ONE AND MANY

AN AGENT PERSPECTIVE ON INTERACTIVE ARCHITECTURE

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Name	Description
Building Automation System	Monitoring and control of mechanical, security, fire and flood safety, lighting and HVAC systems in a building [2]. BAS usually applies for commercial buildings.
Smart Home	Highly similar to a building automation system, usually connected with a handheld device for distance consulting and/or controlling.[3] Smart Home usually applies for residential buildings.
Sentient Buildings	A sensor-driven monitoring and controlling system that has an internal representation of the building from which it derives control strategies (Mahdavi 2004).
Adaptive Buildings	Usually means smart façade systems that automatically react to inside and outside conditions with respect to solar gain.[4]
Dynamic Buildings	Buildings with physically moving parts so that the internal organization changes or the shape of the building volume changes. [5]
Interactive Buildings	Buildings that engage in an information exchange with a user and can anticipate and initiate change in the building based on an internal representation of the user (Fox and Kemp 2009).
Kinetic Architecture	Buildings with moving components, mostly facade systems (Fortmeyer and Linn 2014) but also other parts of the building (Zuk and Clark 1970) .
Intelligent Buildings	A building that maintains optimum performance by automatically responding and adapting to the operational environment and user requirements (Callaghan 2013, 72).
Portable Buildings	Buildings that can be moved to different locations (Kronenburg 2002) .

1 Kinds of responsive buildings

ABSTRACT

In this paper we look at interactive architecture from a design theoretical/methodological point of view. In particular, we aim to outline how principles from agent theory can form a theoretical foundation for conception and following the design of interactive architecture. Interactive architecture is a special case of responsive buildings—buildings that can intelligently react to, or even anticipate, change. Interactive buildings have an internal representation of the user on which basis they reach decisions for the manipulation of the outside world. For the design of responsive and interactive buildings it is necessary to take change into account throughout the whole design process. This requires rethinking our notions about architecture and design processes. We define an agent, and show how it matches for objects, with increasing degrees of responsiveness. Agents by themselves are not enough to design interactive buildings—they also need to have a behavior defined. For this purpose we define attitudes as mode of operation for agents.

THE DYNAMIC ENVIRONMENT

The Inter-Action Centre, Kentish Town, by architect Cedric Price, realized in 1971, was one of the first contemporary examples of kinetic and flexible architecture. It was a more modest version of his earlier vision of the Fun Palace (together with Joan Littlewood 1961) (Kronenburg 2007, 60), an unrealized educational structure, which could be changed according to the desires of the visitors. The Architecture Machine Group, founded in 1967 by Nicholas Negroponte, was one of the first institutes to explore interactive systems in architecture. In *The Architecture Machine*, Negroponte outlines requirements for interaction between computer and inhabitant (Negroponte 1970, 101–117). In 1969, Gordon Pask argued that architects design systems, rather than buildings and should therefore consult cybernetics to design such buildings (Pask 1969, 494)—cybernetics being the science of control systems (Ashby 1956; Wiener 1948). Flexibility in architecture has always been an important theme, but rarely has it been approached from a self-organizing and dynamic perspective (Kronenburg 2007, 209). Fox and Kemp (2009, 98–131) outline the historical development of various necessary components for responsive building. Schumacher et al. (2010) catalogue contemporary architectural components and technologies for (self-) changing buildings. Easily accessible technology such as Arduino[1] made it possible for architects and architecture schools to experiment with interactive systems.

Traditional solutions to sustainable buildings usually are concerned with reduction of energy consumption. This is realized by means of passive technology such as warmth accumulation through building mass, high isolation values, and low surface-to-volume ratio. Such solutions are not very responsive as they can only adapt slowly or not at all to change in the environment, user demands or function. Therefore, when change or response to change becomes a dominant aspect of the building, the need for change cannot be achieved by traditional solutions. Most likely we should then look at light, flexible and interactive solutions. Buildings that require such an approach are for example commercial spaces (such as shopping centers, offices and retail centers), logistic nodes (such as airports, train stations and bus terminals), cultural spaces (such as stadiums, theaters and concert halls) and (semi) public spaces (such as hospitals, council halls and science centers)—in other words, typically non-residential buildings that regularly take large amounts of visitors.

The majority of buildings are designed first as (multi) functional shells (by the architect), which are then outfitted by the installation experts. For the design of responsive buildings this subdivision of tasks, and most importantly responsibilities, does not work well because it conceives of responsiveness as an add-on and not as an intrinsic property of the building. We argue that responsiveness should be taken into account from the very start of the design process (a similar position is also taken by Fox and Kemp (2009, 179) and Oosterhuis (2012)). In order to do this successfully we need to change our design methods. A number of architectural design offices (such as UN Studio, MVRDV, and Oosterhuis.nl) are taking dynamics into account for their design process (Achten and Kopriva 2010).

