AI IN THE PROFESSION OF DESIGN AND CONSTRUCTION

Abstract

Artificial Intelligence (AI) has yet to have a substantial impact in a quickly changing world where it is being investigated. With this, AI undoubtedly can be seen as a fundamental instrument for the future, although whether it will be successful, while still intelligent, is still in question. Analyzing the various technologies, this research paper will examine which role AI could play in the architectural design process as well as architects themselves. A case study of two houses which have been designed using AI in real time helps to uncover the limitations of current AI and subsequent scope of development in the future for AI to assist in better design solutions. Interviews with field experts helps to understand how present architects can keep pace with the future that Ai offers and the utmost need for SOCIAL VALUE addition to make the designers indispensable. Further look at the AI advancements in other fields, this paper attempts to predict the future critical AI developments which can be revolutionary in the field of architecture and the possible opportunities that it offers to the designers as the programme developer.

Keywords: Artificial Intelligence, Architect, Impact of AI on Architecture, GAN, Architect's role, disruptive technology.

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I. INTRODUCTION AND BACKGROUND FOR RESEARCH

Artificial intelligence (AI) stands out as a digital-age revolutionary technology. With its advancement everyday, it is changing every profession including the work of an architect. The architecture profession is a mix of science, engineering and art. The role of an architect has evolved over the years and has emerged as a so called mediator between different professions to give birth to a building. What was once done by hand is now getting digital. With the rise of AI, there is a common fear that what was developed as a tool to assist designers could eventually replace them and make them obsolete.

1. **Research Aims:** This paper aims to study the current and the expected trends, developments in AI technologies in architecture and if it has an advantage over human intelligence and empathy when it comes to data analysis and designing, considering human emotions, psychology, artistic appreciation and the expected impacts.

   This research also focuses on finding how AI might have an impact on the employment and work-force of architects in the near future.

2. **Research Objectives**

   - To understand various AI technologies and their relationship to the work of an architect
   - To understand the pros and cons of AI generated buildings
   - To understand which parts of an architect's job are likely to get automated in the future and its impact on the future of the architecture profession

3. **Research Questions**

   - What is the expected impact on the conventional role of architects with the advent of artificial intelligence?
   - Where does AI currently stand and what are the current technologies used in the field of architecture?
   - Can the profession be fully automated with computers and machines to be able to respond to all kinds of architectural problems similar to humans?
   - What are the possible advantages and risks of the employment of architects with the involvement of AI?

4. **Research Methodology:** This paper uses the case study method to study certain modern examples in architecture and the current advancements in AI in the field of architecture. Also, some currently practicing architects and planners who have studied and used the advanced softwares/technologies in this field have been interviewed to understand the current and the expected future scenarios when it comes to AI technologies in architecture.

