Ain-Shams University
Faculty of Engineering
Architecture Department

Responsive Robotic Architecture

A Thesis Submitted to the Faculty of Engineering
Ain Shams University in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Architecture

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Department of Architecture

Submitted by: Engy Saad Hassouna
Thesis Title: Responsive Robotic Architecture
Degree: Master of Science Degree in Architecture

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عنوان الرسالة:- عمارة التفاعل الآلى

الدرجه:- ماجستير في العلوم الهندسية فى العمارة

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جامعة عين شمس
كلية الهندسة
قسم الهندسة المعمارية

عمارة التفاعل الآلى

الرسالة مقدمة كجزء من متطلبات الحصول

على درجة ماجستير في العلوم الهندسية فى العمارة

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Acknowledgment

Dedication

Statement

This thesis is submitted to Ain Shams University, Faculty of Engineering in partial fulfillment of the requirements for the degree of Master of Science in Architecture.

The work and material presented in this research has been collected, developed and accomplished by the author at the Department of Architecture, Faculty of Engineering; Ain shams University within 2005 to 2014.

No part of this thesis has been submitted for a degree or a qualification at any other university or institute.

Date: 02 / 11 / 2014

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Graduation Date: - June 2004

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Acronyms

Acronyms	Word
3D	Three Dimensional
AAAD	Algorithm Aided Architectural Design
AAD	Algorithm Aided Design
ADC	Analog to Digital
AI	Artificial Intelligence
ALU	Arithmetic Logic Unit
C / C++ / C#	General-purpose programming language:- C → Developed by Dennis Ritchie, starting in 1969 at AT&T Bell Labs. C++ → Developed by Bjarne Stroustrup at Bell Labs, starting in 1979. C# → Developed by Microsoft, appeared in 2000.
CA	Cultural Algorthim
CAAD	Computer Aided Architectural Design
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CPU	Central Processing Unit
CNC	Computer Numerical Control
CSCW	Computer Supported Cooperative Work
DAC	Digital to Analog Convertor
DC	Direct Current
DOF	Degree of freedom
EAP	Electro Active Polymer
EMS	Elastic Modular Systems
ERF	**Electro**-Rheological Fluid (Actuator)
F2F	File to Factory
FESTO	A worldwide leading supplier of pneumatic and electrical automation technology
GA	Genetic Algorithm
GDS	Group Decision Systems
HCI	Human Computer Interaction
HW	Hardware
iA	Interactive Architecture
IC	Integrated Circuit
iHCI	Implicit Human Computer Interaction
IKS	Intelligent Kinetic Systems

Acronyms	Word
I/O	Input and Output
IVM	Infinite Vision Media
KDG	Kinetic Design group
MAS	Multi Agent Systems
MIDI	Musical Instrument Digital Interface
MIMO	Multi Input / Multi Output
MIT	Massachusetts Institute of Technology
MRF	Magnetorheological Fluids (Actuators)
MSMA	Magnetic Shape Memory Alloy
M-SLE	Modified Scissors Like Element
ONL	Oosterhuis_Lénárd Design Studio
ORAMBRA	The Office for Robotic Architectural Media & The Bureau for Responsive Architecture
PACT	People, Activity, Context & Technology
PAM	Pneumatic Artificial Muscle
PC	Personal Computer
PS	Portospace
RAM	Random Access Memory
ROM	Random Only Memory
RTC	Real Time Computing
SAA	Sensing Analysis Actuators
SAD	System Analysis Design
SI	Swarm Intelligence
SLE	Scissors Like Element
SMA	Shape Memory Alloy
SW	Software
SWOT	Strength, Weakness, Opportunities & Threats
SISO	Single Input / Single Output
t	Time
UCD	User Centered Design
VGT	Variable Geometry Truss
VR	Virtual Reality
VOR	Virtual Operation Room
WBS	Work Breakdown Structure

Abstract

The architectural profession is adopting new digital and physical framework, these frameworks are defined by design methods, instruments and operation. The unconventional frameworks are challenging the traditional ones and technical purists of the architectural discipline.

Responsive structures are those having the ability to change their shape, alter their form and configuration in response to fluctuating patterns in real time with high intelligence to internal and external environmental changes. A responsive robot on the other hand is considered a learning one possessing a high level of intelligence, it acquires novel skills or adapt to its environment through learning algorithms either through autonomous self-exploration or through guidance from a human teacher, the aim of this thesis is to define architecture as a machine to live in; although it is a classic dream, up to current date it is still considered a fresh promising field to investigate in.

The aim of this research is to mimic a learning robot framework and reflect it on architectural applications to produce a responsive transduced automated environment. In order to reach such theoretical framework and determine its basic required components the thesis was built upon three parts defining the method of thinking, software and hardware parts in general notions.

The first part of the thesis gives a brief note of the method of thinking, of acquiring such type of intelligence by introducing cybernetics methodology, soft techniques as artificial intelligence, swarming, algorithms, game theory and agent design. While the second part of the thesis defines the system of such learning transduced machine; how it will interact and respond in real time in the physical world by introducing human computer interaction and different types of frameworks adopted either implicit, explicit or other types. Finally the third part investigates in two methods proposed by the research to build such a structure of a responsive building, first introducing the Tensegrity structures and the second introducing the kinetic structures in between these two systems more practical considerations were tackled as transduction notion and its architectural application as well as a smart novel material introduction, and finally closing down the search with deducted framework.

