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Interactive Form-Generation in High-Performance Architecture Theory

[1]Anoosha Kia, [2]Mohammadjavad Mahdavinejad*
[1] Department of Architecture, Karaj Branch, Islamic Azad University, Karaj, Iran.
[2]Department of Architecture, Tarbiat Modares University, Tehran, Iran.*

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ABSTRACT: Architecture as a designerly way of thinking and knowing, is to interact with its environment. The manuscript is to speculate "interactive form-generation" based on high-performance architecture theory; and discuss the precursors and the potentials. The research aims to explore and determine the roots, aspects of interactive architecture as a part of performance-based design in contemporary architecture.

The research question opens a designerly perspective as an umbrella term that can include many streams of architectural paradigms. Emancipatory new-interpretivism is the research philosophy which is employed alongside deductive reasoning, logical argumentation research paradigm, descriptive research method and cross-sectional study. Based on methodology of the manuscript, the research is to addresses related phenomena, their relationship and interaction. The results of the research show that interactive architecture is an umbrella to address a wide-range of architectural emerging streams such as: 1- The evolutionary architectural trends include kinetics, responsive, smart, responsive and intelligent environment. 2- The emerging phenomena in the field such as leading sci-tech approach toward architectural design process including cybernetics, artificial intelligence (AI), virtual reality (VR), conditional generative adversarial network (cGAN), and agent based modeling.The conclusion of the research indicates that the interactive architecture branched off from high-performance architecture theory. The conclusion emphasizes on: 1- Designerly flexibility: better space efficiency, flexibility, intelligence and smartness; 2- Energy efficient form-generation: using less energy and offering more thermal-visual comfort; 3- Mathematical-algorithmic thinking: the integration of internet of things (IoT), robotics, and kinetics. 4- Futurism: a platform for outlining future architecture and architecture of future.

Keywords: *Artificial Intelligence (AI), High-Performance Architecture, Performance-Based Design, Mathematical-Algorithmic Thinking, Contemporary Architecture.*

INTRODUCTION

Interactive architecture as an emerging phenomenon is to address multiform and variable environment. Technology is growing rapidly, and artificial intelligence and other human achievements have been effective in all areas; Architecture is also necessary to keep pace with this path so that it can have a better relationship with modern man. Interaction means that it is possible to create conversations between humans and buildings in real time (Boychenko, 2017). Interactive design methodology gives architecture a chance to express itself away from the traditional constraints and enhance its performance between its built environment and contemporary social demand to create new possibilities satisfying the desires of challenge and change. The potential of having fully interactive spaces and buildings that are able to physically reconfigure form and space by creating a dialogue between the users and their built environment was achieved on the experimental level, this raises the expectation of developing fully integrated interactive applications in buildings soon. Therefore, the main aim of interactive design in architecture is identifies users' needs and not only responds to them but also influences their choices. In this regard, interactive architecture can be considered in two groups, a group that has been formed with the aim of social needs and the other with the aim of adapting to the environment and climate. It is estimated that the future of interactive design is looking for a

*Corresponding Author Email: *mahdavinejad@modares.ac.ir*

kind of architecture that learns from the environment.
New emerging IoT as groundwork for thinking about the architecture (Mahdavinejad, 2017) and architectural spaces shows a new step toward future architecture. (Amini et al., 2019) The convergence of interaction design and architecture (Mahdavinejad et al., 2014) is a way to interactive architectural design with diverse solution, while responsive interactions enriching architectural spaces.

MATERIALS AND METHODS

This research is qualitative and is done with the analytical and theoretical methods research. The research will focus on the themes that affected and constituted the basics of ideological and conceptual roots towards interactivity (Fig 1). In the first step, the development of the term interactive is examined, then in the next step, the proposed examples are reviewed and the ideas are evaluated, so the prior trends, which led to interactivity in architecture, will be known. (Rahbar et al., 2019) It seems that learning algorithms and probability distributions have opened a new chapter architectural design process and thinking. (Mahdavinejad et al., 2019) AI embodied interaction and ecological psychology and affordance (Mahdavinejad, 2014) might be seen as a tool to match between system and the real world. Finally, the benefits and effects of this process will be examined and this question will be answered: will interactive architecture improve the overall performance of the building?