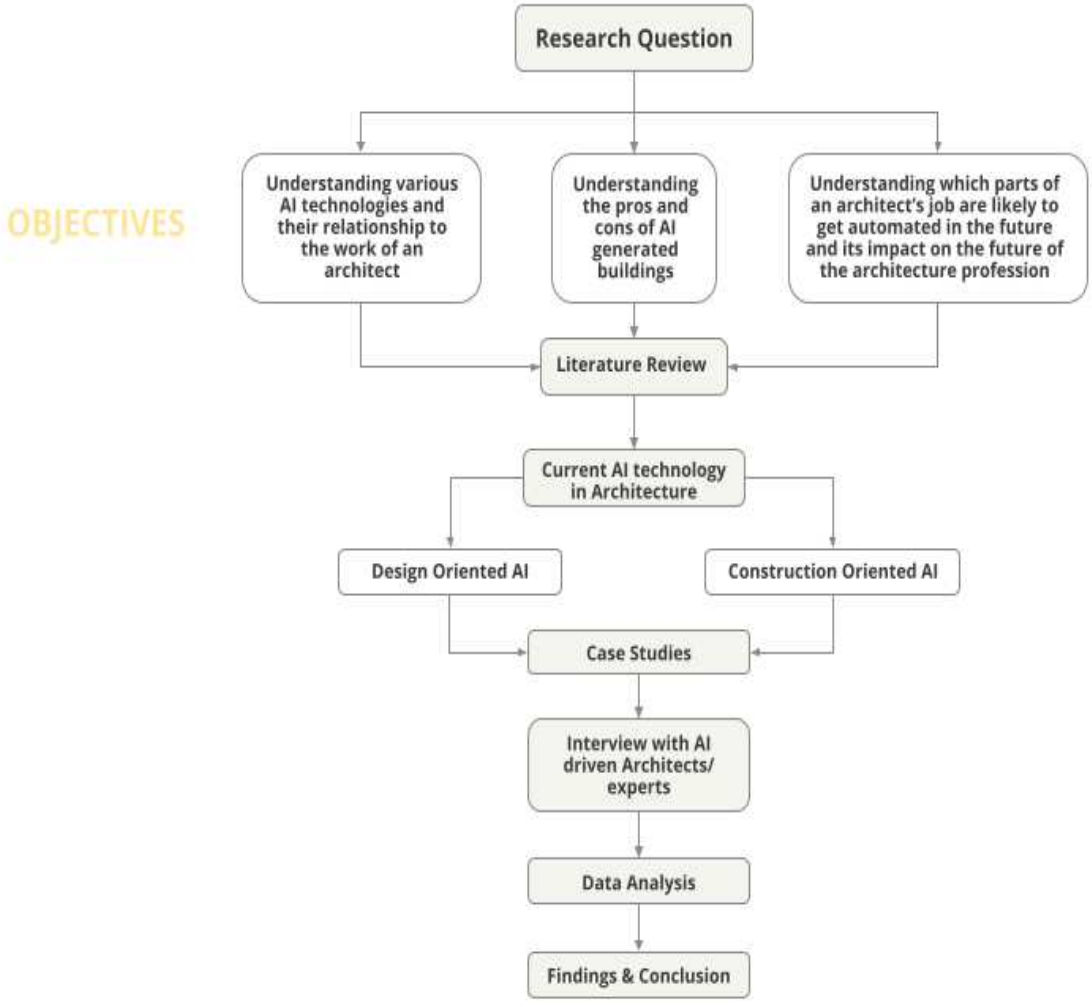

Figure 1: Research Methodology
Source: Author

II. UNDERSTANDING AI

According to Britannica, artificial intelligence is "the ability of a digital computer or computer-controlled robot to do activities typically associated with intelligent beings."

However, "artificial intelligence" has become a common term for any advancements in computing, systems, and technology that enable computer programmes to perform activities or solve problems that require the type of thinking we associate with human intellect, such as learning from previous operations. This ability to learn is essential to AI. Algorithms are generally linked to artificial intelligence, such as the infamous Facebook algorithm that replaced all of our friends with paid content. There is, however, a crucial distinction to be acknowledged.

According to Kaya Ismail, a software journalist, an algorithm is basically a "collection of instructions" or a method for processing data. This is taken a step further with AI, which is made up of a set of algorithms that can adapt and rewrite itself in reaction to the data they're given, displaying "intelligence."

How does AI Work?

AI allows a programme to be 'trained' for a certain activity and then explore and improve on its own. When confronted with unknown scenarios, a smart AI 'works out' what to do. You'll need data to use AI. There is a lot of it. Large datasets are used to train AI algorithms so that they can recognise patterns, make predictions, and recommend actions in the same way that humans can, only faster and better.

III. CURRENT TECHNOLOGIES IN ARCHITECTURE

As a part of the research to understand the current AI technologies that are being used in the architecture industry, the following softwares and technologies have been identified through our extensive research and the opportunities and threats that will have impacts on the jobs in this field. The technologies are divided into two sections:

Section 1: Technologies used in design process
Section 2: Technologies used in construction and project management

Section 1: Design oriented AI

Table below shows the evolution of AI technologies and the current softwares in the industry. It is evident that the future is shifted more towards a time where other than manual documentation work, psychological and emotional intelligence are developed.

Table 1: Development of Software and Technology for Computer Design (Source: Kołata, Zierke, 2021)

Timeline	Type of Software/Technology	Software/Technology Capabilities
Past	2D Designing Software	drafting software to replace freehand drawing
	3D Designing Software	software enabling the creation of spatial structures used to generate particular parts of a design study
Present	Parametric Design	designing 3D structures and patterns following given parameters
	Generative Design	results-oriented design
	Building Information Modeling	3d modeling related to building model production, communication and analysis kit
	Building Life Cycling Modeling	modelling various aspects related to the life cycle of a building
	Augmented Reality	transferring virtual projects into real space using dedicated tools
	Neural Networks	forecasting phenomena based on initial data
	Machine Learning (ML)	collecting data and learning to use it under human supervision
	Artificial Intelligence (AI)	advanced machines and software based on neural networks and machine learning capable of solving complex problems
Future	Active Augmented Reality	real-time creation of spatial models in augmented reality
	Artificial General Intelligence (AGI)/ Strong Artificial Intelligence (SAI)	advanced machines and software based on neural networks and machine learning capable of solving complex problems
	Artificial Super Intelligence	highest form of computer intelligence that will enable the replacement of humans by machines, including architecture

Table 2: Softwares and Technologies currently used and their Application Source: Author

