Metaphor

Metaphor: A tool for designing the next generation of human-building interaction

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Well known metaphors play an explanatory role in human-computer interaction (HCI) and support users in understanding an unfamiliar object with references to a familiar object, for example the desktop metaphor. Metaphors can also support designers in forming and exploring new concepts during the process of designing. We present metaphors that establish user expectations and provide guidance for new design concepts while integrating interactive technology in buildings to enable human-building interaction (HBI). HBI is a research area that studies how HCI research and practice provides opportunities for interactive buildings. Interactive experiences in architecture can be characterized by three metaphorical concepts: HBI as Device (user-centered view), HBI as Robot (building-centered view), and HBI as Friend (activity centered-view). These metaphors provide a tool for architects and HBI designers to explore designs that engage occupants' existing mental models from previous HCI experiences. We expand on each metaphor using analogical reasoning to define exploratory design spaces for HBI.

Keywords: *Human-Building Interaction, Metaphor, Human-Computer Interaction, Interactive Architecture*

INTRODUCTION

Metaphors are widely used in both architectural design and human-computer interaction (HCI) design. In architectural design, metaphors are typically used to create an architectural identity and reveal a unique experience to broaden the feelings, thoughts, and imagination of human beings (Ayıran, 2012). Metaphors in architecture are also used as an explanation for clients or other designers when communicating the architectural concept. The role of metaphor in architectural design differs from the use of metaphor in HCI design. For example, the desktop metaphor is a generalized metaphor that activates a user's mental model of a physical desktop as a basis for interactions across many HCI designs. The icons and affordances of the desktop metaphor are replicated across many interactive systems, devices, and brands. Human-building interaction occurs when technology is embedded in buildings. We claim that generalized metaphors can be useful for

HBI as guiding principles in the design processes. Human-Building Interaction (HBI) is a new research domain within HCI. Alavi et al (2016) define the field of HBI as the study and design of interactive opportunities for people to shape the physical, spatial, and social product of their built environments. Examples of HBI are changing physical conditions (e.g. room temperature), engaging occupants in information (e.g. event visualization), and supporting activities (e.g. embodied AI assistant). Fundamental characteristics of HBI include user immersion and interaction in the building as "machine" with different space and time scales when compared to HCI. In this paper, we expand on HBI research to go beyond the technological view and consider design guidelines that open up novel conceptual spaces for positive user experiences with HBI. Architects and building occupants can benefit from a design perspective that engages a mental model that guides the designer and the users of interactive elements in buildings. We provide a starting point for this shared mental model for HBI designs by establishing metaphors within a theoretical and methodological framework. The role of metaphor in HCI is to facilitate the development, maintenance, learning, and orientation of the conceptual foundation of the interactive application. Metaphors can be powerful devices for designers, in both the design process and within the products themselves. A metaphor can help redefine design problems and help to solve them. It can be used as a research tool to understand new topic areas or as means to create new ideas about familiar subjects. Metaphors provide cues to users about how to understand interactive products. Interaction designers use metaphors to guide user behavior (Saffer 2005). The significant difference between interaction in the contexts of HCI and HBI is that in HBI the use of metaphor is to enable interaction with both digital content and physical objects in a 3D physical building. Whilst in HCI metaphor is used to bring the familiarity of our experiences in the physical world to the interaction with digital information.

METAPHORS FOR HBI

We present and develop three categories of metaphor as a basis for designing HBI by analogical reasoning: device, robot, and friend. To develop a conceptual space for HBI design using these metaphors we apply two frameworks: the FBS ontology (Gero 1990) and the HCI framework. We first describe the three categories of metaphor, then discuss how the metaphors are mapped to potential HBI designs using the FBS and HCI frameworks.