Interactive Architecture

In this type of architecture, artificial intelligence responds to human activity or the environment. The purpose of this work is to improve spatial quality and environmental performance (Fig.2). The important thing in this regard is the intelligent diagnosis of the demand and the type of reaction to it. This is done by the agent. Intelligent agents are independent, can be simple or complex, and use knowledge to guide their activities toward a goal.
Translated heuristics algorithms for "error prevention" (Eslamirad et al., 2020) based on designerly way of knowing and doing (Javanroodi et al., 2019), are the generative matters

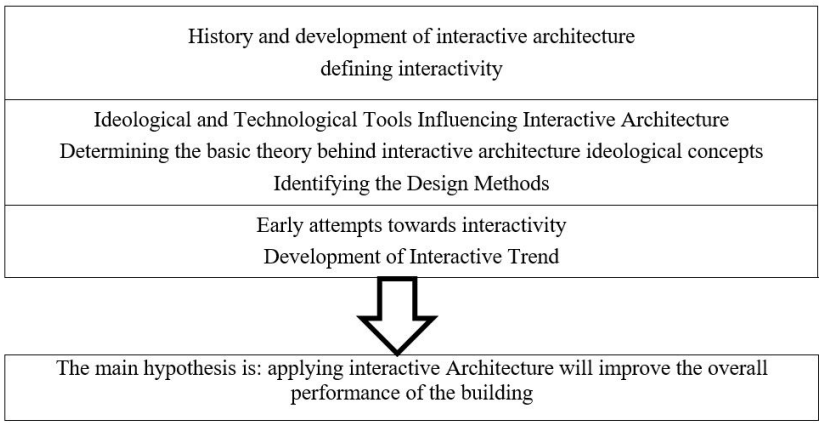


Fig. 1: Research Methodology

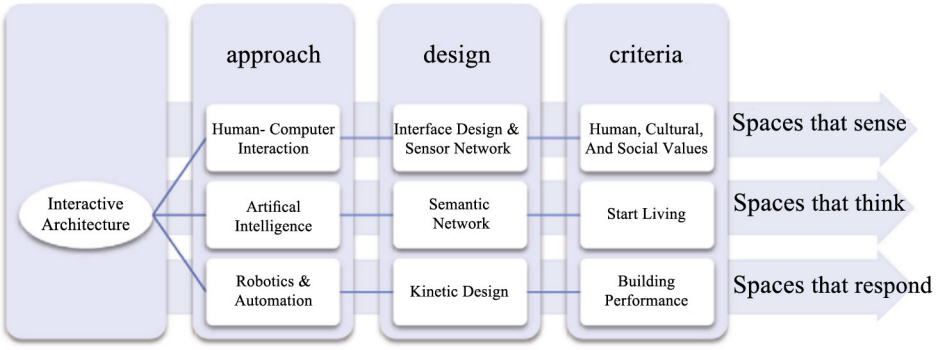


Fig.2: A theoretical framework of interactive architecture (Source: Gu & Wan, 2012)

of “aesthetic and minimalist design” and “visibility of system status”. It achieves this by using special computer technologies to react to people's behaviors and emotions. When a building or a part of the architecture is called interactive, it means that it integrates, or is a system that detects, and reacts to, human behavior or external parameters. Interactive architecture would be ideal when space could change according to users‟ needs over time. Interaction is the communication between messages received from the environment - humans and buildings. Unlike fixed architecture, interactive architecture is not fixed and has mobility flexibility. It is a determining question that “can architecture be programmed to learn from their own experience?” It seems that the answer to this question is going to determine future of interactive architecture and design.

Since this architecture is based on a human or environmental factor, so requires a two-way active relationship to form an interactive architecture. Interactive architecture is not designed to communicate with humans; In the first place, there is an artistic connection between the components of the building, and in the second place, there is a connection between these components and humans; in this architecture, the optimal use of space is targeted. In fact, human behavioral patterns and building tasks are known and a plan for optimal use is created. (Fox & Chen, 2010)

It is cybernetic perspective that outlines the interactive technologies and sociotechnical systems. Since very early in the development of interactive architecture as a field, the description of a new world where buildings have evolved alongside a futuristic society to assume new functional and social roles has populated the imagination of architects. This expectation is justified by two reasons: first, because it is known that technology has the potential to catalyze profound cultural transformations; second, because interactive architecture carries the potential to cause unprecedented shift to buildings’ capabilities, which have otherwise evolved at a very conservative pace (Mancilla, 2011).

