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Utilization of Augmented Reality in Architecture Pedagogy with A Case Study of Lego House Denmark

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ABSTRACT

This study explores the utilisation of Augmented Reality (AR) in architectural education through a case study of LEGO House. AR offers an innovative approach by integrating traditional design methods with digital technology to enhance students' understanding of design exploration. The research methodology includes a literature review, bibliometric analysis, and data collection through questionnaires assessing architecture students' experiences with AR. The main findings indicate that integrating AR with physical models such as LEGO enhances design visualisation efficiency and student engagement in the learning process. Specifically, 96.2% of respondents agreed that digital technology improves design accuracy and efficiency, while 88.5% emphasised the importance of physical models in understanding proportions and scale. These findings align with existing literature, highlighting AR's role in bridging traditional and digital design methodologies. The implications of this research contribute to the development of more innovative teaching methods in architectural education and suggest further exploration of AR's long-term impact on design learning.

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1. INTRODUCTION

Traditional design processes are a cultural heritage that has evolved over centuries. Before the advent of advanced technologies such as computers and design software, architects relied on manual tools like pencils and drawing paper to design and depended on their craftsmanship and knowledge to create their works [1]. It often involved long and complex stages, from sketching to detailed drawings, including conceptual design, such as analysing the site to find a concept that fits the existing problem [2]. A designer is not only required to have a creative vision but must also be able to translate their abstract ideas into a form that clients can understand and appreciate [3].

The world of architecture, with its development from time to time, cannot rely entirely on traditional design processes but must also adapt to advances in digital technology so that architecture itself can evolve to a stage that allows greater freedom to explore design and efficient design strategies [4][5].

One of the emerging technologies that bridges traditional and digital approaches in architecture is Augmented Reality (AR). AR enables architects and students to integrate physical model-making methods with digital visualisation tools, allowing for an interactive and immersive design experience. AR enhances the traditional workflow without eliminating its foundational principles by overlaying virtual information onto physical environments.

Integrating traditional craftsmanship with digital tools in architectural education is crucial to fostering creativity and problem-solving skills. AR is a hybrid platform allowing students to experiment with manual and digital design methodologies, enabling them to visualise spatial relationships, test design iterations efficiently, and bridge the gap between conceptual ideas and real-world applications. Given its ability to merge tangible and virtual design approaches, AR plays a significant role in modern architectural pedagogy. It offers new ways to explore design, enhance engagement, and improve comprehension of architectural principles..