Sl no.	Softwares/Technologies used	Role and Processes in the Architecture and AEC Industry	Specific AI Technology used	Job	Possibility of the jobs in AEC industry that can be replaced in the near future
1	**StyleGAN, pix2pix**	The Pix2Pix GAN is a general approach for **image-to-image translation.** It is based on the conditional generative adversarial network, where a target image is generated, conditional on a given input image. In this case, the Pix2Pix GAN changes the **loss function so that the generated image is both plausible in the content of the target domain, and is a plausible translation of the input image.**	**Generative Adversarial Network (GAN)**	Ideation and concept visualization, 3D modelling, post-production (in terms of visualising renders)	**3D visualisers** in the construction industry will be put to risk.
2	**Planfinder**	PlanFinder **ranks a library of many apartment floor plans to the input given by the user.** It then displays the **best fits. Users can then browse through the options, and pick their preferred option.** PlanFinder uses **Machine Learning to predict room functions, locations of doors, and furniture. At the same time, you can always override suggestions.**	**Machine Learning**	Drafting of plans, and design	**Draftsman's** job would be at risk
3	**NVIDIA Omniverse (GANverse3D), Facebook's AI Research and Google's Deepmind**	Nvidia Research created an AI system that can predict 3D properties of 2D images without any 3D training data.	**Neural Information Processing System**	Automation in 3D modelling, post-production (in terms of visualising renders)	**3D visualisers** in the construction industry will be put to risk.
4	**Delve, Space maker AI**	The developer shares their priorities, such as **minimizing costs, increasing access, daylight,** etc. Then the **constraints are set, such as area and how these areas are divided among residential, commercial, retail, etc.** Delve then **incorporates all the data and produces designs.** Information about each design option is displayed, making it easier to choose the best design.	**Machine Learning**	Design Iterations based on Inputs	Helps developers. Architect is needed for moderation and careful selection of suitable design atleast for the near future.
5	**XKool**	XKool is an AI design cloud platform and several other applications - **it helps getting the site data, build the base and generate designs according to the inputs, in addition it is capable of working on real-life -like situations, design response to sunlight, also do calculations and presentations in an intelligent and desired way.**	**Machine Learning**	Generate Site Data, generate input-based designs and iterations as per constraints and requirements, easy to include local building regulations, calculate and make presentations and analysis.	Helps developers. Architect is needed for moderation and careful selection of suitable design atleast for the near future.
6	**Reconstruct.inc, ARCore, ARKit, HelixRe**	Reflective approaches to dynamic measurement include **sonar, radar and LiDar (Light Detection and Ranging)**, with the latter now an integrated technology in Apple iOS devices — and a growing market emerging for all kinds of measurements, from terrain mapping through to the generation of dynamic AR environments. **ARCore by Google, ARKit by Apple** help in measurements in the 3D environment. Some fundamental principles - **Motion tracking** to identify spatial movement, **Plane detection** and **Lighting Estimation and Tracking** in an Environment. Helps in **Architectural Mapping.**	**Sonar, Radar, LiDar, Augmented Reality**	Documentation, generation of site data, surveys and measurements	Helps the surveyors and architects, there possibly can be lesser scope for surveyors. Helps architects to visualize in better and faster ways.
7	**Alice Technologies**	Uses the power of AI to create construction schedules that reduce risk while cutting costs by 11% and build time by 17%. With ALICE, develop the ideal schedule during preconstruction -- or recover projects that are off schedule and over budget.		Helps in the project management, schedules and bills	In the process of development, if it generates accurate results, the jobs of the project managers reduces in workload, but they are still needed for scrutiny.

This table helps us understand the current level at which AI and can also help us project into how AI can possibly advance in the possible near future in the field of architecture.

Section 2: AI in Construction and Project Management

1. **The Future of AI in Construction:** Construction costs can be cut by up to 20% using

robotics, artificial intelligence, and the Internet of Things. Engineers can wear virtual reality goggles and dispatch mini-robots into under-construction buildings. These robots employ cameras to monitor the progress of the work.Artificial intelligence is being used in modern structures to arrange the routing of electrical and plumbing systems. Businesses are employing artificial intelligence to create workplace safety solutions. Artificial intelligence (AI) is being used to track the interactions of employees, machinery, and materials on the job site in real time and alert supervisors to potential safety issues, construction errors, and productivity difficulties.

AI will not be able to entirely replace the human worker, despite predictions of major job losses. Instead, it will alter the economic models of the construction sector, eliminating costly errors, minimizing jobsite injuries, and improving the efficiency of construction operations.