From a cybernetic perspective, the idea of a more comprehensive interactive architecture should be exploited. Assuming that any interactive architecture system has an internal purpose, then any agent can only respond to a planned goal, and more comprehensiveness is needed for a complete interaction. In fact, architecture is fluid between man and building and virtual information. The simultaneous formation of these three factors promotes the active relationship between man and the environment. It can also have a psychological effect. If the system is intelligent, it can respond to unpredictable complexities and feedback loops (Rangel, 2007). ‘Hyperarchitecture’ defined by Ole Bouman (2002) is the result from the emergence between physical and virtual domains (Fig.3) It is a matter of crossing the analog and digital worlds, of hybrid environments that can no longer be classified as one thing or the other (Lertlakkhakul et al., 2016).

Interactive architecture or four-dimensional architecture showed that there is no boundary between the physical and the virtual world. Digital technology is needed to have this architecture.

The time-based feature of this architecture challenges traditional architecture. Designers are looking to achieve this by changing the boundaries between real and virtual space (Castel, 2005).

Fig.3: Spatial divisions are based on Veronese geometry. The centers are randomly formed and the distance from the center varies. Shrinking components leads to increased flexibility and mobility. (Source: Bullivant, 2005)

2Design	3D Design	4D design
Graphic design	Furniture design	Animatronics
Illustration	Ceramics and glass	Interaction design
Printed textiles	Interior design	Multimedia design
Film	Structured textiles	Product design
Video	Industrial design	Service design
2D animation	Fashion design	Event and game design
	3D illustration	Software design
	architecture	Corporate identity

Fig. 4: Shows that a new category of art has been formed. The four-dimensional design is designed to achieve dynamic content.

In two-dimensional and three-dimensional designs, the focus is on static space, while in four-dimensional design, dynamic space is emphasized, which is a kind of hnetic arts (Fig.4). Designers can focus more on knowledge to add value to the built environment. Many other activities, including time-based design and interaction, which are currently on the sidelines of professional design, become valuable as information becomes a commodity. Industrial design may also be considered as a four-dimensional design when both complex functional and kinetic movements and interaction are involved (Robertson, 1994). Energy efficiency in integrated building systems is depending on the level on integration and interactivity.

Interactive architecture is the complete integration of interactive design and architecture. This is based on computational convergence. Intelligence and a synthetic physical component can meet compatibility (Fig. 5). Combining these factors can allow a building to regulate itself and automatically make physical changes to respond, react, adapt, and interact (Fox & Chen, 2010).

Interactive architecture creates active spaces, that guides the users' behavior by having the ability to reason and learn, leading to the creation of spaces which can maintain a dialogue with their users, not only responding to their demands but proactively engaging themselves in all kinds of featured spatial activities (Jaskiewicz, 2008).

Intelligent Process

An approach, with a high degree of complexity, creates its stages based on the process of human intelligence. Information processing steps are examined from an applied perspective. The advantage of the approach is that the functions can be repeated in different fields, such as computer simulation. However, it should be noted that the results can only be similar when the simulated conditions and methods are close enough to the original case. A classical proposition to examine an intelligent process, using a functional approach based on biological and psychological observations, divides it into three main linear stages (Hayes-Roth, 1995).

Perception → Analysis → action

The first stage is perception, which is formed by obtaining information about the environment and turning it into a communication format. At this stage, the information obtained for use in the second stage is organized, identified

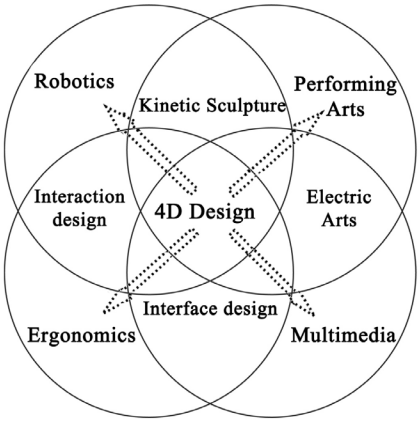


Fig. 5: 4D-design diagram (Source: Robertson, 1995)