Device: User-centered view

An interactive building is a device that extends the concept of a smartphone or smart appliance to the scale of a building. Contemporary buildings require multi-dimensional functionalities and HBI satisfies these requirements in intelligent ways. Interaction in a building based on this metaphor typifies structured and predetermined interactions between a user and a building that has preconceived sets of input and outputs. This metaphor represents a user-centered view of HBI for dealing with occupants' requirements, comfort, and experiences. It encompasses providing better service, satisfying needs, performance, and ease of control for residential and work life (e.g. lighting, air-conditioning). This metaphor emphasizes multiple purposes and operations in a single device, similar to the multiple apps on a smartphone device. The background of this metaphor reflects architecture based on productivism, functionalism, and high-tech architecture.

Robot: Building-centered view

An interactive building is a robot that extends the concept of an intelligent machine capable of performing tasks and managing itself to the scale of a building. An interactive building based on this metaphor reacts to both external and internal changes autonomously to manage building conditions such as energy consumption. This metaphor represents a building-centered view of HBI in terms of self-management. It encompasses building automation, sustainability, improving building/urban environment, and managing building life

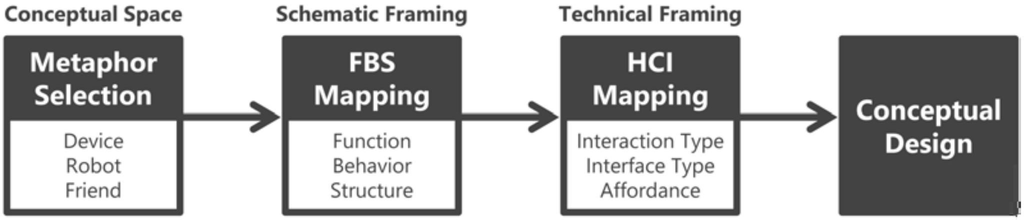

Figure 1
Design process using the proposed metaphors, FBS framework, and HCI framework

cycle (e.g. energy monitoring, kinetic shading). This metaphor emphasizes automation, autonomous decision-making, artificial intelligence and the physical actions of a robot. The background of this metaphor reflects concepts of smart home, adaptive buildings, intelligent building, and kinetic architecture and buildings that learn and adapt through interaction with users and sensors.

Friend: Activity-centered view

An interactive building is a friend in which interaction centers around advising and supporting the occupants of a building. Interaction in a building based on this metaphor supports activities such as playing, cooking, saving energy, and working. The primary characteristic of this interaction is an open-ended structure and outcome, which are characterized by meandering interaction. This metaphor represents an activity-centered view of HBI in terms of supporting occupants' activities. The activities depend on the function of the place such as office, kitchen, bedroom and meeting room. This metaphor reflects research in personification, affect, artificial intelligence, as well as co-learning over time.

EXPANDING METAPHORICAL CONCEPTS WITH ANALOGICAL REASONING

While a metaphorical concept can provide a guiding principle for HBI design, we posit that analogical reasoning provides a process for transforming the metaphorical concept into a realizable design. Analogical reasoning, an inference method in design cognition (Gero & Maher 1992), is a way to develop a design leading to unexpected discoveries. Analogical reasoning is a design process where variables from an existing design or concept can be the basis for a creative design (Qian & Gero 1996). We present two frameworks to support analogical reasoning when designing HBI: a Function-Behavior-Structure (FBS) framework and an HCI framework. The FBS ontology (Gero, 1990) is used to articulate each of the three HBI metaphors in order to map the function-behavior-structure of an HCI design into a design space for an HBI design. The HCI framework is used to map interaction types, interface types, and affordance relevant to each metaphor from the HCI user experience to the HBI user experience. In our examples, we start with a description of the function of an HCI design and adopt a similar function in an HBI design. The FBS framework identifies new designs with specific behaviors and structures for HBI design that share a function with an HCI design, while the HCI framework provides a mapping between HCI design elements and HBI design elements. Figure 1 shows the design process using the metaphors, FBS framework, and HCI framework to create a conceptual design for HBI.