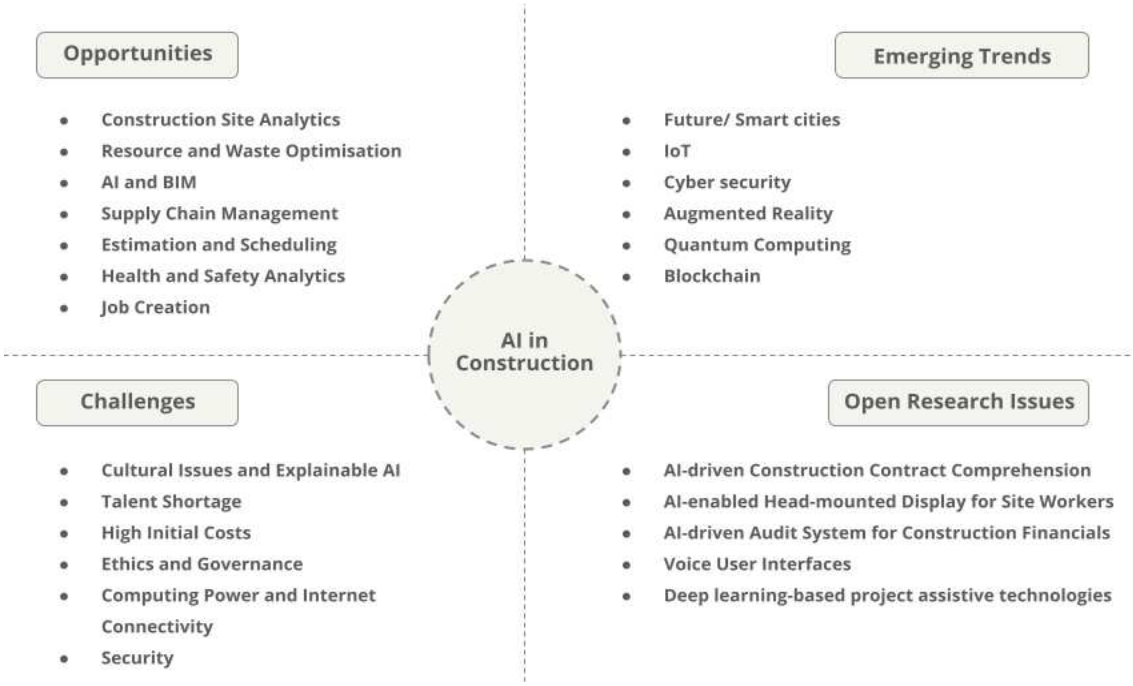

Figure 2: Analysis of Opportunities, Challenges and Further Research in AI in Construction. Source: Author

As market barriers to entry gradually fall and discoveries in AI, machine learning (ML), and analytics accelerate, it is projected that AI (and the allocation of resources focused towards AI) will play a larger role in construction in the coming years. (*10 Examples of Artificial Intelligence in Construction*, no date)

2. Advantages of AI in Construction

- Prevent cost overruns
- AI for better design of buildings through generative design
- Risk mitigation
- Project planning
- AI makes job sites more productive
- AI for construction safety

- AI will address labor shortages
- Off-site construction
- AI and big data in construction
- AI for post-construction
  (*10 Examples of Artificial Intelligence in Construction*, 2022)

AI Subfields	Construction Application Areas								
	Health and Safety	Scheduling	Cost Estimation	Legal (Contracts & Conflict Management)	Supply chain & Logistics	Site Monitoring & Performance Evaluation	Material Management	Offsite Assembly	Plant and Equipment Management
Machine Learning	✓	✓	✓	✓	✓	✓	✓	✓	✓
Computer Vision	✓			✓		✓	✓		✓
Automated Planning & Scheduling		✓							
Robotics						✓	✓	✓	✓
Knowledge-based Systems	✓	✓	✓	✓	✓	✓			
Natural Language Processing	✓			✓		✓	✓		
Optimisation		✓	✓	✓	✓		✓		✓

AI Subfields	Project Planning	Knowledge Management	Design	Risk Management	Temporary Structures	Bids/ Tenders	Energy Management	Sustainability
Machine Learning	✓	✓	✓	✓	✓	✓		
Computer Vision	✓	✓	✓					
Automated Planning & Scheduling	✓							
Robotics	✓			✓			✓	
Knowledge-based Systems	✓	✓	✓	✓		✓		✓
Natural Language Processing	✓	✓		✓				
Optimisation	✓		✓	✓	✓			

Figure 3: A Matrix of different AI technologies and their application at various tasks in a project (Artificial intelligence in the construction industry: A review of present status, opportunities and future challenges | Elsevier Enhanced Reader, 2021)

A new technology that helps in the management of design and construction and cost is the Next-generation **5-D BIM.** It is a five-dimensional depiction of the physical and functional characteristics of any project. It considers a project's budget and timeline, as well as the standard 3-D spatial design features. Geometry, specifications, aesthetics, thermal, and acoustic properties are all included. The implications of modifications on

project costs and timelines can be discovered, analyzed, and recorded using a 5-D BIM platform by owners and contractors. (Mckinsey, 2016)

