics is the study of the semiotic interrelations between organisms and their environment" (1998: 333). In this sense, the living space with smart home technology is a dynamic environment that is a result of the creator's system design and the relation of the user's content programming (fig. 1). The smart object constructed by a creator for a smart home environment is oriented towards the user's perception, and Nöth (2020: 183) mentions, "a sign emitted by a sender aims at the receiver's mind. […] Aiming at her goal, the sender's intention describes a trajectory from its starting point to its target." Therefore, the notion of trajectory can be applied to how a creator of smart home technology relies on semiotic substances (knowing, memory and learning) for the interpretant on how the potential user in a future state will interact and integrate the object into their smart home system.

Nöth discusses how the founder of biosemiotics, Jakob von Uexküll, takes the stance that the environment is represented subjectively as an *Umwelt* which consists of an inner world that is comprised by an organism's perception (Uexküll, Jakob v. 1940. *Bedeutungslehre*. Leipzig: Barth, 158 – *cited in* Nöth 1998: 339). Scholars such as Tetsurô Watsuji and James Gibson provide additional claims that support von Uexküll's notion on the Umwelt theory. For Gibson, the environment is perceived by animal or man (1986: 15), and the ecological reality provides the grounds for a meaning-making process, which is constructed by the organism's subjective reality (umwelt). Augustin Berque notes that Watsuji was most likely influenced by von Uexküll's work through the teachings of Martin Heidegger in Germany during 1927–1928 (2016: 31). Watsuji's book *Fûdo* emphasizes the importance of mediance (*fûdosei*) which is the interpretation of the dynamic relationship between the subject and the environment that is influenced by the subject's milieu (*ibid.*, 30-31). Watsuji provides the concept of trajectionalism, which relies on the claim that, "the environment (S) does not exist unless trajected as a world (P) into a milieu (S/P)" (*ibid.*, 32). As explained by Berque (2016), the environment – (S) a pure object existing in itself – does not exist unless trajected as a world – (P) a pure representation existing only for us – into a milieu – (S/P) which combines both to make it trajective. Applying Watsuji's concept of trajectionalism in more technological sense regarding a smart home, the smart home environment is trajected as a world by the integration of a processing system that constructs and defines technological milieu.

Smart home technology can be designed by an architect into the design process of a home, but this technology can also be appropriated into the users preexistent home, and the technology integrated into a home has the potential to reduce energy consumption, but this requires the semiotic activity to know what the user's ideal living characteristics are (*e.g.*, what temperature the heating or air is usually set on, how much energy the home consumes on a daily basis, and so on), therefore, the goal of reducing energy consumption – especially a living environment with technological milieu – has a trajective path since it aims at an initial goal.

With this being said, a smart home provides the means to not only increase technologically but also environmentally, which provides the milieu for trajectionalism between the dynamic relations of the smart home and the users – section 3.2.1. discusses how the COVID-19 phenomenon has created variations to some common household goods. Users of smart home technology integrate various smart devices into their living space to reach a trajected state by learning what the smart device can offer for their living space, such as improving the security measures or even reducing the spread of the corona virus within their home, this process of a user trajecting their smart home to be oriented towards a specific goal is related to the process of semiotic scaffolding, which the "scaffolding processes direct and focus decision-making, expressed through learning" (Campbell *et al.* 2019: 367). Therefore, a smart home user constructs semiotic scaffolding to reach the trajected goal for the smart home.

1.2.3. Understanding the potential and actual users of smart home technology

This section covers how smart home technology is designed for a *possible* user in the mind of the creator, and further elaborating on who *actually* uses the technology can serve additional insight on the trajectory of the smart device into a user's living space. Two semiotic components, competence, and resources are discussed in this section to explain how creators and users of smart home technology rely on these two semiotic components to construct a trajectory for a smart home system.

A designer's conception on who the target consumer is can be viewed as a rhematic interpretant in Peirce's terminology since it is a "sign of qualitative possibility" (*CP* 2.250) of consumption that may or may not exist in relation to the characteristics of a consumer. Subsequently, the individual who purchases the smart device for their home must have a degree of competence on what the device does and how it can be perceived to improve their subjective quality of their living environment. The user of the smart home technology establishes a dicent interpretant because the individual using the smart device generates a "sign of actual existence" (*CP* 2.251) which leads to semiosis that is mediated within their environment (living space). The rhematic and dicent users of smart home technology are shown in the visual model (fig. 1) of affordances, additionally, the subsection of 3.2. emphasize more in detail the semiotic components of the user.

Competence is a vital semiotic component which leads to the user sufficiently appropriating a smart home technology into their living environment. Competence is how the subject, whether it is the user, designer, or the smart home system, discovers meaning in an environment and recombines the semantic and syntactic properties into a pragmatic model. For instance, the designer of a smart home technology must understand who their target audience is, the determinant on who the consumer is heavily lies in the semiotics of commodity (see Nöth 1988 for modelling semiotics of consumer goods), and there exists a sociocultural boundary on who the target consumer is. Thus, the designer must have the competence on who they are designing the smart home technology for.

A user appropriating smart home technology into their living space requires a degree of competence to match their expectations on how the smart device should function. Competence can be induced from the designer's perspective by integrating prior conventions with a preexistent object and integrating the specific conventions into the smart device. Eco elaborates on the perception of a user that is incompetent regarding an interaction with a new technology,

> But clearly a primitive man used to stairs or ramps would be at a loss in front of an elevator; the best intentions on the part of the designer would not result in making the thing clear to him. The designer may have had a conception of the push buttons, the graphic arrows indicating whether the elevator is about to go up or down, and the emphatic floor-level indicators, but the primitive, even if he can guess the function, does not know that these forms are the 'key' to the function. He simply has no real grasp of the code of the elevator. Likewise he might possess only fragments of the code of the revolving door and be determined to use one of these as if it were a matter of an ordinary door. (Eco 1973: 177)

Eco's statement about an incompetent user, otherwise considered as the primitive man in his statement, is in-line with how the user interpreting how to operate an elevator for the first-time lacks knowing the conventions associated with this object, which means a logical interpretant was not formed since "a thought or other general sign, or a habit formed or modified" (*CP* 5.486) did not emerge due to the man comparing the functionality of stairs or a ramp to an elevator. The primitive man seeking to understand the elevator is related to Peirce's energetic interpretant, and as Cornelis de Waal points out, the energetic interpretant is a particular physical and psychical action (2013: 85), which means Eco's primitive man would be more focused on the ontology on what the elevator does.

Another semiotic component that can help reduce the current challenges within smart home technology is resources. Resources are elements used to represent how something can be engaged with to generate meaning, while also potentially leading to discovery and learning (Campbell *et al.* 2019: 358). A user seeking to appropriate a new smart appliance or device into their home must rely on resources to learn how to install and operate the object. Resources for a user appropriating smart home technology can range from asking a peer with smart home technology how to use the device, or even the reliance of a service contractor to help install and program the smart home system or appliances – affording the cost of a contractor can also be deemed as a resource – but user-resources predominantly come in the form of texts such as instruction manuals, tutorial videos, online forums, product reviews, and the frequently asked questions page on the manufacturer's website. These various forms of resources supply the user with an understanding on how to setup and program smart home technology, and when the user learns and discovers the various functions of the smart object, then their competence increases on what the smart object can be used for. Subsection 3.2.1. elaborates more in-depth on the role of semiotic resources from the perspectives of the user, creator, and smart home system. But the notion of resources for a user is a vital component to effectively traject a constructed smart device into a user's ecological reality.

Within a smart home there exists certain types of dicent users that have different relations with the smart home system, these types of users can be broken down into three categories: administrative users who have full access to the configuration of the smart home system, limited access users who can only perform specific functions in the home's system (*e.g.*, children, guests temporarily staying at the home, babysitter, dogwalker, or any other person who has been given partial access by an administrative user to perform defined functions in the home), and lastly, service users such as a technician or smart appliance installer who performs a service within the home system that requires access to make systematical changes. The three types of dicent users do not possess the same rights of accessibility provided by the smart home system, which means that a limited access user or service user does not afford the same functional privileges as an administrative user to control home automations, view data stored on the system, or alter scheduled rules for the smart home system.

2. AFFORDANCE SYSTEMS WITHIN SMART HOMES

The central discussion point for this paper is to identify and explore the various systems of affordances found within a smart home system. The purpose of identifying affordances in a smart home is to elaborate on the qualities and characteristics of an object in relation to a user which generates meaning-making within the environment of a smart home. Constructing a gestalt approach to identify the various systems of affordances in a smart home will enhance the scope of the wide range of relations between the artifacts and users of a home.

Beginning with the ground-level of affordances, the conceptualization and construction of an object within architectural engineering and product engineering can utilize a model of affordances that Chris Baber (2018: 7) considers an “affording situation” for the interrelation of the user-object-environment. Jonathan Maier and Georges Fadel (2009b: 233) highlight that an artifact’s characteristics determine what affordances exist in relation to the user’s characteristics. Additionally, the designer does not have control over the user’s characteristics, but there usually is control on what characteristics exist for the artifact (*ibid.*, 231).

Before the theoretical view of affordances is discussed, the reader should keep in mind that from the engineering perspective affordances do not always lead to a positive outcome for the user who interacts with the object. Maier and Fadel (2009b) take the stance that when designing and engineering a product an affordance can be considered either as a positive or negative affordance (*e.g.*, a hair dryer burning the user is a negative affordance, thus the designer should design characteristics into the dryer to help avoid the user from getting burned, such as casing that protects the heated coils; as another example, a piece of playground equipment where a child could fall off and harm themselves can be viewed as a potential negative affordance, but the integration of a safety net on the sides of the playground equipment aims to eliminate the potential negative interaction of a child falling off the equipment). From the ecological perspective, Gibson mentions how “affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill” (1986: 127). So, affordances can be viewed as either positive or negative, and there is one more additional categorization for affordances regarding the creator’s design task of an object.

When analyzing affordances during the engineering process, there are lower systems of affordances that exists between two components within the artifact (*e.g.*, a smart device affording compatibility with the smart home controller). The artifact-artifact affordance is viewed as an AAA (Maier, Fadel 2009b), and since there is a positive or negative relation, then a distinction can be made if the affordance is either an +AAA (positive artifact-artifact affordance) or -AAA (negative artifact-artifact affordance). Additionally, affordances also exist between a user and an artifact, thus an artifact-user affordance (AUA) follows the same categorizations, such as being viewed as a +AUA (positive artifact-user affordance) or -AUA (negative artifact-user affordance). The distinction of artifact-artifact affordances (AAA) and artifact-user affordances (AUA) being either a positive or negative affordance can help the architect and engineer understand which subsystems interact with one another for a specific purpose (see Maier *et al.* 2009 for insight on how a designer can hierarchically model affordances for a product).

Regarding a smart home, *convenience* is a +AUA if the smart device caters to provide an easy-to-use form of operation – this can include the function of voice-control that is built into a smart device, which would allow the user to stay placed in their current location rather than having to move to perform a simple task such as turning on/off the lights, adjust the thermostat, or even change the channel on the television. On the other hand, automated functions that do not require user-interventions rely on an artifact to interact with another artifact, this means that the smart home must utilize artifact-artifact affordances (AAA) to achieve automated functions. For example, a +AAA is two smart devices sharing the same programming language, this generates the affordance of *synchronicity*. Additionally, a smart device that has its own unique programming language and incompatible with the smart home's modeling language possesses the -AAA of *heterogeneity*. This constitutes as a negative affordance since information becomes untranslatable from the heterogenous device to the system's information processing. More detailed examples of affordances within a smart home system will be included throughout the various systems of affordances, but it is essential to keep in mind how affordances can either generate a positive or negative relation, and how the relation can be between two artifacts or between a user and an artifact.

