Week 13
Artificial Intelligence in Architecture

This week we will explore AI applications in architecture and looking at Generative Design.
Outline

01
Artificial Intelligence (AI)
Ranging from a historical perspective of AI dated in 1954, to the state-of-art of AI applications.

02
AI in architecture
Exploring how AI is adapted to the field of architecture and computational design.

03
Generative Design
Generative design techniques, implementation and potentials.
Aims and objectives

- To contextualise definitions and concepts of AI
- To illustrate historical accounts of AI
- To contextualise AI in the field of architecture
- To elicit the state-of-art of AI in architecture, along with future recommendations
- To expand on Generative Design in computational design thinking
Learning outcomes

*Students will be able to...*

01 Gain understanding on the background knowledge of AI.

02 Enumerate influential figures in AI and AI in architecture.

03 Elicit Generative Design and its potential in computational design.
**Overarching skills**

- **Theory, history and current debate**
  Understand historical background of this notion and relevant debates.

- **Important concepts**
  - Digital fabrication and construction
  - Digital design cognition
  - Human-computer interaction
  - Digital craftsmanship
  etc

- **Software skills**
  Rhino, Grasshopper, etc

- **Research skills**
  Designing through extensive research

- **Personal interest**
  Exploring a preferred scope of design to be developed further

- **Design precedents**
  Learning through analysis of completed project
Read Cudzik and Radziszewski (2018) discussion on three adopted AI methods. Share your thoughts on the fact that these methods will result in more intuitive design tools.

You can find the paper in supporting materials

https://miatedjosaputro.com/2020/05/19/week-13-discussion/
Artificial Intelligence
**Definitions of AI, organised in 4 categories**


<table>
<thead>
<tr>
<th>Thinking Humanly</th>
<th>Thinking Rationally</th>
</tr>
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<tbody>
<tr>
<td>“The exciting new effort to make computers think ... machines with minds, in the full and literal sense.” (Haugeland, 1985)</td>
<td>“The study of mental faculties through the use of computational models.” (Charniak and McDermott, 1985)</td>
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<td>“[The automation of] activities that we associate with human thinking, activities such as decision-making, problem solving, learning ...” (Bellman, 1978)</td>
<td>“The study of the computations that make it possible to perceive, reason, and act.” (Winston, 1992)</td>
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<table>
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<tr>
<th>Acting Humanly</th>
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<td>“The art of creating machines that perform functions that require intelligence when performed by people.” (Kurzweil, 1990)</td>
<td>“Computational Intelligence is the study of the design of intelligent agents.” (Poole et al., 1998)</td>
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<td>“The study of how to make computers do things at which, at the moment, people are better.” (Rich and Knight, 1991)</td>
<td>“AI ...is concerned with intelligent behavior in artifacts.” (Nilsson, 1998)</td>
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**Figure 1.1** Some definitions of artificial intelligence, organized into four categories.
Concerning thought processes and reasoning

Definitions of AI, organised in 4 categories


Thinking Humanly:
The cognitive modelling approach. "The art of creating machines that perform functions that require intelligence when performed by people." (Kurzweil, 1990)

1. Introspection
2. Psychological experiments
3. Brain imaging

"The study of how to make computers do things at which, at the moment, people are better." (Rich and Knight, 1991)

Thinking Rationally:
The "laws of thought" approach. "Computational Intelligence is the study of the design of intelligent agents." (Poole et al., 1998)

Syllogism
Logic
Logicist

"The study of the computations that make it possible to perceive, reason, and act." (Winston, 1992)

Acting Humanly

Acting Rationally

"AI ... is concerned with intelligent behavior in artifacts." (Nilsson, 1998)

Figure 1.1 Some definitions of artificial intelligence, organized into four categories.
**Definitions of AI, organised in 4 categories**


**Concerning behaviour**

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<tr>
<td>“[The automation of] activities that we associate with human thinking, activities such as decision-making, problem solving, acting humanly.” (Carnielli, 2003)</td>
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**Acting Humanly:** (Bellman, 1978)

The Turing Test (#1-4) approach.

- The computer would need to possess the following capabilities:require intelligence
  - Natural language processing
  - Knowledge representation
  - Automated reasoning
  - Machine learning

**Total Turing Test,** computer would need to possess:

1. Computer vision
2. Robotics

**Thinking Rationally**

“The study of mental faculties through the use of computational models.”