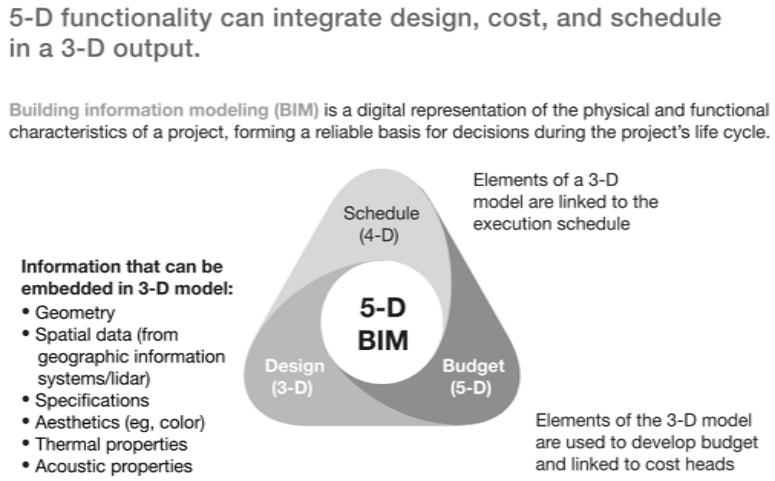

Figure 4: 5-D BIM (Mckinsey, 2016)

IV. PRACTICAL APPLICATION OF SOFTWARES WHICH HELP TO COMPUTE AUTOMATED DESIGN

In order to analyze whether machines can fully replace the architect's job, it is crucial to understand how accurate they are at doing the most important tasks of an architect - developing the building scheme and plans. Currently there are two live projects where AI has been practically applied to develop a building .

This part of the section will discuss the method adopted in these softwares to understand what parameters had been used to compute the data. Later on it will compare the two case studies to analyze the effectiveness of these AI automated design schemes as compared to ones prepared by an architect himself.

1. **GAN Generative Housing:** layout design by Stanislas Chaillou, Harvard

Chaillou's approach is to use Generative Adversarial Networks to develop residential tower layouts (GANs).The design process is divided into three stages:

- The footprint
- The layout
- The furniture

This design approach currently requires some human input and allows the architect to make changes to the design at various phases.

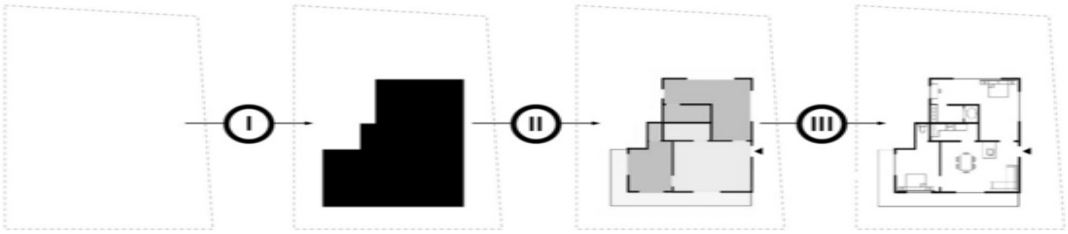

Figure 5: Breakdown of Design Process (Chaillou, 2019)

Stage 1: Generating Footprint

Normal footprints were input into it from real-world Boston layouts, which taught the computer typical footprint shapes for a particular plot of land, which it then utilized to create new footprints.

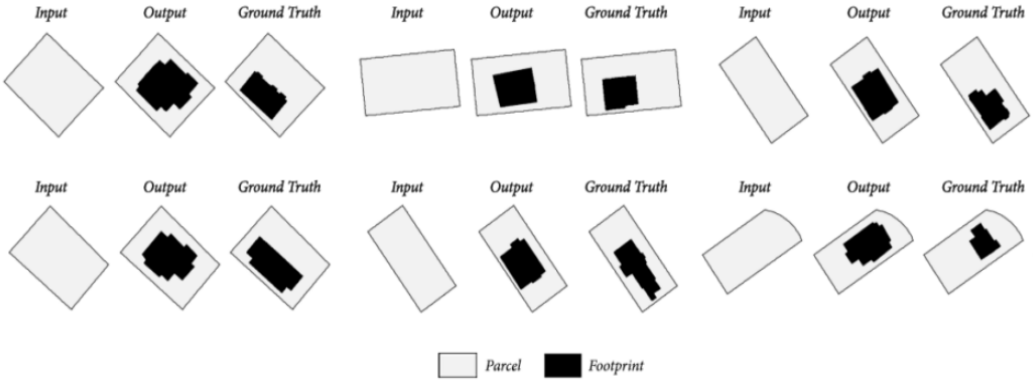

Figure 6: Footprint Layout Iterations (Chaillou, 2019)

Stage 2: Generating Layout

The front door (green square) and the major windows must be manually placed by the architect (red lines). This is then transmitted back to the computer, which generates a layout based on data from over 800 real-world apartment layouts.