The following subsections elaborate on five systems of affordances that exist within a smart home. Attached below is a gestalt visual model of the five systems of affordances within a smart home. As mentioned in the introduction section, the five affordance systems discussed are architectural engineering, product design, perceptual psychology, human-computer interaction (HCI), and automated function.

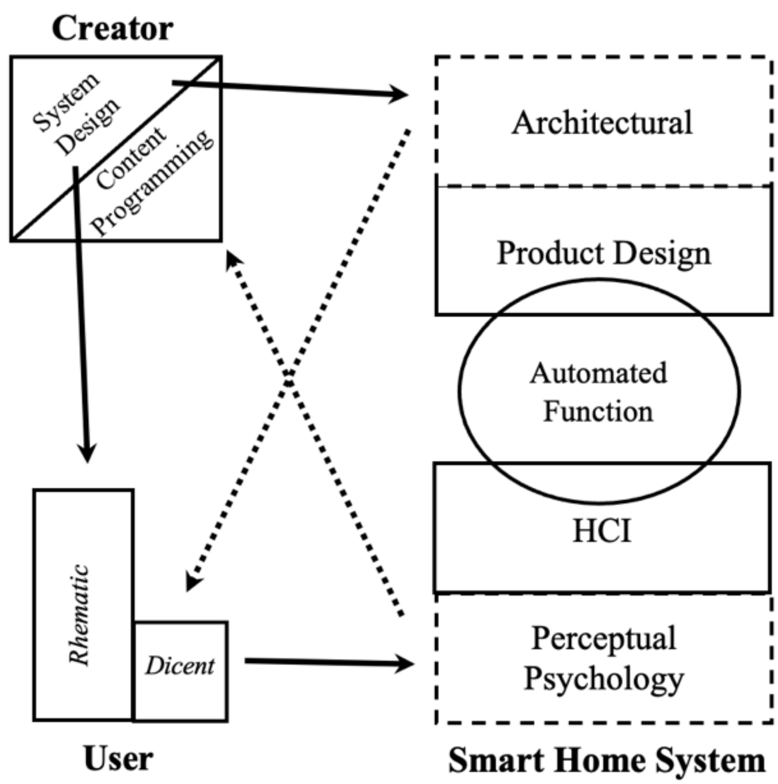

Figure 1. Gestalt systems of affordance model for smart home

As depicted in the visual model, there are three perspectives that are interrelated for the affordances of a smart home, the creator, user, and smart home system. Beginning with the creator's perspective, system design refers to the structural aspect of the artifact that is constructed by the creator, this is back-end of the artifact's characteristics designed by the creator that concerns the engineering properties, which can include physical characteristics of the artifact and algorithmic properties for the artifact's interface. The content programming is the front-end of the artifact that a user interacts with. I will discuss more in detail about the content programming once I discuss the perspectives of the user and smart home system.

Moving onto the user perspective on the bottom left of the visual model, a system is designed for a possible user in mind, which is considered as a rhematic user for this model. As mentioned in the previous paragraph, system design relates to the artifact's physical characteristics or algorithmic properties encoded in the protocol language of the artifact. This relates to a user due to the aspect that affordances are a relation between two subsystems, such as the user and an artifact, therefore, the physical characteristics and the coding language of an artifact are engineered for a possible user in mind. The dicent user refers to the users who uses the artifact, therefore, artifacts are designed to fit the needs of a possible (rhematic) user, the user that interacts with the artifact becomes a dicent user since a relation between the user and an artifact is established.

The smart home system displayed on the right side of the model breaks down the five affordance systems that exist for a smart home. The affordance systems of perceptual psychology and architectural affordances are represented as systems with hashed boundaries, this signifies that the two affordance systems are open and utilize codes outside a larger boundary of a smart home model. Architectural affordances for the smart home system are open to external codes such as characteristics of the natural environment (*e.g.*, the physical reality of the living space that limits architectural codes, and the virtual architecture that limits the capabilities for the algorithmic properties). Perceptual psychology affordances are open to codes emitted from the natural environment as well, Gibson (1986) forms the notion that ambient light within an organism's niche leads to the perception of affordances. Also, perceptual psychology affordances are open to the subject's perceptual bias, the mood or feelings generated from within the subject orients our perception on how interaction should be approached to attain a goal with an object, which section 2.3. discusses more in detail. The systems of architectural affordances and perceptual psychology affordances should be viewed as the lower-level systems within the gestalt framework of a smart home system's affordances.

Regarding the affordances of product design and human-computer interaction (HCI), these two systems are represented as closed systems that are constructed from the codification of two open systems mentioned in the prior paragraph. These two affordance systems represent active systems that emerge from the lower-level affordance system, meaning the affordances for perceptual psychology are codified and emerge into affordances for human-computer interaction, and the architectural affordances are codified into the product design affordances.

The last system of affordances to discuss is a smart home possessing automated function. This affordance system is scaffolded by the user's understanding on how to construct automated protocols within the home system. An automated function emerges from the affordance systems of product design and human-computer interaction, which causes the smart home system to respond to user-defined signals within the smart home environment to perform home automations. In this sense, automated function affordances operate in a top-down manner since the user schedules the smart home system to interact with an object rather than the user having to physically perceive or interact with object themselves.

The remaining aspect of the model that needs to be elaborated is the significance of the arrows and content programming. The solid arrows depict inferences, and the hashed arrows are presuppositions for the inferential functions to exist. A creator designs a system that requires an inference on who the object is made for (rhematic user) and establishing an inference in relation to the smart home system's architectural affordances. A dicent user's architectural affordances is a precondition that forms an inference of the perceptual psychology affordances, which, in turn, the aspect of a user perceiving information in an object is a presupposition for content programming. Content programming relates to the user being able to schedule rules that is inputted into the smart home system, the user becomes a quasi-creator within the smart home environment, meaning that the user can define the behavior of devices connected to the home's network and scaffold home automations to functions to the defined signals of content programming.

2.1. Architectural Affordances

Architectural affordances are the initial modeling system that a creator must first conceptualize and design before an inhabitant defines higher-level affordances within a home with individual smart objects that emerge from the codification of this system. Architectural affordances provide the foundation on what characteristics should exist for the form of an object. Furthermore, architectural affordances are related to any designed object, rather than being limited solely to architecture. Affordances for engineering design are the "relationship between two subsystems in which a potential behavior can occur that would not be possible with either subsystem in isolation" (Maier, Fadel 2009b: 226). This means that four upright walls that can support the weight of a roof allows the affordance of shelter to exist for a user. The affordance of shelter can be deemed a higher-level affordance, meaning that lower-level affordances must first be designed for high-level affordances to hierarchically inherit the lower-level affordances (Maier *et al.* 2009: 401). Elaborating more on the previous example, if the four walls were designed with a material that could not support the weight of a roof, then a user would be exposed to the conditions of the natural environment, meaning the strength of walls is an affordance for a roof. For this example, the two subsystems for the affordance of shelter are the upright walls and the roof, neither of these objects could exist in isolation to generate the affordance of shelter for a user. Maier and Fadel (2009a: 394) provide a detailed explanation for the essence of architectural affordances:

> First, as to architectural theory, we assert that affordances can be used as a conceptual framework to understand the relationship between built environment and humans over time, especially with respect to the form, function, and meaning of architectural elements. Second, regarding architectural design, we propose that the concept of affordance allows for a common theoretical basis to improve the design process by offering a shared language among those involved in a design project, particularly architects and engineers. Third, regarding architectural practice, we believe that affordances may be used as an evaluation tool to explore the connection between the initial intentions or objectives of the design with how the artifact is actually used, leading to archived knowledge for use in future projects, and the potential for avoiding an array of common design failures. (Maier, Fadel 2009a: 394)

This statement encapsulates the importance of affordances and reiterates how keeping in mind the role of affordances during the conceptual framework, the engineering process, and a reflective point of view once the project is complete can provide the means for a meaning-making process of affordances. Regarding the notion of architectural practice, the user of a smart device may decide to use the object in a way that was not designed by the engineer or architect, the unplanned convention established by the user in relation to the smart device becomes a resource that can be semiotically scaffolded into future generations of the smart device. An architect faces the likelihood of their work being subject to a variety of meanings, and should aim to design variable primary functions, that are the denotations of the object (*e.g.*, a chair denoting to be sat on), while also integrating open secondary functions, which are the connotations (*e.g.*, a throne connoting regality) that can be defined in future codes (Eco 1973: 182).

As mentioned in the introductory section for affordances, there are two types of affordances, one being artifact-user affordances (AUA) and the other being artifact-artifact affordances (AAA). From the architectural level, the lower-level AAAs provide the grounds for the higher-level affordances. Maier and Fadel state, "buildings have many high-level affordances, including affording shelter to occupants from the exterior environment, affording aesthetics to occupants and passers-by, affording storage of goods […]" (2009b: 396). A smart home possesses the same potential high-level affordances as a home without smart technology, but the lower-level affordances within a smart home allows the emergence of new high-level affordances which ultimately depends on the technological integrations in the smart home. High-level affordances of a smart home include affording security for data of home network, affording user-intervention over home automation, affording efficiency of energy consumption, and affording multimodality for a user's interaction with a smart appliance. So, the central importance for architectural affordances within a gestalt approach is to identify the framework of the conceptualized object and to define what lower-level affordance subsystems are required for higher-level affordances to be emerge, while also minimizing which negative affordances should not exist to improve the quality of the designed object.

2.2. Product Design Affordances

Affordances for product design revolve around the implementation of the desired, positive affordances, while at the same time, reducing the possibility of any undesired, negative affordances (Maier, Fadel 2009b: 226). Architectural and product design affordances both rely on an engineering approach to determine what potentialities should exist between the relation of the designed object and the user. However, architectural affordances focus more so on the systematic level of affordances as opposed to product design which focuses on the subsystems of affordances that allows the emergence of higher-level affordances. With this said, it is apparent that the architectural affordances merge into the engineering process of the product.

During the design process of a product, Maier and Fadel (2009b: 226-27) identify six design tasks for affordance-based design:

1) determine the artifact-user affordances an artifact should and should not have;
2) generate concepts for the artifact's overall architecture and components;
3) analyze and refine the affordances of the concepts from the previous stage;
4) select a preferred architecture;
5) determine the artifact-artifact affordances that should exist between the subsystems;
6) design individual affordances.

Utilizing the design task for affordance-based design allows the designer to predict and orient future relations with the artifact. The six design tasks will allow the designer to scaffold meaning for the end-user's future semiotic activity by having a deeper understanding on who the user is. Eco states, "the form of the object must, besides making the function possible, denote that function clearly enough to make it practicable as well as desirable, clearly enough to dispose one to the actions through which it would be fulfilled" (1973: 178).