“The study of the computations that make it possible to perceive, reason, and act.”

(Winston, 1992)

**Acting Rationally:**

The rational agent approach.

Rational agents are expected to act such as: operate autonomously, perceive their environment, persist over a prolonged time period, adapt to change, and create and pursue goals.

(Charniak and McDermott, 1985)
Emergence of AI

Initial effort involved modelling the neurons in the brain, initiated by:

1943 McCulloch and Pits
1949 Donald Hebb
1950 Alan Turing developed an empirical test of artificial intelligence.
1956 John McCarthy coined the term *Artificial Intelligence* in the 2-month workshop at Dartmouth University.

Development of AI


1956-1969
Early enthusiasm, great expectations
Newell and Simon GPS (General Problem Solver) was designed to start to imitate human problem-solving protocol.
In 1958 Marvin Minsky collaborated with McCarthy

1966-1973
A dose of reality
Difficulties of early systems when tried out on wider selections of problems and on more difficult problems. Scaling up problems.

1969-1979
Knowledge-based system
DENDRAL (1969): first successful knowledge-intensive systems, its expertise derived from large number of special-purpose rules.

1980-present
AI becomes an industry

In 1958 Marvin Minsky collaborated with McCarthy
Development of AI

It is now more common to build on existing theories rather than propose new ones.

AI adopts the scientific method
1987–present

Availability of very large data set
2001–present

1986–present
The return of neural networks

1995–present
The emergence of intelligent agents

One of the most important environment for intelligent agents are the internet.

Influential figures of AI:

1. John McCarthy
2. Marvin Minsky
3. Alan Turing
4. Allen Newell
5. Herbert A. Simon
6. J.C.R. Licklider

1927-2011
One of the founding fathers of Artificial Intelligence. He invented Lisp in 1960, a family of programming languages.
Influential figures of AI:

1. John McCarthy
2. Marvin Minsky
3. Alan Turing
4. Allen Newell
5. Herbert A. Simon
6. J.C.R. Licklider

1927-2016
Founder of MIT Artificial Intelligence Project. He believed that AI might eventually offer a way to solve some of humanity’s biggest problems.
Influential figures of AI:

1. John McCarthy
2. Marvin Minsky
3. Alan Turing
4. Allen Newell
5. Herbert A. Simon
6. J.C.R. Licklider

1912-1954
In 1950 he was already grappling with the question whether machines can think. Turing Test remains a useful way to chart progress of AI.
Influential figures of AI:

1. John McCarthy
2. Marvin Minsky
3. Alan Turing
4. Allen Newell
5. Herbert A. Simon
6. J.C.R. Licklider

1927-1992

His central goal was to understand the cognitive architecture of the human mind and how it enables human to solve problems.
Influential figures of AI:

1. John McCarthy
2. Marvin Minsky
3. Alan Turing
4. Allen Newell
5. Herbert A. Simon
6. J.C.R. Licklider

1916-2001

He is best known for his work on the theory of corporate decision making known as “behaviourism”.
Influential figures of AI:

1. John McCarthy
2. Marvin Minsky
3. Alan Turing
4. Allen Newell
5. Herbert A. Simon
6. J.C.R. Licklider

1915-1990

He is considered as the Father of Internet.


The hope is that, in not too many years, human brains and computing machines will be coupled together very tightly and that the resulting partnership will think as no human brain has ever thought and process data in a way not approached by the information-handling machines we know today.

—J.C.R. Licklider
Man-Computer Symbiosis
Important concepts in AI: Intelligent Agents

AI can be seen as a study of rational agent and its environment.

An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators.

An rational agent acts as to maximise the expected value of performance measure, given the percept sequence.