FBS FRAMEWORK AS A STRUCTURE FOR EXPLORING METAPHORS

Analogical reasoning is facilitated by using an ontological framework that provides a common terminology with agreed-on meanings for a domain of discourse. The function-behavior-structure (FBS) ontology (Gero, 1990; Gero and Kannengiesser, 2004) provides such a framework for the design domain. We use the FBS ontology (Gero, 1990) as a framework to represent and expand each of the three HBI metaphors:

- "*Function* (F) of an artifact is defined as its teleology (i.e., what the artifact is for). It is ascribed to behavior by establishing a teleological connection between a human's goals and measurable effects of the artifact (Chittaro and Kumar 1998)."
- "*Behavior* (B) of an artifact is defined as the attributes that can be derived from its structure (i.e., what the artifact does). Behavior provides operational, measurable performance criteria for comparing different artifacts."
- "*Structure* (S) of an artifact is defined as its components and their relationships (i.e., what the artifact consists of). The structure of artifacts includes their form (i.e., geometry and topology) and physical or virtual material."

Qian and Gero (1996) proposed a formalism for design knowledge representation through Function-Behavior-Structure (FBS) paths, as a basis for cross-domain analogy-based design. In such an analogy-based design system, the FBS of a source design in HCI provides a basis for designing the potential FBS of a target design in HBI. In this section, we describe three examples of analogical reasoning for each metaphor illustrating how the FBS of a source design can be applied to the target design of HBI.

Device: User-centered view. Smart devices such as personal computers and mobile phones are now commonly used by most people. Smart devices tend to be multi-purpose ICT devices, operating as a single platform to access multiple application services that may reside locally on the device or remotely on servers. Smart devices tend to be personal devices, having a specific owner or user. The main characteristics of smart devices are: interaction, mobility, dynamic service discovery and intermittent resource access such as concurrency and upgrading (Poslad 2011). To illustrate the analogical reasoning mapping based on the FBS framework, we use a smartphone as a source design. The smartphone design provides, through multiple apps, multi-functionality such as communication (e.g. phone call, text, SMS, email), management (e.g. schedule, health, notification), information (e.g. internet, map, shopping), and entertainment (e.g. music, photo, video, game). In a holistic view, a smartphone enables sets of applications performing different tasks. Similarly, a building has multiple functions such as living service, security, and entertainment. These functions are a characteristic difference between the device and HBI, thus each function from the source can be mapped to HBI designs. For example, the major functions of smartphones are the communication service that is carried out through phone calls and text and there are apps such as calendar, internet, and photo that are involved with other functions. The major function of a building is to provide intelligent living services that are carried out through heating, lighting, and air-conditioning. Recent buildings have additional functions such as a smart security system and smart interactive kitchens. The behavior matching between the two designs would be carried out in a similar way with the function matching in terms of access to individual app/system, control tasks, and display information. The function and behavior mapping would lead the designer to come up with new structures of HBI shown in Table 1.

Using the FBS framework, we map functions of the smartphone to a target design as an example. The target design of HBI is an interactive concierge which is a touch screen for providing virtual concierge services. The major function of a smartphone is providing multiple applications on the device thus the user can perform different tasks using a single device. This function achieved by displaying icons on the home screen. Similarly, the major function of the HBI Interactive Concierge is providing multiple concierge services and this function is achieved by displaying service icons and information screens. The behavior of the two designs, smartphone and concierge, are analogical in terms of both display the information of multiple apps. The associated behavior variables, various apps and concierge services mapped for the behavior matching between the two

Table 1
FBS expanded mapping between a device and HBI

	Device	HBI
Function	Multi-function - Communication - Management - Information	Multi-function - Living Service - Security - Entertainment
Behavior	- Open/close apps - Display information - Control tasks	- On/off systems - Display information - Control environmental conditions
Structure	- Home screen - Apps (e.g. call, SMS, email, music, photo, etc.) - Icons - Folders	- Physical building components - Digital building components - Control panel/interface - visualization

Table 2
FBS mapping between a smartphone and an interactive concierge board design

	Source: Smartphone	Target: Interactive Concierge Board
Function	- Providing multiple apps	- Providing multiple concierge services
Behavior	- Display icons - Open/close apps - Display information - Control tasks	- Display icons - Open/close services - Display information - Supporting services (e.g. wayfinding, restaurant reservation)
Structure	- Home screen - App screen - Icons/buttons - Map	- Home screen - Windows - Icons/buttons - Floor plan

designs. In addition, the structure elements are also mapped. The most structure elements of the two designs, smartphone and concierge, use a generalized graphical user interface (GUI) such as icons, buttons, and windows. However, the map in the smartphone is transferred to the floor plan in the concierge board design as shown in Table 2.