Additionally, Maier and Fadel identify important properties of product affordances as: complementarity, polarity, multiplicity, quality, and form dependence (2009b: 226). Complementarity refers to how an affordance must include two subsystems in relation with another, such as a smart plug being dependent on an electrical connection to afford usability, and the smart plug having a complementarity with a smart phone application to generate the affordance of remote accessibility. Polarity specifies if the affordance is either a positive or negative relation and is determined by the potential behavior which could be either beneficial or detrimental. For example, the affordance of remote accessibility designed into a smart device can be viewed as positive affordance that leads to higher-level affordances in the smart home, however, it could lead to a negative affordance if the smart device with remote accessibility was hacked and could compromise the smart device and potentially the home network. Multiplicity relates to how an artifact can have multiple affordances, such as a smart device having affordances of remote accessibility, hackability, aesthetics, compatibility, energy efficiency, and so on. Quality depends on how well the subsystems support the potential behavior; the affordance of usability is higher if the smart plug contains multiple outlets as opposed to one outlet to plug a device into. Form dependence relies on the physical structure of an artifact, such as the affordance of a compact design, which allows the smart plug to not take up unnecessary space, which could potentially block an additional electrical outlet from being inaccessible.

2.3. Perceptual Psychology Affordances

Perceptual psychology affordances provide the potential for a user to perform a certain, desired behavior by perceiving a feature of an object within the context of the environment. In James Gibson's book, *The Ecological Approach to Visual Perception* (1986), he elaborates that an affordance is always there to be perceived, though it ultimately comes down to the user's needs. The user's needs are a result of the organism's umwelt embedded within an environment, an organism forms meaning from the milieu within an ecosystem that is the organism's interpretation of the environment (Campbell *et al.* 2019: 372; Berque 2016: 31). Referring to the model in fig. 1, the preconditions of the architectural affordances in the user's living space creates an inferential reasoning on what is provided for the perceptual psychology affordances within the dicent user's living space.

Gibson's stance on affordances is that it dichotomously points to the environment and to the observer (1986: 129), this notion implies that an affordance is visually perceived and influenced by an organism's behavior within their ecological reality. Also, W. Luke Windsor supports Gibson's ecological role of affordances that signs cannot be perceived in isolation from their context and "affordances are perceived according to the attentional focus of the organism" (2004:184). In the same vein, a user who needs to open a corked wine bottle but lacks a corkscrew must be resourceful and search for feasible tools in their environment to afford the bottle to be opened (*e.g.*, a shoe and a floor, a lighter, or even a knife). "Each user of a tool may discover novel affordances […] but such novelty is constrained by the social connections between individuals as much as by the structure of an individual artefact or utterance" (*ibid.*, 187).

From a psychological perspective, research by Ellen Skinner (1996) has shown that the sense of being in control plays an important role for humans, and Zimmermann *et al.* (2019:

205) note that smart homes should provide users the sense of being in control over the system. Additionally, Jeremiah Still and Veronica Dark (2013) form the notion that perceived affordances are automatically processed and that the perceiving of an affordance does not orient attention or require significant conscious awareness. This notion of automatically responding to a perceived affordance is in-line with Peirce's stance that a logical analysis is unnecessary within the perceptual field since perception is a "subconscious process" (CP 5.185). For example, research by Adam Fetterman *et al.* (2014) found that the preference to see the color red increased when interpersonal hostile conflicts arose, and hostile participants had the perceptual bias to see red more frequently than non-hostile participants.

The presupposition from perceptual psychology affordances to content programming is a precondition that relates to a user's perception on *how* artifacts function. In this sense, perception is mediated through a mental representation that does not require the user to actively seek the affordances with an artifact, the content that is programmed into the smart home system by the user is preconditioned by the user's perceptual field.

2.4. Human-Computer Interaction Affordances

The next section of affordances found within a smart home focuses on Donald Norman's design concept of human-computer interaction, this section is devoted to how a user finds meaning during interaction with a technological object. For Norman, the notion of affordances is entirely dependent on the competence and capability of the actor to interpret the form of an object in relation to a certain function (Baber 2018: 2; Campbell *et al.* 2019: 364-365). Also, Cho and Choi mention how Norman's take on affordances is applied in the field of design, specifically for the enhancement of user experience (UX) for human-computer interaction (HCI), this allows the user of an artifact to interpret which features of the object are correct for their desired action (2020: 2). Comparisons between Norman and Gibson's stance of affordances are discussed by Joanna Ho and Wayne Ho (2000:181), along with Chris Baber (2018:2) by noting, Norman suggests that affordances are the active process of extracting features to construct meaning of perceived properties, which may not actually exist, and Gibson has the concept that affordances are action possibilities in the environment in relation to action capabilities of an actor that is sensitive to information. In this sense, Gibson's concept of affordances focuses on what ecologically rich objects within the environment stimulates a user's perception, as opposed to Norman's stance that focuses on how an object is interpreted by an actor to have a set of designed features that create affordances. Additionally, in the field of design, Norman (1999) formed the concept that affordances can either be depicted as real or perceived affordances. Cho and Choi state, "real affordances refer to the physical characteristics of an object that help a user perform an action, while perceived affordances provide external clues that help a user recognize an object and determine its action" (2020: 4-5). For example, many smart phones include a home button that is located below the screen, which can be used to turn on the phone or to return to the home screen, this can be viewed as a real affordance. On the other hand, a perceived affordance would consist of a smart phone emitting a blinking light to signify a notification for an app. For this example of perceived affordance, the blinking light acts as an indexical sign for the user since it catches their attention and is existential from the actual object that is being signified. The blinking light emitted from the phone is then perceived by the user and generates the perceived affordance that the user has a low battery, a text message, an email, or an in-app notification. Product designers for a smart phone can utilize various colors of the blinking light to generate conventions for different perceived affordances, such as red a light that signifies low battery, green as an unseen message or call, and blue as an in-app notification.

Based off Norman's concept of affordances, H. Rex Hartson (2003) defines how interactive design affordances can be separated in four categories: cognitive, physical, functional, and sensory.

Hartson's (2003) Four Interactive Affordances		
Category	***Role***	***Example***
Cognitive	To enable intuitive prediction of how a task is performed	The interface of the door lock displaying the digits to unlock the door
Physical	To easily perform physical actions	Unlocking the door by various modes: fingerprint, smart phone, 4-digit combination, or with a key
Functional	To increase accessibility to perform a desired task	Easy assembly; changing the pattern for the digits shown on the interface; sharing an "eKey" with guests
Sensory	To perceive stimulus by seeing, hearing, or feeling	Notification via connected smart phone when someone opens or unlocks the door

Table 1. Categorization of interactive affordances and example of Smartly Door Lock

Product designers for a smart home environment can integrate these four categories to generate more subcategories and affordances designed into the object. On the other hand, the user being able to understand the various subsystems associated with a smart device will lead to discovering greater meanings and affordances in the smart home.

Cognitive affordances provide visual clues that enable intuitive prediction of a how a task is performed (Cho, Choi 2020: 6). The example in the previous paragraph of the blinking light on the smart phone requires the user's cognition to perceive there is an action required, whether that means charging the phone or reading a new message. Additionally, the mobile app for a smart home control system uses icons and text to signify the various appliances within the home. Research by Hannah Alvarez (2015) shows that interpretations of labeled icons were 88% correct to predict the function, unlabeled icons were perceived 60% as the predicted function, and unique icons without supporting text were 34% correct to predict the function. From a semiotic perspective, this means that iconicity plus the supporting symbolic convention of the linguistic sign generates the most correct, predictable behavior. Using icons in an app that are unique and abstract without the support of a linguistic sign can be deemed as an artistic text since the user lacks the prior cognition on what the icon represents.

Hartson's categorization of physical affordances is in line with product design affordances that is mentioned in section 2.2., since it relies on the artifact's physical characteristics. Physical affordances refer to a design that easily allows a user to perform physical actions (Cho, Choi 2020: 6). Cho and Choi provide insight on improving the physical affordances for artifact such as a smart home controller, which includes the integration of multimodality in the product design, the ability to control the device with few simple actions and provide a Home button on the wall pad to reduce work steps (*ibid*., 16). These suggestions would best suit a smart device like Brilliant's All-in-One Smart Home Control[9], because this artifact relies mainly on physical affordances to generate a user interaction. This smart controller replaces the traditional light switch that is found in a home and provides the user with a multimodal design to control the dimmability of up to four lights (depending on the model

[9] https://www.brilliant.tech/products/brilliant-control-two-switch-smart-lighting-smart-home-control?variant=white

variation) while also affording to control all the smart devices within the home's smart environment. Additionally, this smart controller utilizes the cognitive affordances listed in the previous paragraph by depicting icons with supportive labels on the touchscreen interface, the interface lacks a Home button but includes a Back button which affords convenience to easily reverse actions for the user if the wrong feature on the display is selected.

The third category for Hartson's stance on interactive design is functional affordances. Functional affordances are design features that increase accessibility to commonly used functions and effectively allow a user to accomplish a desired task (Cho, Choi 2020: 5-6). User customization is one method to increase functional affordances for smart device interfaces, this will let the user define which functions should be given prioritization. Functional affordances can be improved by including accessibility to shortcut buttons, the ability to set customized modes (scenarios) within the indoor environment, allow users to set custom interface preferences (*e.g.*, screen brightness, volume, font, and font size), provide feedback on how to fix an error within the smart environment, and include a Back and Cancel function to reverse actions (*ibid*., 17).

Sensory affordances are the last category for Hartson's interactive design. These refer to a design feature that helps the user perceive some sort of stimuli by means of seeing, hearing, or feeling (Cho, Choi 2020: 6). This category of affordances for interactive design enhances the perceptual awareness for a user, which is related to section 2.3. of perceptual psychology affordances. Product designers that utilize sensory affordances can improve the affordances of aesthetics and notifications. Regarding aesthetics as an affordance, recommendations for sensory affordances include to avoid decorative fonts, to refrain from using more than four colors on one screen, to apply a color with high visibility to signify danger or an error and include buttons for emergency functions that should be distinguished from other noticeable functions (*ibid.*, 18).

I will now go over a specific example of a smart door lock, specifically the Lockly Secure Plus model with a latch[10]. This specific type of smart lock contains the same affordances that would be found for a typical door lock, the smart lock affords the latch to be pushed, affords unlocking with a mechanical key, affords security from unwanted visitors, affords easy

[10] https://lockly.com/products/lockly-secure-advanced-smart-lock-door?variant=21228386910267

assembly for the installer, and affords the conventional characteristics for the aesthetics of a door lock. However, this smart device includes several affordances related to Hartson's four categories of interactive design due to its integrated technologies, such as affording notification to a connected smart phone when someone opens the door, multimodal access, power, connectivity with other artifacts in the home's ecosystem, Bluetooth connection, remote accessibility, automated locking, and unique codes as temporary access for visitors. Lockly patented a security feature that alters the numerical pattern each time a combination is entered by a user on the door lock, this feature makes guessing the four-digit combination an almost unsolvable task for intruders; a tactile interface leaves behind traces of the most commonly used parts of the screen due to oil of a user's skin, in this sense, pattern recognition can be considered an interactive cognitive affordance that can be used by an intruder to intuitively guess the door code, Lockly's integration of this technology is a functional HCI affordance to reduce the possibility of an unwanted visitor guessing the door code. This smart device is an ideal example of how an ordinary object found within a home can integrate new technologies that can enhance cognitive, physical, functional, and sensory affordances.