## Important concepts in AI: Properties of Task Environments

### PEAS: Performance Environment Actuators Sensors

<table>
<thead>
<tr>
<th>Agent Type</th>
<th>Performance Measure</th>
<th>Environment</th>
<th>Actuators</th>
<th>Sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical diagnosis system</td>
<td>Healthy patient, reduced costs</td>
<td>Patient, hospital, staff</td>
<td>Display of questions, tests, diagnoses, treatments, referrals</td>
<td>Keyboard entry of symptoms, findings, patient’s answers</td>
</tr>
<tr>
<td>Satellite image analysis system</td>
<td>Correct image categorization</td>
<td>Downlink from orbiting satellite</td>
<td>Display of scene categorization</td>
<td>Color pixel arrays</td>
</tr>
<tr>
<td>Part-picking robot</td>
<td>Percentage of parts in correct bins</td>
<td>Conveyor belt with parts; bins</td>
<td>Jointed arm and hand</td>
<td>Camera, joint angle sensors</td>
</tr>
<tr>
<td>Refinery controller</td>
<td>Purity, yield, safety</td>
<td>Refinery, operators</td>
<td>Valves, pumps, heaters, displays</td>
<td>Temperature, pressure, chemical sensors</td>
</tr>
<tr>
<td>Interactive English tutor</td>
<td>Student’s score on test</td>
<td>Set of students, testing agency</td>
<td>Display of exercises, suggestions, corrections</td>
<td>Keyboard entry</td>
</tr>
</tbody>
</table>

**Figure 2.5** Examples of agent types and their PEAS descriptions.
Contemporary figures of AI:

1. Andrew Ng
2. Yoshua Bengio
3. Yann LeCunn
4. Demis Hassabis
5. Geoffrey Hinton
6. Fei-Fei Li
What can AI do now?

1. Robotic vehicles
2. Speech recognition
3. Autonomous planning and scheduling
4. Game playing
5. Logistics planning
6. Robotics
7. Machine Translation
8. Any many more..
AI application in COVID-19 in healthcare


**Main applications** are:
1. Early detection and diagnosis of infection
2. Monitoring the treatment
3. Contact tracing of individuals
4. Projection of cases and mortality
5. Development of drugs and vaccines
6. Reducing healthcare workers’ workload
7. Prevention of the disease

![Diagram of AI and non-AI based applications](image-url)
AI application in COVID-19 in other areas


AI infused technologies have presented potentials during pandemic, such as:

1. Labour-replacing robots in recycling industry, AMP Robotics.
2. Robotic telepresence platforms (college graduation experience in Japan).
3. Noisy fans in empty stadiums, baseball games in Taiwan.
misconceptions of the proliferation of AI:

https://www.business.com/articles/4-misconceptions-about-ai/

1. AI is actively looking to replace people (or architects)
2. AI can solve any problem
3. AI is infallible
4. AI will be the end of humanity
Artificial Intelligence in Architecture
Virtual exhibition (due to the pandemic) "Architecture and AI" at the Pavilion de l’Arsenal in Paris.
28 February - 5 May 2020
http://stanislaschaillou.com/arsenal/vtour/
“AI does bring a more holistic approach to understanding architecture and uncoding its complexity in terms of computer commands.”

Stanislas Chaillou
Architect and AI Researcher

“.. (AI) enable the architect to get a very fast feedback... and that’s very important. .. the faster the iterations are, the faster you can process new design, the more ideas you can explore..”

Bastian Dolla
Cofounder, HABX

“..the magic is really created when you combine architectural intuition and artificial intelligence and give the architect superpowers.”

Anders Kvale
Cofounder & President, SPACEMAKER

“..it necessitates the collaboration between architect and the machine.. It will allow the architects to be challenged in their many choices, but architects will not be replaced.”

Nathalie Watine
Executive Vice-president, Innovation, Digital Transformation and Information systems, Bouygues Immobilier

https://vimeo.com/400297372
**SPACEMAKER:**
Using AI to maximise potential of building site

Key product features

<table>
<thead>
<tr>
<th>Generate and optimize</th>
<th>Analyze solutions</th>
<th>Refine and iterate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lamellae #1</strong> (10 Aug - 7 Sep)</td>
<td><strong>Lamellae #2</strong> (10 Aug - 7 Sep)</td>
<td><strong>Lamellae #3</strong> (10 Aug - 7 Sep)</td>
</tr>
<tr>
<td>Area: 19,750 m²</td>
<td>Area: 19,780 m²</td>
<td>Area: 20,660 m²</td>
</tr>
<tr>
<td>Sun: 202 m²</td>
<td>Sun: 201 m²</td>
<td>Sun: 170 m²</td>
</tr>
<tr>
<td>View distance: 70%</td>
<td>View distance: 70%</td>
<td>View distance: 70%</td>
</tr>
<tr>
<td>Noise: 4%</td>
<td>Noise: 4%</td>
<td>Noise: 2%</td>
</tr>
</tbody>
</table>

Design better cities with artificial intelligence
Historical viewpoints: technological paradigms of 4 architects:

1. Christopher Alexander
2. Richard Saul Wurman
3. Cedric Price
4. Nicholas Negroponte

The discussions in the book are based on questions such as:

In what ways were these practices architectural, and how did they push the boundaries of architecture?