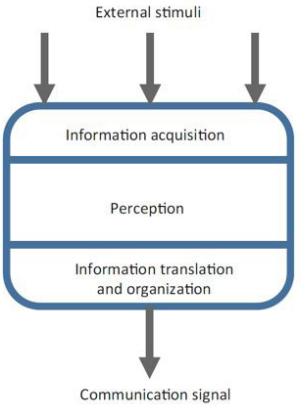


Fig.6: Perception as information acquisition (Source: Capeluto & Ochoa, 2016)

and interpreted. The physical environment is mapped and its properties are known using the rules that have these properties. The characteristic of "consciousness" is expressed by recognizing abstract variables such as "space" and "time" that go beyond simple data collection. In nature, information is provided by various biological receptors, commonly known to humans with five senses. Fig. 6 (Gallo et al., 2015; Sinha et al., 2016).

Action, is the third step in controlling activity in response to the initial stimulus detected by the perceptual system. The

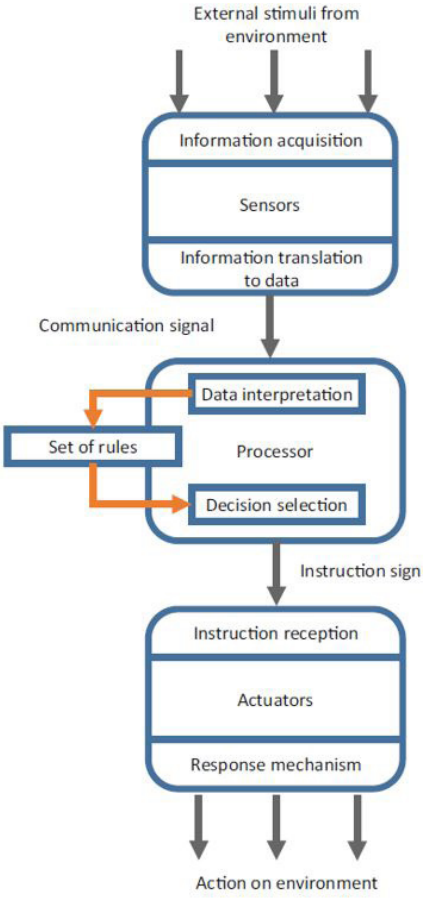
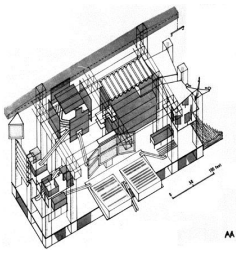
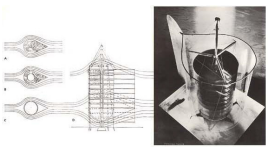
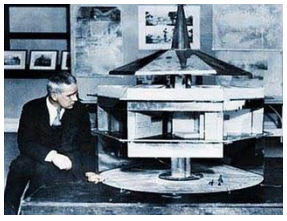


Fig.7: Diagram of main parts that carrying out the intelligence process for inanimate objects (Source: Capeluto & Ochoa, 2016)

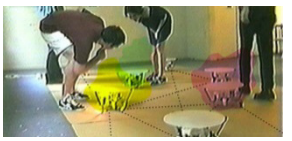
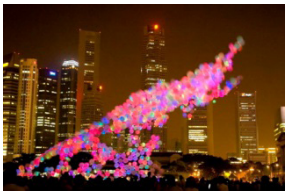
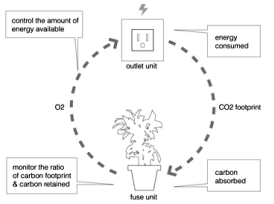
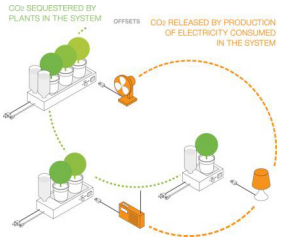
desired goal is achieved by changing the physical properties and movements considered. To form this, the center of reasoning must be in constant contact with certain organs or tissues that perform the intended function. Fig.7 shows how the intelligence process is applied to machines. It describes the relationship between sensors, analyzers and actuators. As seen in the text, different types of agents can be derived from this process, helping to conceptualize a series of intelligent envelopes (Capeluto & Ochoa, 2016).

Early architectural attempts toward interactivity might be seen as a comprehensive approach toward design. There have been several attempts starting from the second half of the last century from several architects towards having architectural and built spaces that are flexible enough towards their current social situations (Table 1).