2.5. Automated Function Affordances

Home automations in today's era are increasing in their complexity which is partly due to the diversity of smart devices offered in the consumer market, along with the compatibility of the smart home controller being able to connect and interact with various devices on the home's network. As previously discussed in the research (section 2.), subsystems of affordances lead to higher-level subsystems of affordances, and regarding a smart home, the automated function affordances are the higher-level affordance subsystem that is constructed and scaffolded by the individual artifacts connected to the home's network, and with every new smart device connected to the smart home system constructs and "introduces new sign and sign systems in its user's universe" (de Souza 2005: 318). The smart home itself is an object, but the system of the home comes into existence and emerges with the integration of various smart devices that are connected on the system using a technological network. Thus, the individual who wants to improve their subjective quality on what their smart home affords is determined by what smart devices are integrated, and by how the devices are appropriated to function and interact with other smart devices within the smart home.

The active and passive devices integrated within a home lead to home automations, both types of devices are artifacts, and the meaning given to an artifact "is intrinsically related to both the creator's intent and to its users' interpretation of how, when and where it can be used" (de Souza 2005: 319). Automated functions for artifacts connected on the smart home system require the user to input commands into the controller of the home, this is where the rules and exceptions are defined for the automated protocols. Defining the exceptions for specific automated protocols affords an override of the automated function. For example, if the smart vacuum is programmed to automatically start a cleaning routine once the inhabitant's smart phones are disconnected from the home's network, then this can cause an inconvenience if by chance someone is still in the house, such as a babysitter watching a child or guests staying at the house while the owners are gone. So, to override the automated protocols when the owners are away there should be exceptions defined within the home's controller to let the babysitter or guests to be in some form of control over the home's automation. This can easily be solved by including a smart switch in the home when the limited access user (babysitter or guest) can press the switch to signal the home's system to not run certain automations. Pressing the switch to define which type of limited access user is inside the home affords the automations designed for the specific type of limited user – *e.g.*, the homeowner may want to record visual footage of the living room and the child's bedroom when the babysitter is watching the child, as opposed to the owner may want to exclude visual footage of the living room and the child's bedroom when guests are selected on the designated smart switch.

Automated functions for a cloud-based smart home rely on the user's inputted commands and exceptions into the smart home controller, the former can be viewed as an inclusion of interrelations between a smart device and a certain signal, and the latter is a defined exclusion which causes the automated function to not proceed. Artifacts have an intrinsic intellectual dimension and "the utility of intellectual artifacts is determined by the user's ability to master the linguistic encoding of problem and solution [...]" (de Souza 2005: 322), which pertains to how a user configuring home automations must understand how to identify the problems and solutions needed to construct successful automated functions within the home system. Automated lighting is a common function within a smart home, but this type of automation can greatly vary due to the user's lighting preferences, quantity of smart lights, quantity of passive devices to generate information that can be synced for the automation, and the user's competence on how to properly define the affordance level of automated lighting. To further elaborate on the complexity of a user defining automated lighting, I will discuss an automated function that concerns the smart lights automatically turning on when motion is detected. For this form of automation to occur there must be smart motion sensors in a fixed location within the home that can detect movement. The motion sensors placed within the home can be programmed to connect to specific smart lights, such as the motion sensor in the foyer can signal the light inside the entrance of the front door to turn on, or the motion sensor located in the living room can be connected to a user-defined accumulation of smart lights. So, the smart sensor that registers movement will signal the automated function for the connected smart lights. To take it one step further in the automated functions, the administrative user can define the brightness of lights during the automation by including the time of day that is known by the smart home system. Therefore, a user can program the automated light function at full brightness during certain times of the day and have reduced brightness for certain times as well. Additionally, as an exception programmed into the automated function, if the lamp with a smart light in the living room is on, then there is not a need for light to automatically turn on, which means the automation does not proceed.

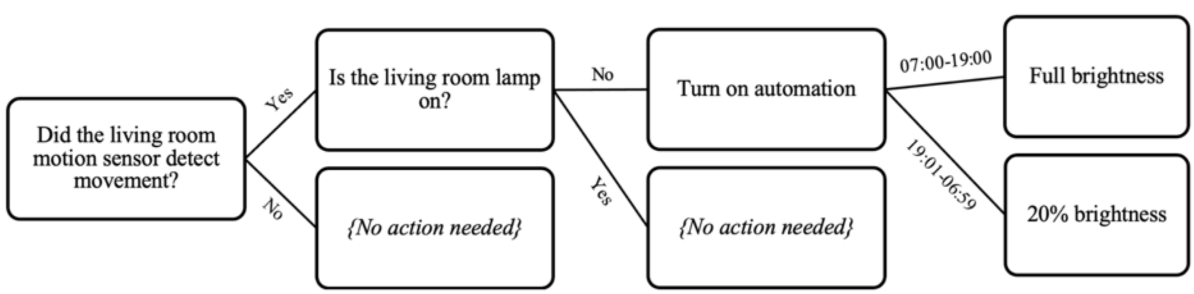

Figure 2. Example of automated lighting function using motion and a timestamp

This example highlights the complexity and systematical variables associated with a common household routine such as turning on a light. Rather than relying on the affordance of pushing a switch on a wall to turn on or off the lights, the integration and utilization of home automations greatly vary depending on the user's goals, the resources provided to attain the specific goal, and the user's competence on how to afford the defined future behavior with an object. As with any new technology, there is always a learning curve that the user is faced with, a novice user with little experience in computer programming should begin with simple home automations before more complex automations are scaffolded. Concerning semiosis, the smart home system does not possess unlimited semiosis as a biological organism would, "the human interpretive process, also called unlimited semiosis, cannot be modeled by algorithms for lack of precisely definable halting conditions" (de Souza 2005: 325). In turn, what a smart home system does possess is the capability of limited semiosis, because computer artifacts rely on algorithmic interpretations of symbols that is a part of the designer's semiosis (*ibid.*, 326). Therefore, a user appropriating and scaffolding smart home technology into their living space is reliant on the designer's semiosis to communicate with the dicent user.

Regarding a smart home system with artificial intelligence, artificial neural models can be designed into the system to construct automated functions, which means that the integration of AI would exist in the automated function affordances for a smart home system. As Xu *et al.* states, "acquiring user demands is the beginning of all automation and intelligent management. […] How to acquire user demands non inductively is the very first problem that should be studied for a smart home platform" (2016: 119). The notion of intelligence and knowing is essential for an artificial intelligent system because it relies on the user knowing how to integrate automated functions into the system and allowing the AI-enabled devices to respond to the proper signals, which is a process of semiotic scaffolding and is elaborated in the third section of the research. Xu *et al.* (2016: 120) provide a detailed explanation about the algorithmic process of AI of smart homes as followed:

> Artificial Intelligent Decision Algorithm: Currently, the controls of smart home devices are almost all based on scheduled rules, which have little flexibility and high complexity, and users cannot obtain a comfortable and convenient smart home service. With the continuous progress of deep learning and neural networks, artificial intelligence (AI) can constantly learn users' living habits without any artificial rules and then provide an automatic smart home service with continuous improvements. The real smart home will be reflected mainly in automation control and man-machine interaction by using AI technology. […] An AI-based decision algorithm requires a data set as a training set to gain intelligent decision ability. Software defined smart home (SDSH) can get data from various heterogenous devices and provide a basic data set for the smart home control. (Xu *et al.* 2016: 120)

This statement identifies the overall aspects related to the sign processes and requirements for artificial intelligence of a smart home to generate home automations rather than purely relying on the user inputting scheduled rules. The mention of scheduled rules is associated with a signal from one device that is communicated to another smart device in the smart home's system, this requires user appropriation to define automated functions within the home environment, and the home system undergoes methods of inductive or deductive logic with the data inputted into the system's knowledge set. Xu *et al.* (2016: 120) point out that neural networks are integrated into the system's data set by the programmer, and currently, there is still not a universal data model to formally describe the monitoring data of the smart home.

3. SEMIOTIC APPROACH FOR UNDERSTANDING SMART HOMES

The systems of affordances that can exist in a smart home is a dynamic model that utilizes semiotics to further understand how affordances can exist for a future behavior. The semiotic model used in this paper will be what is explained by Campbell *et al.* (2019) that semiosis is framed by resources, competence, affordances, and scaffolding. Additionally, using the concept of semiotic fitting will specify how the smart home system, users and devices generate semiosis. This thesis emphasizes three relations of affordances that exist within the concept of a smart home, which includes the relation between the creator/designer of a smart home and the affordances designed into a smart object, an agent (artifact or user) that generates a relation with a smart object within the smart home, and lastly, the smart home system that affords automated functionality by relying on the semiotic components of the user and creator. These three different relations are interconnected to create a complex model based around the concept of affordances. Designers of smart home technology can get a better understanding on where the fundamental issues exist, and from a semiotic perspective it can be identified if the issues are related to the architectural language, the product's design, or how the user appropriates affordances within the smart home system.

As Vyacheslav Ivanov mentions, "semiotic modeling systems form complex hierarchical series of levels where the system on the lowest level serves to codify the signs which enter into the systems at a higher level" (1978: 201). In this sense, the potential affordances engineered into a smart object are then appropriated by the user to define user-artifact behaviors within an environment, and if the environment affords an artificial intelligent system, then there exists a mediation for the codified signs from the lower hierarchical levels of the smart home model.

Each artifact has its own set of affordances in relation to an agent, and the smart home system is a conglomeration of affordances that exists on a higher-level system of affordances that is bounded by the ecological reality within the home's architectural affordances. Meaning that affordances of the smart devices within the home's system create subsystems for the entirety of the home's system, and a home that has smart appliances or devices integrated into the architectural affordances can expand the semiotic resources for the higher-level system of affordances. What begins as a conceptual framework becomes designed and programmed into products, then integrated into the user's habits and needs, which, in turn, alters the overall system's affordance structure.

Artificial neural models rely on a knowledge base built from semiotic activity, whether that is constructed by the programmer or customized by the end-user. Overtime, the AI affordances will adapt to a user-scaffolded, desired behavior of the smart home's current state. This allows the home's system to make the proper choice, semiotic fitting, on which action to pursue. Reliability is a low-level affordance within the system of AI affordances, meaning that the AI system's semiotic fitting should afford reliability for the user, then by improving the lower-level affordances of AI the system can create new higher-level affordances.

3.1. The fitting of smart home technology in a semiotic and ecological sense

Semiotically engineering a smart home modeling system enhances the relations of affordance systems and can trans-mutate the epistemic values that are experienced within the home. Peirce states, "semiotics is the epistemic logic representing our confrontation in reality; it is the methodeutic of all our true representations of external reality" (*EP*: 136-137). Affordances in architecture and product design utilize the prior knowledge on how a user interacts with an object but the design affordances also require predicting a subject's future behavior with the artifact. Furthermore, the affordances perceived by the user in a smart home requires a level of knowledge and competence to program smart technology into the home's ecosystem to appropriate a defined systematical behavior. It should also be noted that smart objects that are a new product-line or technology will require more appropriation since the smart object has to be learned from the bottom-up, because the user's construction of semiotic activity will adjust the semiotic components on what the object offers (*e.g.*, Samsung's Bot Handy[11],

[11] https://www.cnet.com/home/smart-home/samsung-ces-2021-robots-will-clean-your-house-and-pour-you-a-glass-of-wine/

which is currently in the conceptual stage, is designed to be a robotic butler that affords putting away dirty clothes and dishes, and even pouring glasses of wine).

The design stage and user-appropriation for a smart object is in line with the concept of semiotic fitting. Semiotic fitting is the agent's capacity for making and preserving the local semiotic bonds, meaning the agent's functional or communicational match with its surrounding (Kull 2020: 9). This definition of semiotic fitting can be easily elaborated how a product designer must keep in mind who the rhematic user is.