Robot: Building-centered view. There are many kinds of robots that have different roles, appearances, and interaction types. For instance, some of them are humanoid and use speech interaction, others have the shape of a machine and use physical movement. The robot metaphor for HBI captures the design space for autonomous features of building. Autonomous robots are intelligent machines capable of performing tasks in the world by themselves, without explicit human control (Bekey 2005). For this metaphorical concept, we use a generic robot as a source design and a smart autonomous building as a target design. The source and target design are analogous in terms of performing tasks and managing itself. The autonomous features of robot can be mapped to target designs of HBI. For example, a kinetic facade which controls daylight automatically can be adapted as a target design. One function of a kinetic facade is providing optimal daylighting and this function is achieved by detecting external daylight, opening/closing the louvers, setting/controlling the optimal level of daylight. Table 3 shows an expanded mapping between the robot and HBI including various functions/behaviors/structures of the source and target design.

Using the FBS framework, we map a function from the robot design to the target design of a build-

	Robot	HBI
Function	- Self-maintenance - Task performance - Autonomous navigation - Avoid situations that are harmful to people, property or itself	- Managing energy consumption - Monitoring building conditions - Maintaining security
Behavior	- Sensing the environment - Learn and gain information about the environment - Work for an extended period without human intervention - Move either all or part of itself throughout its operating environment autonomously	- Detect environmental conditions - Control building environment - Learn and gain information from users' pattern
Structure	- Robot components (e.g. body, arm, leg, head, display, motors) - Sensors	- Building components (e.g. facade, door, window, motors) - Sensors

Table 3
FBS expanded mapping between a robot and HBI

	Source: Robot	Target: Smart Building
Function	- Self-driving	- Maintaining home security
Behavior	- Detecting obstacles - Steering using information - Setting/navigating locations	- Detecting occupants/visitors - Open/close the door - Setting/control by an app
Structure	- Legs or wheels - Sensors - Motors	- Door lock - Sensors - Smartphone

Table 4
FBS mapping between a robot and a smart building

ing. A function of a moving robot is self-driving and this function is achieved by detecting obstacles, steering using visual information, and setting/navigating locations. A function of a smart building is maintaining security, achieved by detecting occupants/visitors, opening/closing doors, setting/control the security, and displaying visitors' information. The behavior of the two designs, robot and smart building, is analogous since both designs detect conditions and control the system autonomously. The associated behavior variables, driving information and visitors information are mapped for the behavior matching between the two designs. Other associated behavior variables, steering and open/close are also mapped as controlling behavior. The major structure elements include mapping legs or wheels of a robot to door locks in a smart building. The remaining structure elements, sensors and navigation in the robot design are transferred to the structure elements of the smart building, sensors, and smartphone, as shown in Table 4.

Friend: Activity-centered view. Friends who know you well play various roles depending on the occasion (e.g. buddy, partner, colleague, and trusted adviser). The essential characteristic of friends for this metaphor is the role a friend plays while interacting with the building occupant. This characteristic role is related to the occupants' routine activities in certain spaces or situations and this metaphorical reasoning can identify HBI that support occupants' activities as a person. This metaphor can be applied to building components (e.g. personified door or window) or

Table 5
FBS expanded mapping between a friend and HBI

	Friend	HBI
Function	- Advising - Playing - Helping - Training - Collaborating	- Working - Cooking - Studying - Entertaining
Behavior	- Raising issues - Identifying issues - Conversation about issues - Providing information	- Detecting occupants - Detecting issues - Searching information - Providing information
Structure	- Voice - Expressions/gestures	- Building Components - Virtual character - Voice/gesture