Similarly, how did their experiments with computing and technology push the bounds of the technological fields in which they were working?

What did computational, cybernetic, and artificial intelligence researchers and engineers stand to gain by engaging with architects and architectural problems?

How did architecture become useful territory for the imagination of new digital worlds?
Historical viewpoints: technological paradigms of 4 architects:

1. Christopher Alexander
2. Richard Saul Wurman
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4. Nicholas Negroponte

He and his colleagues developed an operating system for order, which is called pattern languages. His approach to pattern is vital to human-centered design. He is regarded as the father of the **pattern language** movement.
Historical viewpoints: technological paradigms of 4 architects:

1. Christopher Alexander
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For Wurman, *information architecture* referred to the organisation of information on the page, in a map, within a book, as a design language.

Wurman influenced a generation of software and web designers with the concept of *information architecture* by application on the structure and design of websites, software and mobile applications.

He is also best known for founding TED conferences.
Historical viewpoints: technological paradigms of 4 architects:

1. Christopher Alexander
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Price designed buildings that were determined by their flows of information. He incorporated cybernetics feedback loops in projects, which challenged relationships between: architects, users, sites and technology.

Most of his projects are unbuilt, yet they provoke fellow architects, students and got them to question what a building can be and how computation might change its notion.
“Intellectual experiment”

Fun Palace (1958-1964)

Cedric Price and Joan Littlewood

“The fun palace was not a building in any conventional sense, but was a socially interactive machine, highly adaptable to the shifting cultural and social conditions.” *

A model for the 1976 Centre Pompidou

"Intellectual experiment"  
Fun Palace (1958-1964)  
Cedric Price and Joan Littlewood
Historical viewpoints: technological paradigms of 4 architects:

1. Christopher Alexander
2. Richard Saul Wurman
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4. Nicholas Negroponte

Negroponte, along with his colleague Leon Groisser, founded MIT’s Architecture Machine Group (AMG) in 1967. It became the foundation of MIT Media Lab. The lab’s research area includes AI, machine-learning, intelligent environments, virtual reality, remote sensing and drone surveillance.

His vision includes architecture machine that would turn the design process into a dialogue.
Current debates in AI in architecture:

The application of AI in architecture is still in infancy stage, prominent figures and design practice are pushing boundaries at what AI could bring to the field.
Three adopted methods from AI


1- Evolutionary algorithms

Inspired by biological evolution. It enables adjustment of input parameters, leading to optimised configuration in the reference of set goals. Example of this in architecture includes the use of in optimisation to reduce materials usage. Commonly known as Genetic Algorithm (GA).

Architectural evolutionary system based on Genetic Algorithms

Read more on GA (can be downloaded from supplementary materials):
• www.interactivearchitecture.org/architectural-evolutionary-system-based-on-genetic-algorithms.html
Three adopted methods from AI


2- Swarm Intelligence

Behaviour-based solution. A collective behaviour of decentralised, self-organised systems. For example: a collective behaviour of bird flocking. It presents potential in macro-scale intelligent system of simple rules at local level, which in turn provides designers an efficient and simple tool to generate bio-inspired complex design.

The flock algorithm.
Three adopted methods from AI


3- Neural Network

The system enables training the artificial neural networks based on the provided examples (training set), in the form of: input parameters and corresponding output values. According to Cudzik and Radziszewski (2018), possible wider application of NN might take place during all planning phase. In particular repeatable and predictable activities.
Adopted methods from AI


Combining machine learning with intelligent construction

Re-perceive 3D printing with Artificial Intelligence

Dechen Chen¹, Dan Luo², Weiguo Xu³, Chen Luo⁴, Liren Shen⁵, Xia Yan⁶, Tianjun Wang⁷
¹,²,³,⁴,⁵,⁶,⁷Tsinghua University
²luo_dana@126.com

How can machine learning be combined with intelligent construction, material testing and other related topics to develop a new method of fabrication? This paper presents a set of experiments on the dynamic control of the heat deflection of thermoplastics in searching for a new 3D printing method with the dynamic behaviour of PLA and with a comprehensive workflow utilizing mechanic automation, computer vision, and artificial intelligence. Additionally, this paper will discuss in-depth the performance of different types of neural networks used in the research and conclude with solid data on the potential connection between the structure of neural networks and the dynamic, complex material performance we are attempting to capture.