RESPONSIVE BUILDINGS

With the term "responsive buildings" we mean buildings that intelligently react to the environment, user needs and conditions within the building. Such buildings or systems are known under a variety of names with slightly different meanings: building automation systems, smart homes, sentient buildings, adaptive buildings, dynamic buildings, interactive buildings, kinetic architecture, intelligent buildings and portable buildings, to name a few (Table 1). There is no widely agreed categorization. It seems that most terms gravitate around a particular set of technologies that have a specific purpose; therefore, the current distinctions are very much in transition due to the influence of technological advances.

MULTI-AGENT SYSTEMS

We propose that one of the key concepts for designing responsive buildings is "agency." Agency comes from Multi-Agent Systems (MAS) theory, which is the most recent information technology approach to consider the analysis, design and development of complex systems. It originated from the general research field on Artificial Intelligence and more specifically Distributed Artificial Intelligence. MAS acknowledges two basic observations:

(a) most of intelligent activity can be considered as distributed in one way or another, and

(b) the isolated symbol-processing approach seems to have reached the limits of what can be achieved.

Based on this, the notion of an "agent" as a situated and autonomous entity capable of interacting with the world and other agents has gradually developed (Nilsson 1998; Russell and Norvig 1995; Weiss 2001). Although the mainstream of work on multi-agent systems usually conceives agents in human-like terms, a number of researchers have proposed to apply the multi-agent approach to the cognitive functions of intelligent behavior (Brooks 1990; Maes 1989; Minsky 1988). Franklin sums up such directions and identifies agents as a necessary building block for complex and intelligent behavior (Franklin 1995). Research on multi-agent systems focuses not only on the capabilities of the agents themselves, but more-

Object	Degree of responsiveness
Passive	Any object that simply reacts to outside influences by the laws of nature (physics, chemistry, biology and so on). Its behavior is completely determined by these laws. There is no additional influence from the object itself that will modify its behavior in any way.
Reactive	A passive object to which a controller is added that modifies the reaction of the system. Typical modifications are to amplify, decrease, delay or speed up. In many cases the output of a reactive object is different than the input (e.g. a thermostat takes as input the temperature and has as output lowering or increasing the amount of heating in a room).
Autonomous	A reactive object with "a mind of its own." It has a controlling mechanism, which consists of three parts: state, goals and reasoning mechanisms. The state describes the current condition of the object. The goals describe the performance targets. The reasoning mechanisms look at the state, derive how the state differs from the goals and then determine the most proper reaction to reach the goals. The autonomous object then produces some action in the outside world.
Agent	An agent is an autonomous object, which is able to do two additional things: (a) communicate directly with other objects and (b) initiate changes by acting before an input from the environment is received. Contrary to autonomous systems, an agent can decide on its own (not waiting for some input) to do something. Through the communication capability it can exchange information with others including users.

2 Increasing degrees of Responsiveness of objects

over on reasoning within groups as cooperating or competitive individuals. It is generally found that conceived this way, multi-agent systems can function robustly in highly dynamic and unpredictable environments.

Agency is not limited to the design of complex software. In fact, the notion of agency can be generalized very well to any complex artifact, including the built environment. We define an agent as follows:

> An agent is an autonomous entity, situated in an environment, capable of sensing this environment and other agents that are in that environment, able to send out and receive signals from the environment and other agents, and capable to manipulate aspects of the outside world.

This notion of agent has two major advantages with respect to responsive buildings:

1. There is no distinction between objects and people: both can be considered as agents. Therefore, interaction between people and objects is unified under the agent framework.

2. Responsiveness is an intrinsic property of agents: every agent can sense its environment and other agents by definition. Therefore, using the agent concept immediately requires consideration of its responsiveness.

DEGREES OF RESPONSIVENESS

Using agency in the built environment forces us to think about aspects of responsiveness and relationship with people from the very start. Not everything has to be an agent though, and not all agents are equal—they will have different levels of competence in sensing, reasoning and manipulating. We propose the following distinctions show in (Table 2).

	Direct system involvement	Indirect system involvement
Passive user	The system's actions are partly based on user needs through observation, monitoring, measuring, or other means of detection. For the user, the system seems to act as a "perfect butler."	The system runs autonomous without direct consideration of the user's current state. For the user, the system is something running in the background without need for control. To the user the system seems completely "environmental."
Active user	The system and user engage in a "dialogue," in which the system takes note of the user needs and actions and the user actively is influencing the system. This can be characterized as the system as "partner."	Most of the system's actions are tuned to keeping some kind of state that the user requires but does not need to know or understand how it actually functions. This is typical for the control of complex systems or where the actual functioning is shielded or filtered through an interface. The system acts as a "wizard."