Table 1: Early architectural attempts towards Interactivity

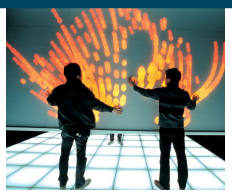
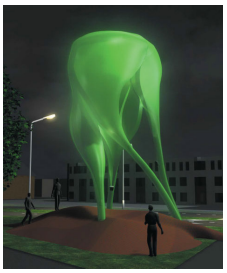
		Theory	Project	
			Image	Description
1- Attempts towards having more flexible and dynamic architectural	Cedric Price	- Allow us to think the unimaginable - Create an architecture that would be capable of evolving, learning, predicting and adapting to the program.	 Fun Palace, 1964	- Flexible enough to reconfigure itself - Compatible with the social and economic conditions of its time and place - Parts of the building are moved in different ways.
			 InterAction Centre, 1977	- Modular, prefabricated elements can be inserted and removed if necessary.
		(Canadian Centre of architecture Cedric price archives, 2011; Beesley & Khan, 2005, 22; Kronenburg, 2007)		
	Buckminster Fuller	- Ephemeralization; is a result of the Evolution of Technology, by which technological advancement can do more and more with less and less until eventually, you can do everything with nothing.	 4D Tower,1928	- Implement the latest technologies of their time to improve the resource usage and adapt to their surrounding environments - 4D: thinking of consequences for humanity instead of only immediate personal gain - Dymaxion House: use natural winds for the purposes of cooling and air circulation.
			 Dymaxion House,1945	
		(Schwaller, 2012; Ragan, 1999; Kronenburg, 2007)		

Continiue of Table 1: Early architectural attempts towards Interactivity

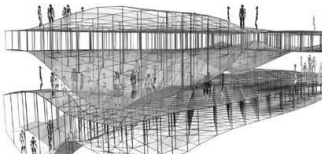
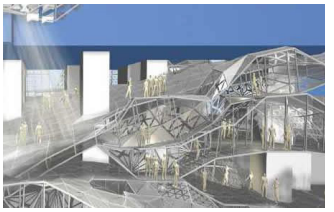
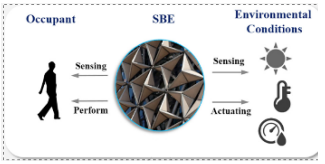
Theory		Project	
		Image	Description
1- Attempts towards having more flexible and dynamic architectural Usman Haque	- He differentiates architecture into hard and soft space (an architecture that cares about the pleasure of the senses). - The new language of architecture would have to entice each of the five senses, because each culture understands space differently, using a different combination of the senses.	  Moody Mushroom Floor,1996	- The community of mushrooms begins to converge on particular behaviors after they have spent time in their environment.
		  Sky Ear, 2004	- Usman, the artist and architect who designed the project, used balloons filled with helium gas that hangs in the air. Mobile LED light and electromagnetic sensors are other components of this set. Due to the sensor circuits, different colors have been created and created an attractive urban space.
		  Natural Fuse, 2009	- The project is about the structures of participation as it is about energy conservation. The network, through its users‟ interaction, determines the amount of energy flow in the system -The main concept of operating the system according to the carbon level. -A diagram showing connections of various appliances to the system.

(Bullivant, 2005; Langlois, 2010; Shute, 2009)