For example, a conceptualized smart appliance that is intended for senior citizens must afford an intuitive design for user configuration and diagnosis. If the smart appliance is deemed too complicated for installation or repair, then the elderly user requires the affordance of third-party technician (a service user). Subsequently, the formation of semiotic fitting would be potentially limited for the elderly user due to their lack of functional and communicational bonds with the smart appliance.

Another aspect that relates to affordances of a smart home is the concept of ecological fitting, this is when an organism searches and finds what fits them by using the mechanism of choice and learning, which, in turn, means it is a semiotic mechanism (Kull 2020: 15). An example of ecological fitting is a consumer searching for which smart devices can increase the ecological value of their home. If a consumer has a need to increase security of the home, then the consumer will actively seek for the appropriate device that best suits their need. The affordances associated with the product help determine the consumer's potential value of the object, such as the commonly identified affordances of cost, durability, longevity, security, and compatibility. This decision-making process is a choice that the consumer must undergo to improve the ecological qualities in the home. Kull states, "choice is an aspect of semiosis, or interpretation, and learning is the corresponding change in memory as a result of semiosis" (*ibid.*, 15). One critical factor concerning the ecological reality of a smart home is the dicent user's brand loyalty, although brand loyalty is within the scope of marketing and commodification, brand loyalty still serves as a critical factor due to the user being familiar on how the devices function, and the choice of staying with one specific brand could potentially lead to the affordance of synchronicity amongst the devices within the smart home. The user has previously learned how to interact with a certain brand's interface, which could afford a level of comfort knowing what is expected from integrating a new device into their home.

3.1.1. Mediation of signs

The mediation of a sign is the relation formed between a subject and an object within a given environment. As Nöth notes, semiosis for Peirce is a process of mediation that provides the semiotic bridge between constructivism and objectivism since it gives a mediating account of the relation between a subject and an object in their *umwelten* (2001: 697-698). To elaborate more on this notion of mediation being a link to semiosis, Stéphanie Matthews mentions that "the ability to share, store, and recall the various signs that allow us to relate to welts, seem to be at the helm of semiosis" (2016: 7). Mediation for agents, whether they are biological or artificial, require the three major processes of sensing, planning (reasoning), and acting to attain semiotic activity (Horton *et al.* 2012). In addition, Matthews states, "mediation of signs is where semiosis lies, and semiosis is the product of an exapted co-relation of semiotic activity. The inner structures built to represent the outer structures are mutable and plastic and [...] so are the models that are to be constructed" (2016: 7). In this sense, the exapted co-relation between a subject and an object generate new affordances by the means of mediation. Thus, the mediation of a sign grounds the current semiotic activity which orients future behavior within the given environment.

In this perspective, it should be seen that the mediations related to the designer's concept, the consumer's needs, and the artificial neural model that controls the smart home are plastic and malleable. Mediation exists on all relations found within the smart home, which this research specifically focuses on the relations of the product designer and the rhematic user, the programmer and the smart home system, and the smart home system and the dicent user. If the smart home has an artificial neural network, then the line weights that define the meanings between the input and output can alter overtime, which makes the mediation of the sign plastic since the neural network positions itself accordingly. Additionally, the consumer needs are malleable to the affordances perceived while shopping for the most appropriate smart devices to purchase to improve their home environment. After a smart device is purchased, it must undergo the process of semiotic fitting, in this sense, the newly purchased smart device affords voice commands, which was the target affordance for the purchaser. Take for example a smart voice assistant purchased as a gift to the elder of the house and was purchased with the idea help the target user adjust the smart lights in their bedroom. If the smart voice assistant does not generate any meaning-making in the target user's ecological niche, then hypothetically, the voice assistant could be appropriated by another inhabitant in the house who should be more active in their lifestyle but has the target affordance of convenience. The example highlights how a consumer perceived a positive affordance for the target end-user, but a mediation occurred when the target end-user rejects the appropriation of the smart voice assistant, and the voice assistant is then appropriated to be more functional in another room of the house. Relocating a smart device to a different location of the living environment will cause new forms of meaning to emerge, and as mentioned in the example above, could potentially lead to generating negative affordances for specific users who interact with the device (*i.e.*, the elderly rhematic user who was intended to afford a convenient way to adjust the lights in their bedroom, and the sedentary dicent user who affords mobility).

3.1.2. Semiotic freedom

This subsection examines semiotic freedom, which is related to function of choice and the process of learning. As already mentioned, semiotic fitting and mediation relies on a construction for meaning to be bonded with an agent's relation to an object, there must exist a constrain or binding to limit the meaning of a sign. However, semiotic freedom allows for the unfolding of a constraint, this is because sign relations are arbitrary, but their freedom is limited by fitting (Kull 2020: 16). In other words, the freedom of a sign's mediation is constrained by semiotic fitting. "Signs have always been negotiable and malleable" (Matthews 2016: 11) and this negotiation is constrained by the forces against semiotic freedom, which refers "to the complexity of choice an organism has for channeling learning in a way that sustains meaningful relationships with its umwelt" (Campbell *et al*. 2019: 372). Nevertheless, to harness a meaning with a model or a sign there must be a mediation on what the sign stands for, in this matter the performance of semiotic fitting utilizes the agent's ability to choose and to learn what the object represents. For example, a smart home system is constrained by what artifacts exist within the ecosystem, along with how the user defines what automations the system should remember.

The vagueness on what a smart home represents is what makes this object rich, individuals can identify various affordances on what a smart home could possess, whether that affordance is a higher level of security, an increase in leisure, and even the affordance to reduce the miniscule habitual tasks that the individual may perform (*e.g.*, seeing who is at the door, turning on a light, adjusting the thermostat, seeing if the water heater is leaking, learning a new recipe, and so on). In this sense, the choices the consumer makes and what they learn to do with their smart devices in the smart home is because of semiotic fitting, the role of semiotic freedom is a sign's unbounded tethering that has not yet been mediated. Robert Innis mentions that perception is embodied in language, while language is embodied in perception (2002: 50). Therefore, what lies outside of the embodiment can be viewed as the freedom that has not yet been constrained to an agent's perception.

3.2. Semiotic activity in the perspectives of the creator, user, and smart home system

In order to thoroughly explore the ways in which affordances come to existence within a smart home, using a semiotic model provides the essential components on how a mediation from one relation leads to semiotic activity of other relations within the smart home. For Campbell *et al.* (2019: 356), signs are qualitative semiotic units that dynamically change and grow, and refer to the meaningful relationships that sustain, enable and constrain the organism's interactions. Furthermore, the dynamic changing and growing relationships with a sign is viewed as semiosis, and "as the basic meaning-making process grounds learning and knowing" (*ibid.*, 374). This research investigates the semiotic activity regarding the creator (architect, product designer, software engineer), a user, and the smart home system, each of these three sources undergo semiotic activity within a smart home when they come in relation with a sign that exists inside of this environment. For example, the user who defines the home's automation function relies on competence to understand and choose which devices should provide an automated function during the user's customized daily morning routine. Additionally, the smart device programmed to exhibit certain functions rely on the home's modelling system to transfer the essential information for the desired action to occur. In retrospection, the programmer of the smart device must integrate product characteristics to become affordances with an agent – this can include the smart lights in the kitchen having the affordance of compatibility with the smart home's controller or a smart device affording the multimodal interface of mechanistic access, such as allowing the user to physically turn on the smart light in case the light loses access to the cloud server and cannot function. This transferring of semiotic activity is due to the role of semiosis and is linked to the sign's ability of being interpretable, shared, and carry meaningful content in relation to specific context (Matthews 2016). Therefore, the semiotic activity at the lower-level system of affordances for a smart home model influences and stores meaning for the higher-level affordances.

3.2.1. Resources

The following four subsections examines each individual semiotic component in relation to the perspectives of the creator, the user, and the smart home system. Providing insight from each of the three perspectives is intended to give detail on the meaning-making process and to show that by strengthening the semiotic components from each perspective (creator, user, and system) the entirety of the model constructed for this research can be semiotically scaffolded to lead to a techno-semiotic revolution for smart home technology.

Various forms of text for the user act as a resource, such as product tutorials, product reviews, and third-party websites to configure home automations[12] can allow a rhematic or dicent user to learn and explore how a smart device functions and how the device can be utilized within a smart home environment. The conventions that exist with the 'old' technology, such as using the mechanistic component in a smart door lock, will allow the user to understand the denotative function of the device, while at the same time, the affordance of multimodality

[12] https://www.home-assistant.io

designed into the smart lock will lead the user to discover new ways to lock or unlock the door. Additionally, interactive affordances (see section 2.4.) designed into a product provide human-computer interaction affordances for the dicent user that allows a clearer understanding on what functions are possible with the smart device. Interactive affordances utilize cognitive, physical, functional, and sensory affordances built into the object's characteristics offers the user to discover new methods of affording situations with the object.

Resources from the creator's perspective generates semiosis to help define who the potential rhematic user is, while also getting additional insight on how the dicent user interacts with the product. A creator can learn from current market trends to design products with certain, desired affordances. For example, the global pandemic of COVID-19 has affected several sociocultural conventions, but in the context of this research, the pandemic has influenced the creation of smart home products to combat the potential risk of spreading the virus within the living environment. For example, the startup company Ettie, a doorbell manufacturer, is designing a doorbell[13] that can read a visitor's temperature when they come near the vicinity of the door. Besides this revolutionary doorbell, there is a significant amount of smart home products designed to reduce or eliminate the spread of the virus within the living space, these devices range from touchless sinks and toilets, refrigerators with a water dispenser that undergoes UV sterilization, and UV air filtration and purification units that autonomously move around the home. It should be noted that a creator's semiotic resource can in fact transition into a user's semiotic resource (learning if the visitor at the door shows potential signs of COVID-19), and this is due to semiotic scaffolding which will be discussed in section in 3.2.4.

Concerning product design affordances, a creator can utilize the Affordance Structure Matrix (ASM) during the conceptual and design stage for a product (see Maier *et al.* 2009). This tool can be used to define what negative and positive affordances exist within the various subsystems of a product. As mentioned in section 2.2., the product designer should aim to improve positive affordances (*e.g.*, reliability) while reducing the number of negative affordances (*e.g.*, hackability) that exist within a product. A creator can revise a product's ASM during the various conceptual and design stages of a product, and a product's ASM can also be reviewed once the product is on the market so future generations of the product can be improved

[13] https://www.techhive.com/article/3603470/ettie-video-doorbell-takes-your-temperature.html

to semiotically fit the user's connotative, open secondary functions. Additionally, creators should aim to potentially include multimodal interfaces in a smart device, by doing so, a semiotic bridge is established which retains prior conventions of a household good (see section 1.1.1. and physical affordances in section 2.4.).

From the perspective of a smart home system, the quantity of users and smart devices (active and passive) on the home's network can be viewed as resources for the system of the home. The data collected and shared from the home's technological ecosystem allows for a deeper understanding on the meaning-making components within the home. This can include discovering which parts of the living environment use the most electricity, and at what times of the day the most energy consumption occurs. System resources can also help define how frequent the individual smart device and appliances are used, which could help educate the inhabitant if a certain smart object is not being efficiently utilized.

3.2.2. Competence

As discussed in section 1.2.3. of the research, a user's competence on how to effectively appropriate a smart device into a smart home system is a current challenge with this technology. Campbell *et al.* (2019: 358) state, "from a semiotic perspective, resources and competences are complementary and inseparable concepts." Therefore, the inclusion of semiotic resources that exist for smart home technology subsequently increase the level of competence for the user, creator, and smart home system.