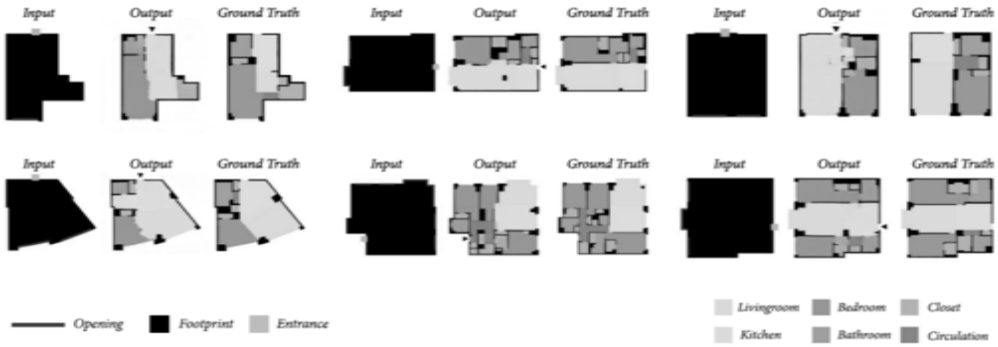

Figure 7: Spatial Layout Iterations (Chaillou, 2019)

Stage 3: Creating Furniture Layout

A new feature was added that allows the architect to determine the individual footprint of each floor. Load-bearing walls, on the other hand, are currently unspecifiable.

This might be corrected using the same method as the positioning of doors and windows.

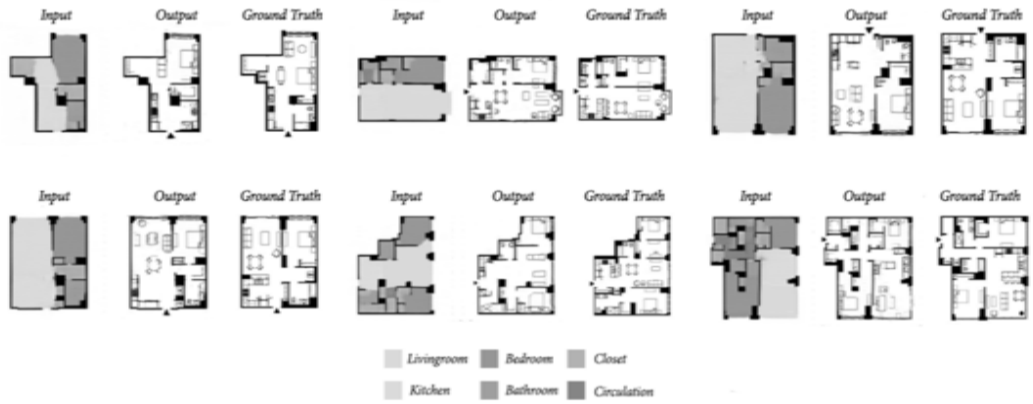

Figure 8: Furniture Layout Iterations (Chaillou, 2019)

2. **House (Y) Amnitski by Benjamin Ennemoser, California:** In this research, certain case examples were chosen to examine the projects and build an Analytical machine learning algorithm, ranging from John Lautner and Frank Lloyd Wright to modern real estate houses. In order to train and build the design, datasets were constructed from street view pictures, ImageNet, Google Database, and 3D models.

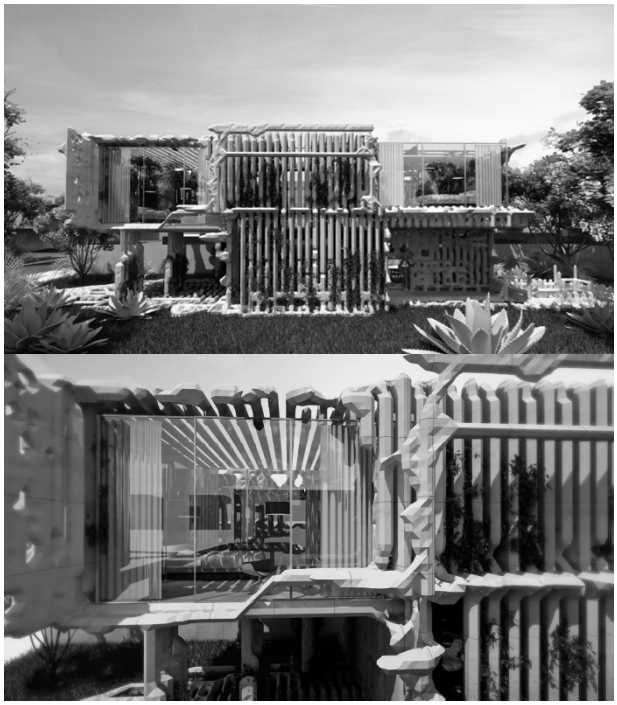

Figure 9: 3d Visualization of the House as Generated by GAN (Ennemoser, 2020)

After creating a series of artificially generated 2D facades, it is further developed to 3D models and geometry by GAN.

Figure 10: Concept Sketches of House developed by GAN (Ennemoser, 2020)

The 3D GAN is a way to implement machine learning into a collaborative design process, where the designer curates the generative process by choosing a specific dataset. The curational act influences the decision making process of artificial intelligence and what the machine learning algorithm thinks to be a modern Californian house.