Table 6
FBS mapping between a friend and a personified building

	Source: Friend	Target: Personified Building
Function	- A friend is a person that knows you well, gives advice, and reminds you to do things	- Personifying the advice and reminders about sustainability behavior
Behavior	- Identifying issues - Conversation about issues	- Detecting proximity of occupants in a certain space - Displaying visual information
Structure	- Voice - Expressions/gestures	- Text message - Character

to a whole space/building (e.g. personified room or building) to support certain activities in appropriate situations. For instance, a personified meeting room supports the meeting and a personified kitchen supports cooking. Table 5 shows an expanded mapping from the friend in HCI to HBI.

In this framework, we use friendly HCI as a source design and a personified building which provides messages about sustainability as a target design. The personified building character, the target design, is a visualization system that presents relevant information in a particular space by the personified building character for saving energy with changing behaviors of occupants. The functions of friend are achieved by having a conversation. Similarly, the functions of personified building are advising and reminding about sustainability behaviors. These functions are achieved by displaying information with a personified building character. The behavior of the two designs, friend and personified building, are analogous in terms of both giving an advice and the relevant information. The associated behavior variables, identifying issues and detecting the proximity of occupants in a certain space are a mapping for the behavior between the two designs. The conversation about issues from the friend is also mapped to displaying visual information in the personified building. In the structure mapping, the voice from the friend is transferred to text message in the personified building and the expressions/gestures from the friend are mapped to the character in the personified building.

HCI FRAMEWORK FOR ANALOGICAL REASONING FOR DESIGNING HBI

We use an HCI framework comprising interaction types, interface types, and affordances to expand the three metaphors from an analogous HCI design.

While the FBS framework focuses on identifying specific behaviors and structures for new designs, the HCI framework enables a systemic mapping between a source and target design. Interaction types are the ways a person interacts with a product or application (Rogers et al. 2011). Rogers et al. (2011) proposed four main types of interaction: *instructing*, *conversing*, *manipulating*, and *exploring*. We modified the four main interaction types adding an interaction type *sensing* to describe the interaction between ambient environments and users.

- *Instructing*: Where users issue instructions to a system, such as: typing in commands, selecting from menus, speaking commands, gesturing, pressing buttons, or using function keys.
- *Conversing*: Where users have a dialog with a system. Users can speak aloud or type in questions to which the system replies via text or speech output.
- *Manipulating*: Where users interact with objects in a virtual or physical space by manipulating them, such as opening, holding, closing, placing.
- *Exploring*: Where users move through a virtual environment or a physical space. Virtual environments include 3D worlds, and augmented and virtual reality systems.
- *Sensing*: Where users interact with ambient environments in a physical space that includes sensors such as vision, motion, sound, and smell.

Interface types describe the technology that enables and supports the interaction. There are numerous interface types and new types are designed regularly, for example WIMP, GUI, touch, speech, wearable, tangible, AR, and VR. Some of the interface types primarily focus on a function, while others are associated the interaction style used, the input/output device used, or the platform being designed (Rogers et al. 2011). Affordance refers to the perceived and actual properties of a design that determine how it is used. Affordances emerge from the interaction between the user and the artifact based on the perception of strong clues or signifiers about the operations of the artifact (Norman, 2013). In HCI designs, visual signifiers are widely used, such as buttons and icons. HBI designs require both types of affordances: physical signifiers for building components (e.g. door handle) and visual signifiers for digital components (e.g. screen images). We demonstrate the analogical reasoning mapping from the HCI framework to HBI design for each metaphor with the same source and target designs used in the FBS framework.

Device: User-centered view. The interaction type of the smartphone and concierge is *instructing* based on the user giving commands by touching icons, pressing buttons or voice. The interface type for a smartphone and concierge is a GUI or voice so we can apply a similar visual design from the source representation to the target design. In addition, the interface type of mobile and touch used in smartphones are mapped to multimedia, shareable, and touch. The smartphone includes various affordance elements such as icons, buttons, and maps. The general affordances in the GUI thus can be transferred to the HBI designs. In this example, the HBI design of an interactive concierge includes a floor plan with the general affordances, as shown in Table 7.