Keywords: 3D printing, AI, automation, material, fabrication
Architects’ challenges in AI-enabled architecture

https://towardsdatascience.com/the-advent-of-architectural-ai-706046960140

1. Architects have to pick up on adequate **taxonomy**. I.e. the right set of objectives for the machine
2. Architects must select, the vast field of AI, the **proper tools** and **train** them.
AI design practices:

Adapted from https://www.archdaily.com/936999/pioneers-6-practices-bringing-ai-into-architecture

1. Xkool
2. AI + Architecture
3. 3XN
4. Ai Build
5. XL Lab SWA Group
6. Sidewalk Labs
7. Jenny Sabin
Generative Design
Computational Design:
1. Parametric
2. Generative
3. Algorithmic Design

Generative Design is a design approach that uses algorithms to generate designs.

More autonomous than parametric design.

Caetano et al. (2020)
https://thispersondoesnotexist.com/
Generative Adversarial Networks

GAN was invented by Ian Goodfellow and his colleagues in 2014.

It is a class of machine learning.
Generative Adversarial Networks


Goodfellow’s Introduction to GANs (2017): https://youtu.be/9JpdAg6uMXs
Generative Adversarial Networks

Adversarial Training:
“Training in a model in worst-case scenario, with inputs chosen by an adversary”
Generative Adversarial Networks

The **Discriminator** is trained to recognise images from a set of data. With proper training, this model is able to distinguish between a real example, taken out of the data set, from a ‘fake’ image, foreign to the data set.

The **Generator**, is trained to create images resembling images from the same dataset.

As the **Generator** creates images, the **Discriminator** provides him with some feedback about the quality of its output. The **Generator** adapts, to produce even more realistic images.
Stanislas Chaillou, explored the potential of AI applied to floor plan generation
Generative Adversarial Networks in Architecture:

Stanislas Chaillou, explored the potential of AI applied to floor plan generation

https://towardsdatascience.com/ai-architecture-f9d78c6958e0
Generative Adversarial Networks in Architecture:

Multi-step pipeline emulating process taken by architects:
1. Building Footprint
2. Room Split & Fenestration
3. Furnishing

https://towardsdatascience.com/ai-architecture-f9d78c6958e0
Generative Adversarial Networks in Architecture:

**FINCH (Under development tool for architects)**

It aims to automatically generate floor plans based on site constraints.

[https://finch3d.com/video-blog/](https://finch3d.com/video-blog/)
[https://architizer.com/blog/inspiration/industry/finch-automatic-plan-generator/](https://architizer.com/blog/inspiration/industry/finch-automatic-plan-generator/)
Generative Design in Urban Context:

Sidewalk Labs


[https://youtu.be/h7gq7OrgbxY](https://youtu.be/h7gq7OrgbxY)

What Sidewalk Labs generative design tool offers compare to non-AI enabled architecture:

1. Using machine learning, generating many comprehensive planning scenario.
2. It can evaluate the impact of each scenario.
Generative Design: Five design techniques

1. Cellular Automata
2. Genetic Algorithms
3. L-systems
4. Shape grammars
5. Swarm Intelligence

Singh and Gu (2012) propose a framework of an integrated Generative Design system that can support these five techniques.

What is the future of AI in Architecture?

https://www.archdaily.com/937523/how-artificial-intelligence-will-shape-design-by-2050

- AI will continue to shape how we live, work and play
- Urban Intelligence and Big Data
- Transportation, transit is being re-imagined on the street and in the air
- Construction will be hugely affected, towards human-free construction process
- The Singularity moment, the point at which exponential technological advancements cross the threshold of ‘strong AI’ and machines possesses a broad intelligence that exceeds human levels.
Re-iterated aims and objectives

- To contextualise **definitions and concepts of AI**
- To illustrate **historical accounts of AI**
- To contextualise AI in the field of **architecture**
- To elicit the **state-of-art of AI in architecture**, along with future recommendations
- To expand on **Generative Design** in computational design thinking