A user must have competence to understand the purpose of appropriating a specific smart device into their living environment, as well as elaborating on how the user must be educated enough to program and define the product's function within the home's network. Competence from the user's perspective also includes if the user is aware that they lack the skills needed to install and program the device and if they will require a service user who can successfully install the device. The rhematic user should ask themselves, *what* would I use this device for in my home? – *e.g.*, is it to afford an overall increase in leisure or convenience, to afford more of an understanding on energy consumption within my home, to afford increased security measures to make sure my delivery packages are not stolen outside the front door, to afford bragging rights to an audience of the futuristic home automations that can occur by the press of a button on a wall, and so on. From the rhematic user perspective, it is essential to have a form of competence on what the intention for having smart home technology should provide. Additionally, the rhematic user should have competence on lower-level affordances to use the device in their home, this can include understanding that a monthly subscription is required to store the video surveillance footage, and even the understanding if the smart device is compatible with the smart home's controller.

The dicent user of smart home technology must have a level of competence to answer the question of, *how* do I install, define automations, and utilize the various functions that exist in relation to the smart device and the smart home system? For example, there may be a basic understanding of knowing that the newly purchased smart washer requires a technician, but competence is needed to learn how to reduce energy costs with the machine and even how to schedule washes via smart phone. Dicent users should utilize the semiotic resources available to improve their competence on how to improve the potential interactions with the smart device, this allows for optimizing what the device has to offer and will provide the user with a deeper meaning on the applicability of owning smart home devices and appliances.

Competence for a creator pertains to understanding who the rhematic user is and how the product can undergo semiotic fitting from the rhematic user's perspective. This means that the creator must be aware on who the product is intended for; the characteristics of the rhematic user provides insight on what affordances should exist within the product design. To elaborate more on the example in section 3.1. of a senior citizen semiotically fitting a smart device, the creator should conceptualize how the specified rhematic user will appropriate the technology into their living space – *e.g.*, will the senior citizen rely on a technician or even their grandchildren to show them how to use the smart device, or are they expected to already know how to use the device? Additionally, competence from the creator's perspective should aim to better serve the users' semiotic resources, this will provide the means for rhematic and dicent users to learn and discover new functions that can potentially be used with the device. Also, the interactive affordances designed into a device correlates to the creator's competence on who the rhematic user is, this can range from allowing the customization of font and icon size for users who are visually impaired, the weight of the product not becoming a burden for a user trying to hold the device, and easy to find troubleshooting features to help educate the user on how to properly use the device. Even though these recommendations are aimed at a smart device, rather than the system itself, it is important to reiterate that a user interacts with the smart home system by using a smart device within the home's technological ecosystem, therefore, in order to improve the overall system a creator should aim to educate how the individual smart device or appliance functions, because each smart object with their own affordance are a congruent which constructs the higher-level affordances of the smart home system.

Regarding the competence for a smart home system, the system should be able to identify which type, or even which user, is interacting with the home system. As discussed in section 1.2.3., I have defined three types of dicent users: administrative, limited, and service users. The system should have a level of competence to differentiate between each individual type of user, additionally, administrative users can define in the home's system parts of the home that should be inaccessible to make systematical changes to the system (*i.e.*, the homeowner can define one central location of the home that can afford configuring the home automations, such as the office or living room).

Currently, some of the newer generations of Amazon's smart voice assistants can differentiate between an adult or child communicating with the device by the audible pitch frequency of the user. If the voice assistant identifies the pitch falling into the parameters of a child, then the device will generate a response designed for a child – this aspect of system competence is a prominent factor for data and privacy regulation since applications on the smart voice assistant that uses child-directed skills cannot promote content or collect data on this certain type of user (more information regarding the regulations can be found on Amazon Developers site[14]). While on the topic for voice recognition of a certain type of user, it has been overlooked from the industry perspective of the implications of mimetic speech, such as a parrot communicating to a voice-enabled device. A parrot who has the competence on how to command the smart voice assistant can instruct the device to turn on/off the lights in the room,

[14] https://developer.amazon.com/en-US/docs/alexa/custom-skills/policy-testing-for-an-alexa-skill.html#cert-child-directed

add products to an online shopping list, and any other command the animal might have heard their owner say to the smart device. So, even though the phenomenon of a parrot ordering products via a smart voice assistant may be a miniscule amount on who the dicent user of the device is, this predicament is associated with a level of competence that exists for the smart device and the smart home system.

3.2.3. Affordances

The entirety of section 2. discusses the various systems of affordances that can exist within a smart home system, this subsection is intended to provide insight from the perspectives of the user, creator, and system, rather than elaborating on the affordance systems. Being that affordances are created from lower-level subsystem affordances, it is important to review how affordances from each of the three perspectives can enhance the overall smart home system.

Beginning with the creator's perspective, affordances relate to how future users would semiotically fit the smart object into their unique living space, creators must be open-minded that a user may interact with their product in a way that was not intentionally designed for (see section 2.1. on Eco's open secondary function of an object, and the example in section 2.3. of using a tool to open a wine bottle). Predicting the future behavior of the rhematic user in relation to the designed product is a crucial component that the creator must understand the high-level affordances that are constructed by the user.

During the conceptual stage of creation, the creator should aim to define who the rhematic user is. This includes the creator having the competence on identifying not only the demographics of the rhematic user, but understanding the cultural conventions associated with certain household goods and IoT devices. For example, within the European Union, Germany has recently made significant efforts to integrate smart metering and tariffs by offering smart appliances offered in the consumer market, however, the rhematic user not seeing a feasible reward to appropriate this technology is still viewed as a negative affordance by the rhematic user (Wilson *et al.* 2017). Additionally, the creator must take into consideration the cultural affordances of the designed object, meaning the creator should understand the cultural conventions of the object in relation to the culture within a certain environment. One unique example of cultural affordances not applied to architectural theory is the short-lived public housing development of Pruitt-Igoe in St. Louis, Missouri. Three of the Pruitt-Igoe high-rises were demolished after 18 years of being constructed, there were flaws in the design stage that included long corridors with insufficient lighting and inoperable elevators which led to sociocultural issues that resulted in an increase of crime within the housing development. "The building achieved its intended affordances of providing high density, inexpensive housing. Its failure was due to the multiple macro-scale unintended negative affordances that resulted in such bad actual living conditions" (Maier, Fadel 2009a: 399). This statement is in-line with the architectural and product design affordances mentioned in sections 2.1. and 2.2., along with the previous paragraph on how a creator must afford predicting the future user's behavior with the object.

Regarding the creator's perspective in the design stage of a product or smart home system, the creator should aim to increase the amount of semiotic freedom that exists for the smart device, this includes relations between the user and the smart object, and the smart object and the smart home system. This approach relies on the resources integrated into the object as well as the level of competence of the user or system. Semiotic freedom designed into a product can range from the affordance of a customizable interface for the home's controller, a doorbell affording a customizable sound rather than the traditional chime associated with ringing a doorbell, using internal servers and solar energy on the smart home's energy grid to mine cryptocurrency, and any other device function or feature that is decided upon by a user's choice and is appropriated by the user learning how to define the customized behavior for the product.

One last key takeaway point for the creator's perspective of affordances during the design stage of a product is to reflect on this question that is centered around the affordances of an object, "What does the object *want*?" By answering this question and exploring the various affordances, a creator can get a clearer understanding on what potential action-possibilities are related to the product's perspective and refine what affording situations should exist for the object – *e.g.*, the cup wants to be held in one hand, the ball wants to bounce off a wall, the laptop wants to not break if it falls off a desk, the smart fridge wants to notify the connected smart phone that the fridge door is open, the smart home wants to inform and instruct the user how to resolve a system error, the AI in the home's system wants to recommend the user what to cook based off of the ingredients in the smart fridge, the AI vacuum cleaner wants to notify the smart phone that it is immoveable, and so on. This reflective question can provide sufficient insight for identifying positive or negative affordances that exist as an artifact-user affordance (AUA) or artifact-artifact affordance (AAA).

Now moving onto the user's perspective of affordances, an individual must possess smart devices connected on a network in their living space to have the affordance of a smart home system; a user interacts with the smart home system by the affordances of the smart devices and appliances connected on the system. For example, if a user desires to turn off the smart lights in the living room, then several affordances may exist within the smart home to achieve this task – this can include commanding the nearby voice-enabled device to "turn off living room lights", remotely turn off the lights by using a smart phone or walking to the light switch on the wall to turn off the lights. The decision-making process for a user can greatly vary depending on the current situation within the home (*e.g.*, maybe the user wishes not to perform the affordance of voice command in case the baby in the other room might wake up, maybe the affordance of remote accessibility via smart phone is located in a different room, which, in the examples provided above, would mean that the user would still have to move in order to turn off the lights). This hypothetical situation of a user having the primary task of turning off the living room lights and the desire of not waking up the sleeping baby in the next room is to emphasize that affordances being viewed as potential semiotic resources that an organism enacts (detects, reads, uses, engages) to channel learning-as-choice in its environment (Campbell *et al.* 2019: 367).

Affordances from the perspective of a smart home system rely on the individual technological artifacts that are integrated into the system. This relates to the architectural affordances listed in 2.1. how affordances are a hierarchical construct that is built on the foundation of lower subsystems of affordances. System affordances are processed in a top-down manner, as opposed to the user who integrates the various artifacts into their living space from a bottom-up relation. Some higher-level affordances that can exist due to a smart home system includes home automations, energy reduction, and homeostatic functions (*e.g.*, maintaining a defined temperature or air quality within the home).

3.2.4. Scaffolding

The last semiotic component to discuss is scaffolding. Semiotic scaffolding requires the semiotic activity of learning based off the prior choices made by an organism, which is then oriented by the semiotic activity of learning (Campbell *et al.* 2019: 368-371). Regarding the research, the user and creator individually scaffold meaning with a smart device from their own perspectives, and the user scaffolds meaning and orients the smart home system to perform defined rules and automated functions, but the system itself only possesses limited semiosis as opposed to the creator and user that possess infinite semiosis (see section 2.5.).

Regarding the smart home system and scaffolding, the defined rules and scheduled behaviors of the smart devices connected to the home's system can be viewed as codes since the defined signals are binary, and as Kull mentions, functionality distinguishes scaffolding from codes, because semiotic scaffolding has a supporting task or function, which, in turn, forms habit that results in codes (2014: 116; 2015: 230). Therefore, code plurality is needed for scaffolding to occur since there is a requirement for decision-making and learning from the prior choices made (Kull 2015: 227). In this sense, a smart home system that possesses an artificial neural network has the means for semiotic scaffolding since the artificial neural model can refine the line weights and integrate new connections. Additionally, the system's artificial neural model utilizes memory of the prior events that existed within the home (*e.g.*, using a passive device to record a room's temperature which can be logged and time-stamped in the neural model, or keeping a time-stamped record on when a room within the home consumes electricity), and with the recorded data of a room's temperature and energy consumption the neural model can learn how to reduce the amount of energy used. Thus, an artificial neural network for a smart home system generates the scaffolding of knowing how to be efficient and predictable with a synced smart object within the technological ecosystem, and a system's neural model capable of semiotic scaffolding will be in-line with the user's explicit meanings (in the case of this example, the smart home system learning how to minimize energy consumption).