In terms of a case study, the project focuses on a new method to computational design that leverages machine learning to provide an alternative to current parametric models. The exterior and structure will be created using digital fabrication and precast fiber-reinforced concrete panels. As a result, AI is a successful designer since it can develop a new conceptual shape based on prior work fabricating new methodologies.

3. Comparative Analysis of GAN based Design and Architects's Design

- Comparing the design with a modern house in California, it is **clearly different in terms of materiality** with **some similarities in the nature of design.**
- Because the computer in both situations was using the supplied data, it was discovered that it wasn't actually designing anything new, but rather calculating comparable conclusions from previous designs. **However, an architect has the ability to create new concepts and design individual building experiences.**
- The existing design is also confined to data from building layouts in a single location, and does not reflect the design preferences and needs of a worldwide audience. This contextual sensitivity can be improved in the future, but at the same time, an architect's judgment towards contextual and social sensitivity will always trump a machine's.
- The designs are not without limitations, stating that the architect's contribution to the machine learning design by inputting case examples and datasets in the AI, influenced the final design.

V. QUESTIONNAIRE PREPARED FOR THE INTERVIEWS

- What is **your take** on **current AI trends in architecture**? Is/Will it be a **boon or a bane**?
- What are the **present trends** and **technologies** with AI in architecture?
- What do you think about AI **taking over human jobs** and making the work faster and easier? Can AI replace architects?
- What are the **recent** major developments and **expected developments** in AI in the near future?
- What **current duties of an architect** can be **worked/automated** by AI?
- What **aspects/qualities/duties** of an architect prevent the profession from complete automation?
- How can **architects adapt to the fast-pacing AI** development in the field of architecture?

1. Key Takeaways from Discussions

- AI can produce much more **logical and rational thinking decisions** but it can take longer for the machine to understand the **social, emotional and intuitive** aspects of humans. Hence, one can expect that in the near future, although the scientific and technical aspect of an architect's job may be completely automated, the artistic side of the profession will always require human input.

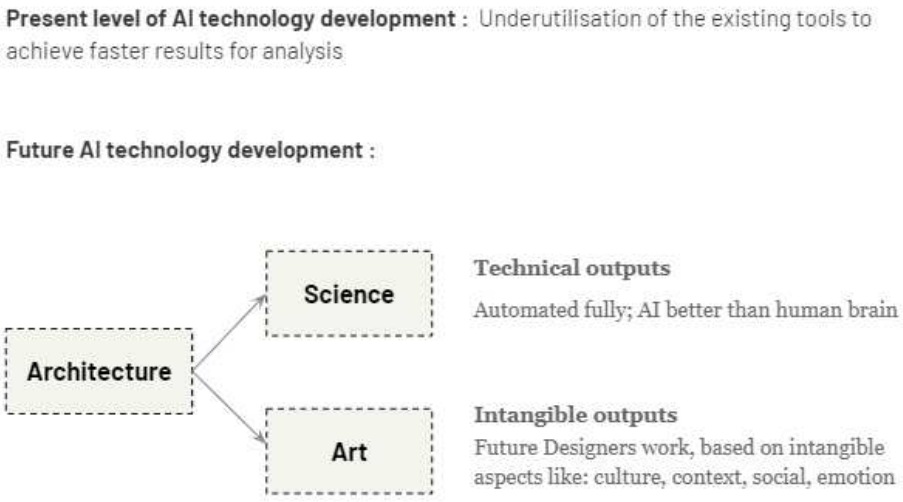

Figure 11: Role of an Architect which can be automated in the Future
Source: Author

- **Another major limitation in use of AI for designs is in the input data** that helps the AI to design, as the data can be **misleading and requires some human supervision currently. However, as research is going, the near future allows the possibility of the machines to improvise their solutions on their own and resolve more complex problem statements.**

- Computers require a lot of data input to design a building which has its own limitations in terms of the number of parameters which can be used at a time. Since architects use their intuitive skills, they will always remain to have an upper hand even as AI gets advanced in the future.