3 Styles of interaction between building and user

From the theory of multi-agent systems we can take the notion that a complex agent can be created out of a number of less complex agents. This has two important implications for the design of responsive buildings, namely:

1. A complex system can be considered as an agent on any arbitrary level of analysis: "agency" is not reserved for a limited and highly specialized group of objects but rather can be applied on any level in the design.

2. A multi-agent system can be a mix of many components of different levels of responsiveness (taken from (Table 2)), but there should be at least one component on the agent level: agency is not an emergent feature—the capability to communicate with others and initiate change outside of a predefined set of reactions has to be created for that agent.

BUILDINGS CONCEIVED AS AGENTS

If our assertion is true that we may consider a complex system as an agent on any arbitrary level of analysis, then we are allowed to consider the building as an agent as well. This has the advantage that we can define the buildings' behavior in terms of agency on the one hand, but we can leave the technical realization of the agency to a multi-level subdivision of less complex agents that work together.

Conceiving the building as an agent does not deny the fact that in the end we have to define, develop and create systems and system components, which realize agency. The "building as agent" in other words, does not solve this problem for us—we still have to define sensors, actuators, control structures, material systems, communication strategies and so on. What the "building as agent" allows, however, is a description of the interaction or responsiveness on a level that we

	Instructing	Conversing	Manipulating	Exploring
Performing	Trainer	Fellow	Specialist	Explorer
Sustaining	Mentor	Helper	Scout	Discoverer
Servicing	HAL	Host	Assistant	Technician
Symbolizing	Icon	Peer	Chaplain	Guru
Entertaining	Idol	Buddy	Crew	Improviser

4 Attitudes of interactive buildings

are very familiar with, almost as if we are talking about a person. This level, in which we attribute goals, desires and behaviors to someone or something, is known in cognitive science as "intentionality" (Flanagan 1984, 28-30) or the "intentional stance" (Dennett 1997).

By using the intentional stance, we can define on an abstract level the behavior of a building as an agent and postpone the technical realization to a later point. At this point, we have developed two intentional notions that help with the design of interactive buildings: styles of interaction and attitude of interactive building.

STYLES OF INTERACTION

The styles of interaction inform the overall way that the interaction between the user and the building is achieved. The user can be considered as passive or active. A passive user is one who does not "tell" or "instruct" the system what to do. An active user is one who initiates action of the system by "doing" something or "activating" something in the system. The interactive system can be directly involved with the user or indirectly. The direct system involvement means that the system expects some kind of input from the user so that it can come up with an appropriate reaction. The user will see more of the systems' internal workings so that (s)he can make an informed decision. The indirect system involvement means that the system does not require an active engagement of the user to tell it what needs to be done. The combination of passive and active user, and direct system involvement and indirect system involvement leads to four different styles of interaction (Table 3), which can be typified as "perfect butler," "partner," "environmental" and "wizard" (Achten 2011).

ATTITUDES OF INTERACTIVE BUILDINGS

Interaction presupposes a relationship between the building and the user. From the field of Interaction Design we can take four fundamental interaction activities (Sharp, Rogers and Preece 2007, 64): instructing, conversing, manipulating and exploring. Instructing occurs in learning situations where the user has an information need and the system can provide the information (such as in cases of wayfinding or skill acquisition). Conversing is an interaction activity in which user and building exchange information in a dialogue manner. This may occur for example in information retrieval or setting a desired series of patterns for the future. Manipulating occurs when the user wants to achieve something and the building acts as an intermediate–for example setting different lighting rigs in an exhibition or show or lowering energy consumption. Finally, exploring is an interaction activity when both user and building explore options and various settings without a predefined goal or performance criterion. Most research and development that is done on responsive buildings cite sustainability and improved building performance as the main reason for pursuing this direction. These are obviously important and relevant goals, but they seem to unnecessarily narrow the potential of responsive buildings. We propose to first determine the theoretical boundaries for what can be done with interaction and then see to which degree current work on responsive buildings maps on these possibilities. Apart from sustainability and performance we suggest three more "worldviews" of a responsive system: servicing, symbolizing and entertaining. *Performing* is a worldview in which the building's behavior is optimized to a limited set of performance criteria (glare reduction or solar gain reduction, for example). *Sustaining* concerns reducing environmental pressure of the building (carbon output and reduced energy footprint). *Servicing* occurs when the main focus of the building is on optimal performance for the user need, without necessarily considering sustainability (interior lighting conditions for particular types of work or maintaining optimal water temperature in a swimming pool). *Symbolizing* has a focus on the representative role of buildings such as religious, cultural and national events. Finally, *Entertaining* looks at buildings as stages for events (such as concerts, leisure or relaxation).