The main emphasis of this thesis is to introduce novel techniques that enable the formulation of such responsive robotic systems, in a way that is suitable for the purpose of interaction and control, while dealing with uncertainty issues and guaranteeing intelligent robustness. Solution

Keywords

Responsive – Interactive – Transduce – Sensors – Actuators – Systems – Cybernetics – Kinetic Structures – Tensegrity Structures – Smart Materials.

Introduction

Responsive architecture is fast becoming a buzzword in architecture and related disciplines. However, it is not entirely clear what constitutes Responsive architecture and how relates to or differs from such closely related camps as Smart architecture, Performative architecture, Kinetic architecture, Interactive architecture, Transformable architecture and Adaptive architecture.

Assuming that the promises of Responsive Architecture outweigh the risks, the greatest challenge is to develop a working responsive architectural system. No-one has yet fully succeeded in making a truly self-evolving building system, the revival of the trend in recent decade, driven by increased power and decreased cost of digital technologies brings new hope. However, the challenge of creation of responsive architecture is manifold. Three main aspects of this challenge are methodology, technology and operation and that's what will be addressed theoretically through the thesis chapters to reach a framework for a responsive robotic building.

Developments in innovative technologies and smart materials have created new opportunities and are suggesting significant changes in the way we design and build architecture. Traditionally, however, there has always been a gap between the new technologies and their applications.

Even though, most technological innovations hold the promise to transform the building industry and the architecture within, and although, there have been some limited attempts in this area recently; to date architecture has failed to utilize the vast amount of accumulated technological knowledge and innovations to significantly transform the industry. Consequently, the applications of new technologies to architecture remain remote and inadequate.

The knowledge required to build a truly responsive form of architecture is substantial, an understanding of architecture, robotics, artificial intelligence and structural engineering are all beneficial. The links that are required between each knowledge base to actuate and control the responses of this type of architecture further complicate matters – suggesting potential reasons for the ambivalence of architects towards deeply exploring to the topic or extending it beyond the aesthetic application of an event-based architecture.

This thesis explores the theoretical roots of responsive architecture while establishing a framework that describes the relationships between the physical systems used within responsive buildings, their finesse, construction, and program led behaviors, in-order to pin down the gap of the rapid challenging high technological interactive community.

These intricate, complex responsive systems are usually within five common debates which are, first: **Real-time environmental response**, second: **Structure**, third: **Smart material**, fourth: **Automation**, and fifth: **Transduction**; Embedded microprocessors, sensors and actuators.

This search at the beginning of the study aimed to go from theory to practice by building a real physical model, but due to lack of tools and technological capabilities, it was only limited to cover the theoretical section hoping for further investigation to elaborate an actual working physical model in real time.

Responsive Robotic architecture are not merely an issue of interacting with sensors and auctioning by actuators and controllers. They are more likely aiming to build an environment that is capable of learning and responding intelligently in real time; an environment that takes part in the daily life of the occupants and integrating with the surrounding natural environment. That's what makes the difference between responsiveness and other interactive and reactive techniques in short, it is a learning environment capable of adapting and fulfilling occupants' needs.

Research Problem Statement

Introducing a responsive robotic architectural model challenging long held assumptions about architecture as a passive static arrangement, up to date, there do not yet exist a true full responsive building, current buildings may include some parts with embedded actuators and sensors. Yet, there have not reached the required level of intelligence to be actually learning and in continuous change.

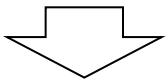
The ambivalence is towards deeply exploring the topic of responsive robotic architecture and extending it beyond the aesthetic application of an event-based architecture.

"THE ONLY CONSTANT IS CHANGE SO DO RESPONSIVENESS" [1]

Problem → Buildings are static

Solution →

Designing for Uncertainty



Acting in Real Time

Responsive (Communicating) + Robot (Learning)

Responsiveness + Robotics = Variable Environment

In simple words, we need a variable architecture as our variable life, the only constant in our life is change so do the buildings embracing us ought to be, the problem is our buildings are stuck in the good old days while our current environment is full of innovations, technology and rapid continuous change the aim is to catch up and fill up the gap by conducting such research a proposed framework is conducted and an analysis of parts of such learning environment is introduced.

1) Original quote "The Only Thing That Is Constant Is Change" by Heraclitus of Ephesus (Ἡράκλειτος, Herakleitos; c. 535 BC – 475 BC) a Greek philosopher.

Thesis Question

How can we design, execute and operate buildings in real time, in so many contexts, with so many different occupants and by an infinite number of scenarios?

The answer is given through this research, introducing a framework for a responsive robotic architecture .

- **Why Responsive?**

→ To communicate with the occupants and the surrounding environment and adapt to change

- **Why Robotic?**

→ To be innovative and learning

- **Why Responsive Robotic?**