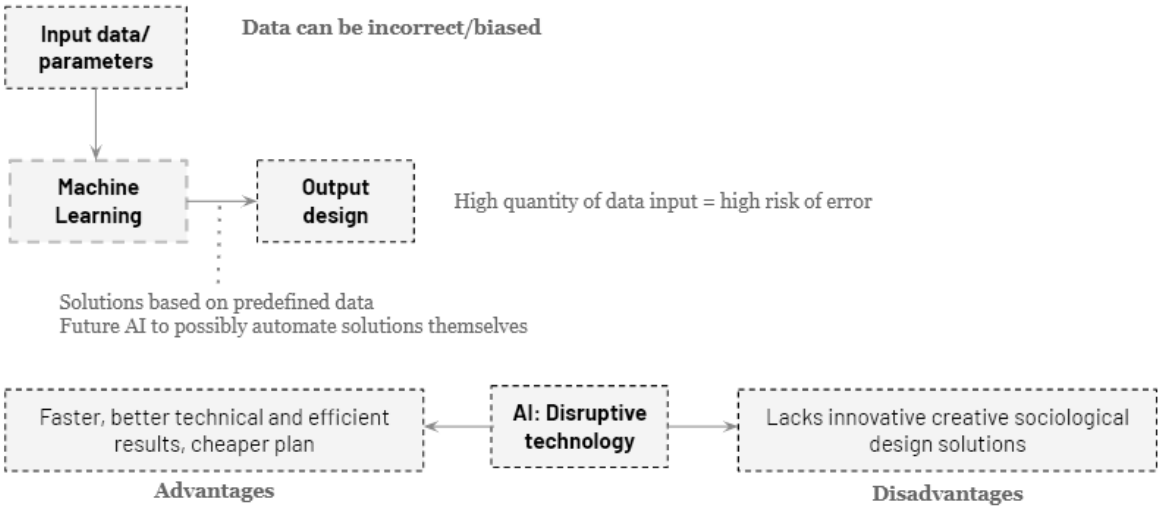

Figure 12: AI as a Disruptive Technology
Source: Author

VI. PREDICTING THE FUTURE OF AI FROM TECHNOLOGICAL DEVELOPMENTS IN OTHER FIELDS

This part of the research looks at the development of AI in different fields to draw inferences on how the architecture world could be advanced in the future. A remarkable advancement which shows to what extent the future could be transformed by AI is the use of **Predictive Policing**. This helps the cyber security teams to predict the future crime scenes and helps in preventing unfortunate accidents in the future. A very similar application of the same can be easily expected in architecture in the future where the on site work can be monitored online and accidents and structural failures be predicted on the site.

Currently, **drone technology and robots** are being developed which can in future eliminate the need of an architect to visit the site and control the work. With a possible combination of the two, one can visually assess the site work from screens and command the robots who could be the future construction workers to do specific tasks.

The **Ecole Polytechnique Fédérale de Lausanne** has developed a machine-learning algorithm that can be linked to a human brain and used to control a robot. Based on electrical inputs from the brain, the programme can change the robot's movements. Currently the technology is being used for tetraplegic patients who are unable to speak or perform movements. A future adaptation of this technology can be expected in architecture, the senior architect can feed information into robots from his brain and command them to complete tasks thus eliminating the need to employ multiple junior architects and draftsmen. This could in one way be a threat to the jobs of many architects whose role is limited to assisting senior architects in project completion.

3D printing is another technology that is currently and in the future changing architecture. **3D printing** is predicted to become a common technology by the end of 2030. More phases in the production process will be affected by the decision between 3D printing and traditional production, such as ramp-up goods being printed while product series are manufactured conventionally, and after-market products being printed again. The huge performance boost of machines, automated workflows, and product designs that are natively available for 3D printing will all contribute to this. Newer materials explorations will lead to easy availability of a wide range of customized products in the manufacturing and construction industry.

Future Opportunities for Architects due to AI: While it is clear that machines will be deployed in certain aspects of an architect's job, AI also presents a vast opportunity for architects to explore in the future. AI softwares which aid in design are emotionally intelligent deep learning softwares which if developed by the architects, can be more effective in design application. Architects can combine software development and computation to develop better AI making design better. Digital world like the metaverse is another opportunity for architects to expand their work in limitless possibilities.

VII. CONCLUSIONS FROM THE RESEARCH

From the research it is evident that AI is better at **technical outputs** whereas Architects are **better at social** and spatial experience. AI has **the ability to take over human thinking** in the very long run, but the way how it can be achieved is **quite unsure and unpredictable** at the moment. It can fill **gaps of unknown or unthought solutions** in the profession of architecture, however, **as of now**, single-handedly an AI system **will not be able to** generate a more successful design than that of a human designer, mainly due to the need of human-nature in design. As AI can work on to produce rationalized designs based on the type of inputs, with the increase in scale of architecture to urban design and to urban planning, **the number of variables increase, therefore the data to be fed into the machine is also higher, posing greater level of risk.**

When looking at the developments taking place in other fields, it can be predicted that man force in construction and architecture could very well be replaced by robots and the need to employ multiple architects in a firm could be reduced significantly. Therefore in keeping pace with the fast-paced AI development and for the architects to survive their **jobs**, it remains of high importance that they contribute some **VALUE** which AI lacks. Architects would **need to stay up-to-date** with the developing technologies in the world and not just architecture. In the future it can be expected that the role of an architect gets redefined and might be limited to critical and creative design thinking approaches. But at the same time AI is currently a more boon to the profession than a bane as it helps designers get results faster and more accurately and efficiently. AI also presents architects with an opportunity to combine software development with design and develop these AI technologies themselves for better results. It now depends upon the users to make the best of AI and become better designers.

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