Continiue of Table 1: Early architectural attempts towards Interactivity

		Theory	Project	
			Image	Description
2-Interaction Architecture	Klein Dytham	The installation allows the audience to process and play with data in a very tangible and experimental way. ICE – the interactive communicative experience is a 'smart' info-lounge planted within this busy urban space.	 ICE, Bloomberg headquarters	The sensors convert movements and touch, converting them into optical and acoustic signals, inputs that are relayed back as vibrant, ever-changing reflective patterns, like manipulable fire, that cast giant electronic shadows.
	Lars Spuybroek	D-Tower is the result of several interactions and architecture is one of them. In this project, participation is based on social and emotional content. Collective sensation affects the building and the resulting interaction is the result of the connection between sense and space.	 D-Tower, 2004	The complex and soft form with the prefabricated epoxy structure is changed every night by colored light. Indigenous people express their opinion about their daily feelings on the poll site, and based on the opinion of the majority, the color of that feeling will be chosen and displayed.
	ONL	According to the designer, participation means a complex matching system; And in an intelligent building, all components must be programmable so that they can react based on social behavior.	 Digital Pavilion Korea,2006	Multi-media content immerses itself in the dynamic internal structure of the space and creates a multi-layered experience of the internal cellular structure of the space. Fig shows a panoramic view.
		(Castel, 2005; Bullivant, 2005)		
3-Kinetic Motion in Architecture	.Giselbrecht & Partner	Smart architecture refers to buildings and components that can be adapted to changing weather conditions. These buildings are also able to respond to non-climatic environmental changes such as movement, sound, etc.	  Kiefer Technic Showroom, 2010	Dynamic façade
	Mitsuru Senda		 Magnolia Stadium, 2007	Moving stadium ceiling
	Philip Beesly	- Ecological issues and sustainability reintroduce the importance of appropriate architectural interaction with the local and universal environment in which it is built.	 Kinetower 2011	- A common approach in large buildings that have mobility is to allow buildings to change their body shape in response to weather conditions. - Concept of a building whose façade elements respond to sunlight or the user inside.
		(Fox & Kemp, 2009; Brown, 2003, 32; Beesley et al., 2006, 20; Mahdavinejad & Nazar, 2017)		

Continiue of Table 1: Early architectural attempts towards Interactivity

Theory			Project	
			Image	Description
4-Responsive environments	Robert Neumayr	-Responsive environments: Changing its architectural form (shapeshift); It is the ability to change its architectural form according to environmental conditions, weather, and user's needs. In responsive architecture, the building or space envelope itself is a conditional indicator.	  Topotransegrity - Non-Linear Responsive Environment, 2006  Smart Building Envelopes- 2017  ETH Zurikh- 2019	In the evolved type, a responsive structural system is compatible with all spatial needs. This structure is able to sustain various changes, which are caused by changes in small-scale joints to large-scale deformations.

(Kim & Kim, 2017; Soliman Baghdady, 2013; Talaei et al., 2020; Cotrufo et al., 2020)

RESULTS AND DISCUSSION

"Interactive" as a term was already found in nature, as it is an emergent need for continuing by repeatedly changing in a continuous loop to meet the demands of different stimuli. It is a natural need necessary for survival. The relevance of interactive applications nowadays was related to the technological development brought by the information age, digital media and technologies, and remote communications. Thus, interactive architecture is not a result of technology development but a means of expressing the occurred development.

The roots of interactive architecture were based on previous practices done by architects like Cedric Price in the sixties and Buckminster Fuller. The main concept, which motivated their design approaches, was the use of the cybernetics theory in terms of both conceptual design and computational tools. There were always attempts to reach the goal of a more adaptable and flexible architecture that interact to changes through practicing the trends of kinetics, responsive and intelligent environments (Fig.8)