Scaffolding for a creator can improve qualities designed into the future generations of the smart device or even through software updates for the current product. Also, improvements on how the designed smart device interacts with the other various devices can be scaffolded to generate deeper meanings, subsequently, a creator scaffolding higher-level affordances between two smart devices within a smart home ecosystem will lead to a stronger and a more dynamic smart home system. Creators can also design products to include the semiotic resources for a user, by having competence on who the smart device is being made for the creator can incorporate the proper semiotic components into the object (such as product design and human-computer interaction affordances). To elaborate more on the full scope of scaffolding connected to the four semiotic components, Campbell *et al.* (2019) states:

> As such, semiotic competences are employed to scaffold knowledge, which is to say, to develop models of (aspects of) their environment, which result in a capacity to navigate in the environment. A scaffolding is similar to what it aims to grasp, being deemed a model, because, following this metaphor for learning, it moulds onto it. The erection of new scaffoldings, thus, leads to environmental changes that evoke new semiotic resources. In the scaffolding process, not only organisms change – their environments, too. Thus, as new semiotic resources become available and are used, organisms and environments co-develop. (Campbell *et al.* 2019: 359-360)

In this sense, a creator having the competence of who the rhematic user is can be scaffolded into providing sufficient resources built into the smart product. Then, learning who the dicent user is and how they interact with the product can lead to a better understanding on what high-level affordances are scaffolded from the user's perspective. Lastly, the ways in which the dicent users appropriate and scaffold their smart home system can lead to changing the environment of the home. Technological changes provide the semiotic resources for an inhabitant to alter their living environment (*e.g.*, the invention of the television and the mediation of appropriating this household good into a living room).

Currently, smart home technology has made more of a significant impact on being appropriated into the pre-existent living space, rather than bringing in a new era of architectural forms that are designed around the function of smart home technology. However, there are homes engineered around smart home technology, but this is still a niche industry that varies depending on where the home is located. The semiotic resources for designing and constructing a smart home greatly differs on the location, this can include regulations set in place by the local government, local consumer market of smart household goods, qualified professionals to install the smart home system, the cultural perception of appropriating numerous technological devices within a living environment, a data infrastructure capable of processing a wide range of IoT devices, and last but not least, rhematic users' level of enthusiasm to learn the capabilities of smart home technology that they can personally scaffold into their own living space.

The future of smart home technology could benefit from a generation of do-it-yourself smart household goods. A DIY revolution of smart home technology would increase the semiotic components, especially the users' semiotic competence that pertains to the programming of a device. In turn, the creators of DIY smart devices would have to provide sufficient resources for the quasi-creator (the dicent user assembling and configuring the device), and one fundamental resource to provide the quasi-creator is open-source software. This approach to appropriating open-source software of smart home technology into a living space will allow the user to semiotically scaffold the device to include a fully customizable UI and UX. One of the best examples of a DIY smart device is the smart mirror, if you were to search online 'DIY smart mirror' you would be given hundreds of product tutorials and various communities that discuss how to make your own mirror that can be turned into a central hub for a smart home. The semiotic resources for DIY smart mirrors, such as MagicMirror[15], guides the potential user step-by-step and lists the required components needed to create their own personal smart mirror. Additionally, the online communities surrounded around this smart device can utilize the open-source software and allow others the potential to integrate the specific program features into their own device.

[15] https://docs.magicmirror.builders

4. DISCUSSION

This research is intended to cover a wide scope on the theoretical components that surround the evolving meaning-making process around the creation and functionality for current smart home technology. Affordances are an excellent semiotic component to analyze because of two reasons: 1) a creator of an object must conceptualize how a user in a future state will behave with the object, which is related to Umberto Eco's (1973) denotative and connotative functions of an object; 2) a user must utilize the semiotic substances of learning, memory, and knowing to perceive how to interact with an object, and once the user identifies certain characteristics of the object that creates affordances the interaction with the object does not require a significant amount of consciousness, which means that once affordances are learned they become at the helm of a subconscious process (Still, Dark 2013). Modeling the various systems of affordances that exist within a smart home aimed to provide insight that meaning is interconnected between the creator, user, and the smart home system. Additionally, providing an explanation on the four semiotic components necessary for semiosis that exists within a smart home is to elaborate on how the three perspectives (user, creator, smart home system) utilize resources, competence, affordances, and scaffolding to generate a deeper connection for the technological ecosystem.

Results of this research has found that the four semiotic components exist within the locus of each affordance system. This means that the individual affordance systems can be improved and provide a deeper meaning for the user and creator if the semiotic components are designed specifically for the respective affordance system. For example, a user may have the competence in the human-computer interaction affordances but lacks the competence on knowing how to define automated functions into the smart home system for an aggregation of smart devices. Therefore, the user must seek resources to help educate them on how to scaffold the automated functions into the system, and this is where various forms of texts such as video tutorials or websites can serve as vital resources to make the user's smart home system operate more complex automated functions. Additionally, the results of the research have found that creators of smart home technology should understand who the product is designed for and what potential interactions the rhematic user may user the device for. A creator knowing what potential interactions may exist in a future state for a user is related to designing affording situations, which means that the creator should predict how the user will understand the product.

Further semiotic research regarding smart home technology and the concept of the smart homes could benefit from looking at three semiotic questions. First, how can smart home systems and IoT devices be utilized to improve the semiotic scaffolding in a broader ecological perspective rather than being centered around an individual's ecological niche? Second, if a smart home system with an artificial neural network contains the four necessary semiotic components that leads to semiosis, then to what extent does the home's system have an artificial umwelt? Third, what would be the impact of integrating abductive logic into the smart home system, which could lead to the smart devices in the home's network actively communicating to the inhabitants, as opposed to smart devices being designed to passively react to the commands given to the smart object?

In the upcoming decades, it is foreseeable that smart home technology will make an impact in a variety of niche living spaces, some of the frontrunners that come to mind is smart communities, assisted living, and in-home health care systems. The future for smart homes must be oriented to improve a defined homeostatic objective, which can range from increased measurements of mass surveillance within a community or assisting an elderly inhabitant with their daily routine. Focusing on the latter example, the increasing age of a population in various cultures will bring an influx of consumers who seek attention pertaining medical assistance and daily tasks. In a way, the future smart home can become scaffolded to be an artificial caretaker or nurse, meaning that the home will track and analyze the data that is deemed as the inhabitant's vitals. This can include analyzing how much the individual walked today, what did they eat, if they took their medicine, if they slept too much, and identifying if the inhabitant performed any tasks using top-down cognitive functions. These aspects can be designed and integrated into a smart home environment, but there are several barriers before this technological scaffolding can flourish for the smart home to become a form of an artificial caretaker or nurse – one of the critical barriers is introducing abduction into the smart home system as mentioned in the previous paragraph. A second barrier focuses on the architectural system of affordances and understanding from the creator's perspective how can the current home be adapted to sustain this new role of being an artificial caregiver; can the technology be integrated into the preexisting home or should prefabricated homes for elders include this technology and be considered as the norm? The short answer is that both types of homes will construct their own model of being a smart home, the prefab home will be more of a collective system of connected smart homes that will afford a wider range of capabilities, as opposed to a home that an inhabitant has lived in for decades and does not want to leave, which will afford the home to become a more customizable, specialized environment that requires more appropriation compared to the prefab smart home. A third barrier for this type of smart home is the blending of active and passive devices, which is discussed in the subsections 1.1.1. and 1.1.2. of the research, along with the improvement of interaction affordances discussed in section 2.4., adapting smart home technology to revolve around assisted living will alter how devices communicate to the other various devices in the home's network and how the home will communicate with the inhabitant. Improving the technology will lead to the inhabitant completing their common daily tasks, such as do they need assistance with getting a glass of water, remembering to eat, putting on socks, and so on; this is a critical challenge because human-computer interaction must physically meet the needs of what is required for the homeostasis of the inhabitant.

CONCLUSION

As mentioned in the thesis, a creator constructs the concept of a smart home technology that is then trajected for the user to appropriate the technology into their living space. The user must semiotically scaffold this technology to afford a desired level of behavior, this leads to smart homes being designed to increase security measures, be viewed as a novelty item to show off to friends, improve the convenience of never losing a remote again since voice command can control home functions, and configure home automation scenarios. To sum up the infinite semiosis related to a living space with smart home technology, a smart home is only as smart as the individuals who created the technology and the individuals who use the technology within their living niche.

The central research objective aimed at how semiotically engineering the four semiotic components of resources, competence, affordances, and scaffolding can improve the trajectory from the creator to the user and generate deeper meanings that exist within a smart home. As discussed in the second section of the research, there are five systems of affordances that construct a model of affordances that are related to the user and creator of smart home technology. Additionally, the four semiotic components serve as crucial aspects that can be analyzed from the perspectives of the creator, user, and smart home system. Semiotics can be a practical apparatus to get further insight on the meaning-making process during the creator's design process, user-appropriation, and system integration of smart home technology. Semiotically engineering a smart home requires categorically defining epistemological connections into groups of meaning (the four semiotic components) that is experienced in relation to the smart home environment. Through semiotic activity the user and creator rely on the three semiotic substances of learning, memory, and knowing which leads to semiosis. The aspect of semiotic engineering is related to each system of affordance discussed in this research, and the creator and user must utilize a bottom-up approach to scaffold a smart home system that can potentially lead to automated functions and artificial intelligence that can interact with the smart devices for the user, this generates a top-down function that must first be scaffolded in order to afford home automation. Affording situations designed into smart home technology leads to the user interacting with the device, it affords influencing the user with semiotic resources and competence, and it affords inspiring the user with a new, futuristic way to improve their subjective physiological needs.

The first research question looked at how semiotic resources can be defined for/in a smart home. The notion of semiotic resources within a smart home is related to the degree of complexity and diversity within the home's technological ecosystem. From the system level, it relates to how many controllers are in the smart home and the quantity of active and passive smart devices that share and collect data with the system. Resources are what leads to the ability to a user defining home automations and customizable scenarios. Additionally, semiotic resources have a correlation with competence due to being aware of what resources are present, and this is applicable to the individual perspectives of the creator, user, and the smart home system – section 1.2.3. and subsection 3.2.1. elaborates in-depth on the importance of competence and resources related to smart home technology.

The second research question focused on how competence is appropriated into a smart home. Subsection 3.2.2. of the research explores how the creator, user, and smart home system must have their own competence to generate a deeper meaning-making process on the relations that exist within the smart home, this includes the creator understanding who the possible user is, and the user having sufficient competence to appropriate and alter the programming functions of smart home technology.

The third research question aimed at identifying what affordances provide for shaping behavior in the smart home's environment. Affordances are discovered by having the competence on what resources exist in the smart home. Understanding affordances shapes future behavior in smart homes by scaffolding the wants that come in existence during the semiosic process – fig. 1 constructs a gestalt model of the various systems of affordances in a smart home that is directly related to the creator and user, and subsection 3.2.3. discusses how affordances can be improved from the semiotic perspective.

The fourth research question focused on how semiotic scaffolding can improve the design process of smart home technology and user interactions. A user's semiotic scaffolding for a smart home constructs a trajective path that is aimed at a desired goal, the state of a home with smart home technology aims to function on a constant, homeostatic level, while also being oriented to improve the characteristics on what a smart home connotes. The scaffolding process for a smart home relies on the user having sufficient competence to appropriate the devices into the system, which causes the potential for automated functions to be defined. In the same vein, a home that is scaffolded to be technologically rich in the ecological reality leads to the smart home environment adapting to the user's scaffolding of the smart home system. Within the conceptual and design stage of a smart home device the Affordance Structure Matrix (see Maier *et al.* 2009) is a practical model for creators and designers to identify any negative affordances that need to be minimized or eliminated, while, at the same time, identifying any positive affordances that emerge into higher-level affordance subsystems. Creators of smart home technology can utilize a concise outline on who their product is designed for and how the actual users interact with the product within their unique living space.