Robot: Building-centered view. The basic interaction type of a robot is *sensing*: sensors enable the robot to interact with its environment and perform tasks autonomously. Human intiatied interaction with robots include physical manipulation and speech interaction. Similarly, a smart building system includes both types of interaction: *sensing* the environment and user *instructing* and *manipulating*. Examples of smart buildings that rely on sensing the environment and user initiated interaction include kinetic facades, smart door locks, and automated lighting systems. For example, a smart door lock automatically detects approved occupants and opens the door. However, the smart door lock will also respond to an individual's instruction to open or lock the door using an app on a mobile phone. The robot and

Table 7
Mapping between a smartphone and an interactive concierge board

	Source: Smartphone	Target: Interactive Concierge Board
Interaction Type	- Instructing	- Instructing
Interface Type	- GUI - Consumer electronics - Mobile - Touch - Voice	- GUI - Voice - Multimedia - Shareable - Touch
Affordance Elements	- Icons - Buttons - Maps	- Icons - Buttons - Floor plan

Table 8
Mapping between a robot and a smart building

	Source: Robot	Target: Smart Building
Interaction Type	- Sensing - Manipulating and/or instructing	- Sensing - Manipulating and/or instructing
Interface Type	- Multimodal (e.g. speech, touch, and multimedia)	- Multimodal (e.g. tangible, and multimedia)
Affordance Elements	- Physical action/status (e.g. waved greeting) - Icons	- Physical building components (e.g. door handle) - Icons

Table 9
Mapping between a friend and a personified building

	Source: Friend	Target: Personified Building
Interaction Type	- Conversing	- Conversing - Exploring
Interface Type	- Multimodal (e.g. speech, tangible)	- Multimodal - Multimedia - Information visualization
Affordance Elements	- A way of talking - Attitudes	- A way of messaging - Shareable - Images reflecting attitudes of the building character

smart building does not have affordances for user interaction when they are fully autonomous.

Friend: Activity-centered view. The interaction type for the friend metaphor is *conversing*. The *conversing* type of interaction transfers from the friend to the personified building by using text messages or speech. The personified building uses sensors to detect occupants in addition to *conversing*. The interface type of friend can be multimodal including speech and tangible interaction. The interface type of personified building can also be multimodal including multimedia and information visualization/-dashboards. In this case, the characteristic of friend which is a conversation by speech is transferred to the personified building as a conversation by speech and/or visualization. A friend often uses different ways of talking and attitudes (e.g. consolation, compliment, and encouragement) in order to induce a recipient's reaction. Similarly, the personified building can use different ways of talking and attitudes (e.g. an encouraging message, and cheerful stances of a character) as affordances.

CONCLUSION

Metaphor provides the foundation for a design tool or guide for the conceptualization of new designs in HCI and HBI. Metaphor can provide cues to users about how to understand and interact with the design and can support designers as a tool for creative thinking. We have presented three categories of metaphorical concepts and two frameworks that enable analogical reasoning for HBI. Each metaphor communicates different types of building designs: device, robot, and friend. Expanding on these metaphorical categories using analogical reasoning with the FBS and HCI frameworks provides guiding principles for innovative HBI designs. The identification of the metaphorical concepts along with analogical frameworks opens a new design and research space for HBI. As computers become increasingly ubiquitous their roles in architecture, embedded in buildings to produce novel functions and behaviors, are yet to be fully explored and understood. Computers embedded in buildings have the potential to change the building from a static to a dynamic artifact, one that requires and produces interactions. These interactions can be with the building's occupants or among components within the building. How to understand these interactions requires novel approaches to both the design of buildings and their use. This paper has outlined a novel approach to the design and understanding of these interactions based on the use of metaphors to drive analogies.

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