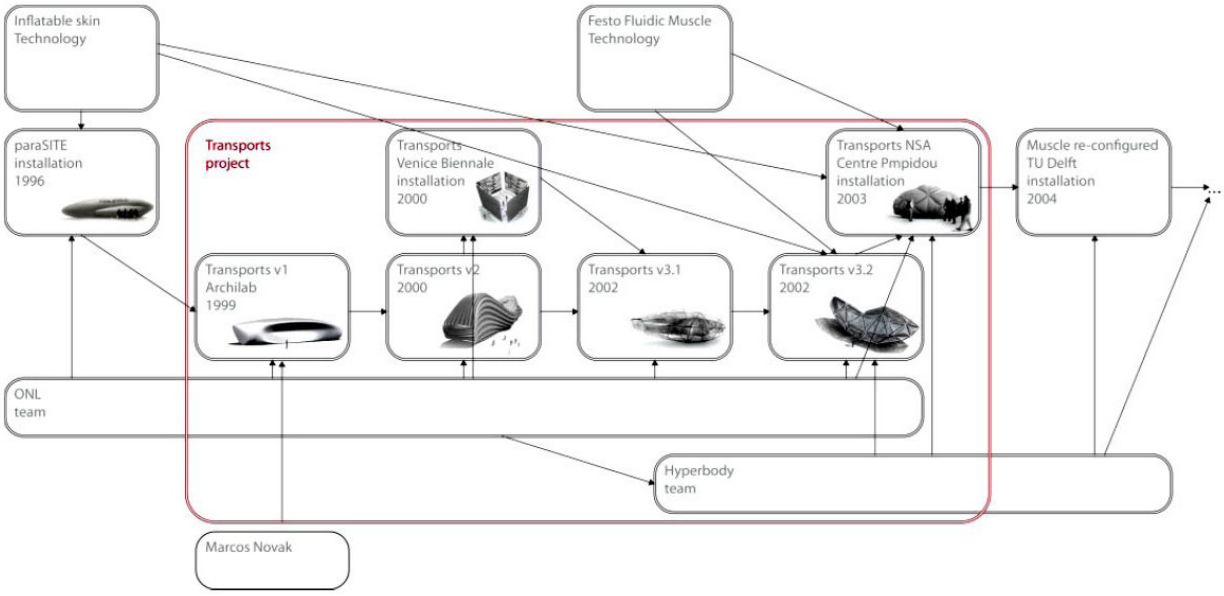


Fig.8: History of the interactive architecture (Source: Jaskiewicz, 2013)

Kinetics can be explored using movement or adaptation through mobility, through different typologies: Embedded kinetic structure, where the system that controls architecture as a whole according to changing factors. Deployed kinetic structure, where the system is transportable and found in temporary locations. Structure acts independently due to the control of a larger background.

"Responsive environments" was an attempt towards dynamic interactive architecture, but it was reactive in approach; it responded to environmental conditions, isolating the occupiers from their outer environments. Therefore, a smart environment can respond in a timely manner to information from a process that is measured and received from external and internal environments by multiple input detectors and information resources to meet the needs of users and with the ability to learn.

The results of the research show that interactive architecture is an umbrella to address a wide-range of architectural emerging streams as long as a theory of future architecture. The main roots of interactive architecture stem from new emerging technologies. It is to deal with two main branches including: -The evolutionary architectural trends include kinetics, responsive, smart, responsive and intelligent environment. -The emerging phenomena in the field such as leading sci-tech approach toward architectural design process including cybernetics, AI, VR, cGAN, and agent based modeling.

CONCLUSION

Interactive architectural features set it apart from others. In this type, space and user analysis is performed simultaneously; therefore, communication with users is provided by creating a unique spatial experience. The intelligent agent in this system allows an environment to be able to respond in a timely manner according to the processed information that can be tracked by trackers and multi-input information resources to meet the needs of users. To achieve the appropriate answer in this architecture, it is necessary to use advanced coding so that computers can enter the parts that were not present before and make the calculations possible continuously. In this way, sound, motion information or climatic parameters are received, and after analysis, they make it possible to make optimal decisions. For interactive architecture, the main parts of a building must follow relatively similar rules (although there will be differences depending on the situation), so minor processes (unlike the comprehensive process) cannot be architecturally responsive to design. Therefore, a central control system is needed for this coordination. For proper operation of this system, it is necessary that the components have flexibility and interchangeability, so the possibility of compatibility increases. Intelligent agent, virtual simulation, digital and media technologies involved in this type of architecture and can develop this system and for this agent, there is the ability to learn from external and internal environments.

The conclusion of the research indicates that the interactive architecture branched off from high-performance architecture theory. The conclusion emphasizes on:

Designedly flexibility: Interactive architectural approach toward design or interactive architecture might be seen as an effective and adaptive process for architectural design since the design problems have ill-defined multi-aspects. It results in

better space efficiency, flexibility, intelligence and smartness. It is to highlight that smart architecture is still very much technology driven, and is in need of more designerly approach in the field.

Energy efficient form-generation: Contemporary architecture in search for ecotopia (eco-utopia) is considering interactive architecture as an adaptive process for energy efficient architectural design; an effective strategy for using less energy and offering more thermal-visual comfort.

Mathematical-algorithmic thinking: Nowadays more than ever, architecture is in need of "integration" rather than "expertism". Sci-tech approach toward architecture emphasizes on adoption of mathematical-algorithmic thinking to integrate computer sciences, mechanics, robotics, electronics, and kinetics.

Futurism: New emerging concepts are to set a platform for outlining "future architecture" and "architecture of future". It is essential to highlight the concepts of embodied interaction and multi-relations. A pedagogical approach to programming for interactive architecture emphasizes on interaction of "tangible-intangible" and "physical-spiritual", environments.

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