The combination of four interaction activities and five worldviews lead to twenty attitudes for interactive buildings see (Table 4). The attitudes in the table are "personifications" to clarify the differences in attitudes, but they should not be taken too literally in terms of implementation (Achten 2013). Attitudes have an influence on two important aspects of the building-user interaction. First, they dictate the actual parameter settings of the components of the building (sensor, controller and actuator). For example, a *trainer* attitude will offer more definite advice to the user, how to improve building performance, whereas an *explorer* attitude will allow the user to make decisions which actually decrease performance. The second influence of attitudes concerns the narrative of the interactive system. The narrative is formed by the daily key points of interaction between a building and its user (Lehman 2013, 63–65) . The attitude informs the way the narrative is constructed. In a hospital for example, the patient-spaces' worldview could be servicing. A *HAL* attitude lays emphasis of self-monitoring and instructing the patient; a *host* attitude infers patients' need through dialogue; an *assistant* attitude empowers the patient to a certain level of self-treatment; and a *technician* attitude surveys options open to the patient.

SYSTEMS CONCEIVED AS AGENTS

Complex systems such as agents can be created out of (numerous) other agents, possibly combined with passive, reactive and autonomous components. These systems can be any kind of responsive component in a building, ranging from a small sensor array to reactive façade, roof system or kinetic shape-changing structure. As we have argued above, for the overall design consideration of such components first the interaction style should be defined, and then one or more attitudes for the components. If the system will have multiple attitudes then it is also necessary to define the change conditions which will set the component from one attitude to another (Achten 2014).

Any responsive system consists of sensors, actuators, control structures, and a material system, all of which will need to be designed. Some main parameters for their performance are derived from the interaction style and attitude. For example, environmental system style can be expected in health care institutions and mostly require subtle changes (to provide a calm environment), with no increased noise levels (in order not to distract patients and staff) and a minimum amount of interactions from the users (for hygienic purposes); whereas a partner style can be expected in a home situation with multiple users and desires (family members), that require feedback about current settings (for mutual information) and clear responses whether something has been done (for safety reasons).

However, for the design of a component these considerations alone are not sufficient, and a lot of know-how, experimentation and trying-out has to be invested before a responsive system is up and running. Especially when a building will consist of multiple interactive components, the relationships between the components will form an important factor. Beer (1995) has demonstrated for a fairly simple case (walking behavior of a legged agent under dynamic conditions) that the behavior of the agent is the result of the coupling of two dynamic systems—namely the agent and the environment—and cannot be assigned to just one of the systems. This coupling is also known under the term "situatedness," meaning that we cannot understand an agent's behavior unless we consider the way it is linked to its environment. Clancey additionally states that much of what we do is a re-coordination of previous combinations of perceiving (or sensing), conceiving (or deciding) and moving (or acting), rather than the manipulation of an explicit knowledge model (Clancey 1997, 1-2) . For the design of interactive architecture this means that responsive buildings are by definition situated—therefore it is extremely difficult and in some cases even impossible to imagine their possible behavior separate from their real environments and interactions with other agents.

For the design of responsive and interactive buildings it means that there will be no design methods that are guaranteed to lead to a proper solution. Part of the design of interactive buildings can be approached in a methodological way (Achten and Kopriva 2010), but a substantial part can be only be grasped through iterative processes of prototyping and testing out ideas (Sharp, Rogers and Preece 2007, 530–62).

CONCLUSION

In this paper we have given an overview of the potential of "agency" as a guiding principle in the understanding and design of responsive and interactive buildings. Although there is an increasing amount of experimentation with interactive architecture, it has not yet become a concern in mainstream architecture discourse, theory, methodology or education. There are many technological explorations that need to be put in a theoretical framework. The rather well developed notion of multi-agent systems from Artificial Intelligence can provide this framework, but needs to be formulated in an accessible way for architects. It is clear that architecture has the responsibility to make environments that are on the one hand sustainable and on the other hand relate to the dynamics of everyday life. We have to find the right balance between passive and active technologies although it is too early to say where this balance actually will be. In the meantime we can gain some understanding through "learning by doing" as responsive and interactive architecture by nature is situated.

NOTES

1. "Arduino." http://www.Arduino.cc/.

2. "Building Automation." Wikipedia. http://en.wikipedia.org/wiki/Building_automation.

3. "How Smart Homes Work." *How Stuff Works*. http://home.howstuffworks.com/smart-home.htm.

4. "Adaptive Building Initiative." *Adaptive Building Initiative*. http://www.adaptivebuildings.com/.

5. "Prairie House: House for a Fashion Pattern Maker and Fiber Artist—Northfield, IL." *Orambra*. http://www.orambra.com/~prairieHouse.html.

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