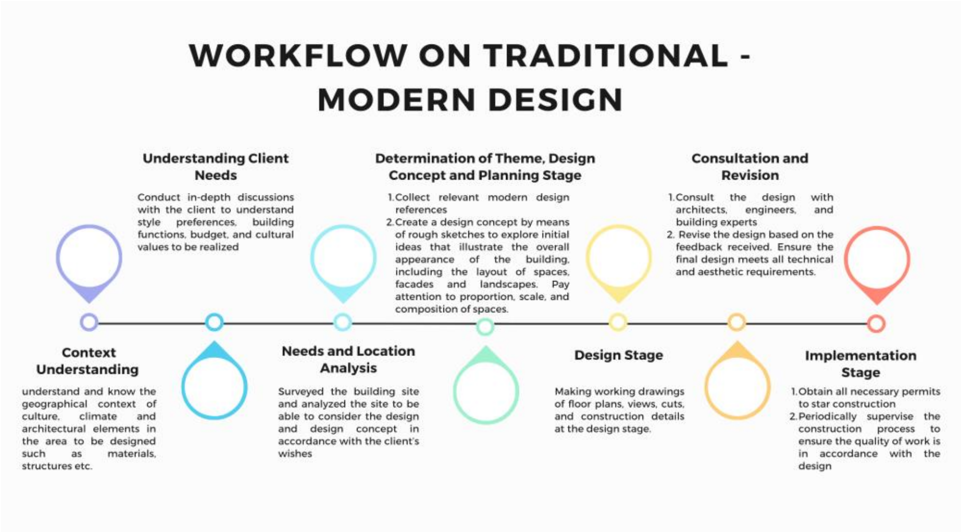


Figure 1. Workflow on Traditional and Modern Design

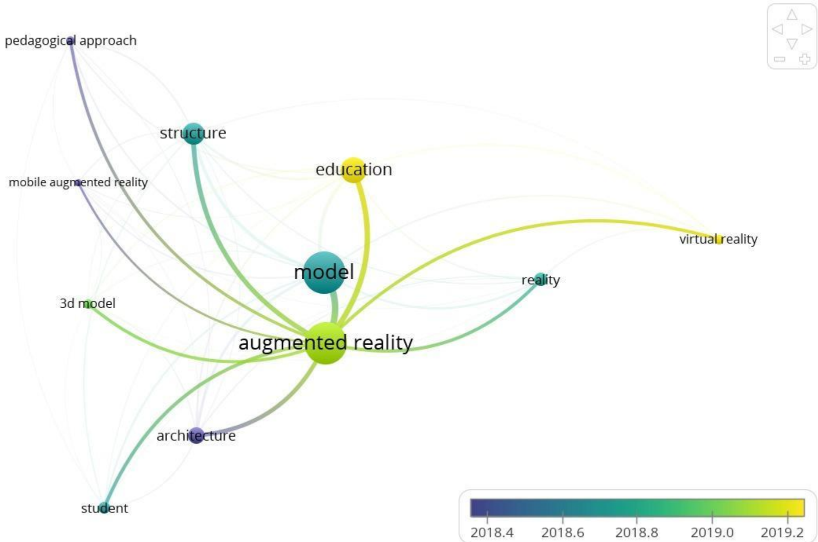


Figure 2. VOSViewer Analysis

Based on the bibliometric results with VOSViewer in the figure above, research trends related to Augmented Reality (AR) in architectural education can be identified. The figure above uses a colour scale that shows the development of research trends from 2018 to 2019. Older colours (bluish green) indicate concepts that were researched earlier. From this visualisation, we can see that "augmented reality" began to develop in 2018, and some aspects, such as "education" and "model", received further attention in 2019.

The association with the "pedagogical approach" shows that AR is starting to be applied in learning strategies, not just as a design tool. The emergence of the terms "student" and "architecture" in bibliometrics signals a research focus on how architecture students use AR in their learning. The presence of "3D model" and "mobile augmented reality" indicates that AR is used for spatial representation and design exploration, which is highly relevant in architecture pedagogy. Based on Figure 2, AR is used to help architecture students understand design models, structures, and spatial exploration, so with this research, we can further understand how AR integrates traditional and digital methods in the design process in architecture education.

Good innovation in digital technology is needed to assist in the design process and strengthen mockup creation to avoid trial and error [6]. So, Augmented Reality (AR) has a particular and deep connection to the design process. This technology has revolutionised the way architects visualise and plan designs. So, AR technology integrates virtual elements into a real environment in real-time. This technology enables users to interact with digital objects as part of the physical world, creating an immersive experience [7]. The effectiveness of using Augmented Reality (AR) in the architecture industry includes several key points [8]:

1. **Client Participation:** AR can enhance client involvement in projects, which is crucial for design success. AR allows users to interact directly with design elements, providing quicker and more accurate feedback. AR reduces misunderstandings often associated with traditional 2D plans or 3D models.

2. **Interactivity and Visualization:** AR enables users to interact with virtual components added to the real environment, giving the impression that the objects are physically present. AR helps visualise designs and better understand the planned space and structure..

3. **Accuracy:** AR allows architects to display virtual models of designs within real environments. AR aids in evaluating design elements such as proportions, scale, and context more accurately, thereby reducing the likelihood of errors in design interpretation.

By using Augmented Reality in the field of architectural design, several benefits can be created, namely, time savings that are raised by better visualisation and detecting errors earlier, AR provides more complete information to architects and clients so that better decisions emerge, opening new design innovations that previously architectural designers had to imagine the designated building.

2. RESEARCH METHOD

This study employs a mixed-methods approach that integrates quantitative and qualitative data collection techniques to analyse the role of Augmented Reality (AR) in architectural pedagogy. The research follows a structured process consisting of four key stages: student questionnaire, literature review using bibliometric analysis, case study analysis of LEGO House Denmark, and Data analysis and synthesis.