Affordances are an insightful semiotic component to analyze within the conceptual view of a smart home due to their hierarchical, dichotomous relations. For the user of smart home technology, affordances must first be learned and scaffolded to provide a meaning, once meaning is designated and categorized for an object the affordance perceived can automatically be processed on an unconscious level by the user. For the creator of smart home technology, affordances are conceptualized for a future state, and the creator must rely on prior semiotic activity to construct a new, potentially revolutionary smart device that is compatible within a smart home technological ecosystem. Thus, semiosis for smart home technology can be improved by understanding the unconscious afforded level in the perceptual field of the user, and by enhancing the semiotic components used by a creator to predict the future behavior of smart home technology user.

REFERENCES

Alper, Alan T.; Shann, Mike; Costanza, Enrico; Ramchurn, Sarvapali D.; Seuken, Sven 2016. It is too hot: An in-situ study of three designs for heating. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. New York, NY: 5262-5273.

Alvarez, Hannah 2015. Making your icons user-friendly: A guide to usability in UI design. *UserTesting*. Retrieved from: https://www.usertesting.com/blog/user-friendly-ui-icons (accessed 25.03.2021).

Baber, Chris 2018. Designing smart objects to support affording situations: Exploiting affordance through an understanding of forms of engagement. *Frontiers in Psychology* 9: 1-8.

Berque, Augustin 2016. Nature, culture: Trajecting beyond modern dualism. *Inter Faculty* 7: 21-35.

Campbell, Cary; Olteanu, Alin; Kull, Kalevi 2019. Learning and knowing as semiosis: Extending the conceptual apparatus of semiotics. *Sign Systems Studies* 47(3/4): 352-381.

Chagas, Bruno; Redmiles, David; de Sauza, Clarisse 2018. Observed appropriation of IoT technology: A semiotic account. IHC 2018, October 22-26 Brazil.

Cho, Younjoo; Choi, Anseop 2020. Application of affordance factors for user-centered smart homes: A case study approach. *Sustainability* 12: 1-23.

Eco, Umberto 1973. Function and sign: Semiotics of architecture. *Structures Implicit and Explicit* 173-186.

Farina, Almo; Belgrano, Andrea 2006. The eco-field hypothesis: toward a cognitive landscape. *Landscape Ecology* 21: 5-17.

Fetterman, Adam; Liu, Tianwei; Robinson, Michael 2014. Extending color psychology to the personality realm: Interpersonal hostility varies by red preferences and perceptual biases. *Journal of Personality* 83(1): 106-116.

Gibson, James J. 1986. *The Ecological Approach to Visual Perception*. Hillsdale, New Jersey: Lawrence Erlbaum Associates, xiv-332.

Hartson, H. R. 2003. Cognitive, physical, sensory and functional affordances in interaction design. *Behaviour & Information Technology* 22(5): 315-338.

Horton, Thomas E.; Chakraborty, Arpan; St. Amant, Robert 2012. Affordances for robots: A brief survey. *Avant* 3(2): 70-84.

Innis, Robert 2002. On the perceptual roots of linguistic meaning. Pragmatism and the forms of sense: Language, perception, technics. University Park, PA: Pennsylvania State University Press, 19-50.

Ivanov, Vyacheslav 1978. The Science of Semiotics. *New Literary History* 199-204.

Katuk, Norliza; Ku-Mahamud, Ku Ruhana; Zakaria, Nur Haryani; Maarof, Mod Aizaini 2018. Implementation and Recent Progress in Cloud-based Smart Home Automation Systems. 2018 IEEE Symposium on Computer Applications & Industrial Electronics.

Kull, Kalevi 2014. Catalysis and scaffolding in semiosis. In: Cabell, Kenneth R.; Valsiner, Jaan (eds.), *The Catalyzing Mind: Beyond Models of Causality*. (Annals of Theoretical Psychology 11.) New York: Springer, 111-121.

– 2015. Evolution, choice, and scaffolding: Semiosis is changing its own building. *Biosemiotics* 8(2): 223-234.
– 2020. Semiotic fitting and the nativeness of community. *Biosemiotics* 13: 9-19.

Maier, Jonathan; Fadel, Georges 2009a. An affordance-based approach to architectural theory, design, and practice. *Design Studies* 30: 393-414.
– 2009b. Affordance-based design methods for innovative design, redesign, and reverse engineering. *Research in Engineering Design* 20: 225-239.

Maier, Jonathan; Mocko, Gregory; Fadel, Georges 2009. Hierarchical affordance modeling. International Conference on Engineering Design, Stanford University, CA. 397-403.

Matthews, Stéphanie 2016. How fit is the semiotic animal? *The American Journal of Semiotics* 1-13.

McGrenere, Joanna; Ho, Wayne 2000. Affordances: Clarifying and evolving a concept. In: Fels, Sidney S.; Poulin, Pierre (eds.), *Proceedings Graphics Interface 2000*. Montréal: Canadian Information Processing Society, 179-186.

Mick, David 1986. Consumer research and semiotics: Exploring the morphology of signs, symbols, and significance. *Journal of Consumer Research* 13(2): 196-213.

Nesher, Dan 2018. "What makes a reasoning sound" is the proof of its truth: A reconstruction of Peirce's semiotics as epistemic logic, and why did he not complete his realistic revolution. *Semiotica* 221: 29-52.

Norman, Donald 1999. Affordance, conventions, and design. *Interactions* 6(3): 38-43.

Nöth, Winfried 1988. The language of commodities: Groundwork for a semiotics of consumer goods. *International Journal of Research in Marketing* 4(3): 173-186.
– 1998. Ecosemiotics. *Sign Systems Studies* 26(1): 332-343.

– 2001. Semiosis and the Umwelt of a robot. *Semiotica* 134(1/4): 695-699.
– 2020. Trajectory: A model of the sign and of semiosis. *Sign Systems Studies* 48(2/4): 182-191.

Paetz, Alexandra-Gwynn; Dütschke, Elisabeth; Fichtner, Wolf 2012. Smart Homes as a Means to Sustainable Energy Consumption: A Study of Consumer Perceptions. *J Consum Policy* 35: 23-41.

Patrono, Luigi; Atzori, Luigi; Šolić, Petar; Mongiello, Marina; Almeida, Aitor 2020. Challenges to be addressed to realize Internet of Things solutions for smart environments. *Future Generation Computer Systems* 111: 873-878.

Peirce, Charles S. 1931. The collected papers of Charles S. Peirce, 8 vols., C. Hartshorne, P. Weiss & A.W. Burks (eds.). Cambridge, MA: Harvard University Press [Reference to Peirce's papers will be designated *CP* followed by volume and paragraph number.]
– 1992. *Essential Peirce: Selected philosophical writings*, vol. 1, Peirce Edition Project (eds.). Bloomington: Indiana University Press. [Reference to *Essential Peirce* will be designated *EP*.]

Skinner, Ellen 1996. A guide to constructs of control. *Journal of Personality and Social Psychology* 71: 549-570.

Souza, Clarisse de 2005. Semiotic engineering: Bringing designers and users together at interaction time. *Interacting with Computers* 17: 317-341.

Souza, Clarisse de; Barbosa, Simone D.; Prates, Raquel O. 2001. A semiotic engineering approach to user interface design. *Knowledge-Based Systems* 14: 461-465.

Still, Jeremiah; Dark, Veronica 2013. Cognitively describing and designing affordances. *Design Studies* 34(3): 285-301.

Uexküll, Jakob von 1982. The theory of meaning. *Semiotica* 42(1): 25-82.

Waal, Cornelis de 2013. *Peirce: A guide for the perplexed*. London: Bloomsbury Academic, viii-183.

Wilson, Charlie; Hargreaves, Tom; Hauxwell-Baldwin, Richard 2017. Benefits and risks of smart home technologies. *Energy Policy* 103: 72-83.

Windsor, W. Luke 2004. An ecological approach to semiotics. *Journal for the Theory of Social Behaviour* 34(2): 179-198.

Xu, Ke; Wang, Xiaoliang; Wei, Wei; Song, Houbing; Mao, Bo 2016. Toward Software Defined Smart Home. *IEEE Communications Magazine* 54: 116-122.

Zimmermann, Verena; Gerber, Paul; Marky, Karola; Böck, Leon; Kirchbuchner, Florian 2019. Assessing users' privacy and security concerns of smart home technologies. *i-com* 18(3): 197-216.

KOKKUVÕTE

Nutikodu võimalduste semiootiline mudel: semiootiliste komponentide trajektoor tehnoloogilises elukeskkonnas

Selle uurimistöö eesmärgiks on esitada semiootiline kirjeldus nutikodu (*smart home*) toimimisele. Kasutatakse nelja keskset mõistet, mis ühtlasi kirjeldavad peamisi tähenduslikke tahke nutikodu kasutaja jaoks: semiootiline ressurss, semiootiline pädevus, sobimus (*affordance*) ja semiootiline toestik (*scaffolding*). Uuritakse, kuidas nende semiootilise keskkonna tahkude kaudu jõuavad tehnoloogia loojate taotlused kasutajani, ja kuidas kasutaja moodustab enda jaoks nutikodus eksisteerivate tehnoloogiliste võimaluste tähendused.

Töö teises osas on lähemalt vaadeldud sobimuste viit liiki, mille alusel konstrueeritakse mudel, mis näitab, kuidas kasutaja järk-järgult liitub sobimuste kaudu nutikodu tehnoloogiaga. Sobimuste analüüs annab hea ülevaate nutikodu semiootilistest komponentidest, tänu nende hierarhilisele suhestatusele. Kasutaja saab ülevaate ressurssidest järk-järgult, kõigepealt õppides ja omandades nutiseadmetega suhtlemise pädevused, seejärel meeldejätmiseks kujundades semiootilise toestiku, mis aitab kaasa võimalustest arusaamisele. Kui see on olemas ja kategoriseeritud üle kõigi asjade, mida ruumis tajutakse, siis muutuvad potentsiaalsed kasutatavused automaatseks, alateadlikuks käitumiseks. Nutikodu tehnoloogia loojale saab sobimuste kontseptsioonist lähtuv mudel olla kasulik, sest toetudes kasutaja semiootilise tegevuse ülevaatlikule esitusele on võimalik luua uusi nutiseadmeid, mis sobituksid olemasolevasse nutikodu ökosüsteemi. Nutikodu tehnoloogia kasutaja tähenduslikku toimimist saab soodustada, kui mõista kasutaja harjumuste kujunemist. Mudeli põhjal on võimalik täiustada semiootilisi komponente, mida looja saab ühtlasi kasutada nutikodu tehnoloogia kasutaja tulevase käitumise ennustamiseks.

I, Alec Kozicki,

(*author's name*)

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A SEMIOTIC MODEL FOR SMART HOME AFFORDANCES: TRAJECTING SEMIOTIC COMPONENTS IN A TECHNOLOGICAL LIVING ENVIRONMENT,

(*title of thesis*)

supervised by Kalevi Kull and Tiit Remm.

(*supervisors' names*)

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