2.1. Questionnaire of Architectural Students

The first phase involves collecting raw data through a structured questionnaire targeting architecture students. The questionnaire includes both closed and open-ended questions to gather:

1. Quantitative data, such as Likert scale ratings on the effectiveness of AR in architectural learning.
2. Qualitative insights, capturing students' personal experiences with AR and its integration into design processes.

The questionnaire is distributed through Google Forms and in-class surveys to ensure a diverse and representative sample. Responses are compiled and analysed to understand students' perceptions, challenges, and benefits of integrating AR into architectural education.

2.2. Literature Review and Bibliometric Analysis

A bibliometric analysis uses VOS Viewer to contextualise the study within existing research. This analysis helps identify research trends related to AR in architectural education, key themes and frequently cited works, and existing gaps in the literature to justify the study's significance.

Bibliometric analysis involves mapping relationships between keywords, citations, and thematic clusters. This visual representation provides insights into how AR has been explored in pedagogy and architecture, forming a foundation for further investigation.

2.3. Case Study: LEGO House Denmark

The third stage focuses on analysing the implementation of AR in a real-world context through a case study of LEGO House Denmark. The case study examines how AR is integrated with physical model-making, the role of interactive digital technology in enhancing spatial understanding, and the relevance of LEGO House as a pedagogical model for architectural education. This case study provides practical insights into the interplay between traditional and digital design approaches and their application in architectural learning. The final stage involves synthesising data from multiple sources—student responses, bibliometric analysis, and the case study. Combining empirical findings with theoretical insights, this study provides a comprehensive understanding of AR's impact on architectural pedagogy and suggests strategies for future educational applications.

3. RESULTS AND DISCUSSION

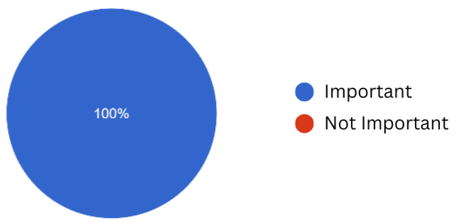
3.1. Questionnaire Results

The questionnaire results discussed the analysis process by integrating digital and non-digital technologies, focusing on on-site analysis, both manually and with the help of simulation applications. It provides an in-depth understanding of a site's physical conditions, environment, and potential. The data obtained from site analysis is valuable as it forms the basis for developing design concepts appropriate to the site context.

Manual site analysis involves traditional methods, which allow designers to observe and analyse site conditions directly in the field. Designers can obtain more detailed and in-depth data regarding topography, soil conditions, vegetation, and other environmental factors through field surveys. Site Analysis with digital simulation involves using simulation applications to analyse site data more quickly and accurately. Simulations can model ecological conditions such as sun exposure, wind direction, and flood potential. It is particularly useful for designing sustainable and energy-efficient buildings.

Table 1. Questionnaire Result

<table>
<tr><th>Questions and Results</th><th>Number Breakdown</th></tr>
<tr><td>1. Is the analysis process in architecture important?

Answer:
100% Important</td><td>
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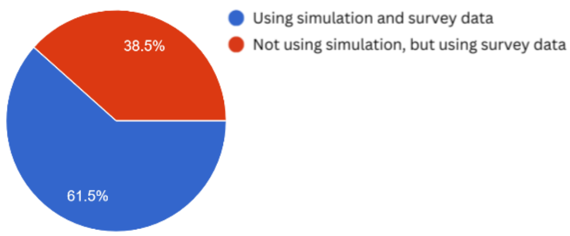
<tr><td>2. In the site analysis process, do you use simulations (supporting applications like Envimet, etc.) and previously collected survey data?

Answer:
61.5% Use Simulations and collected survey data
38.5% collected survey data, but did not use simulations</td><td>
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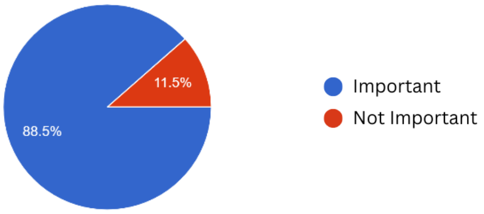
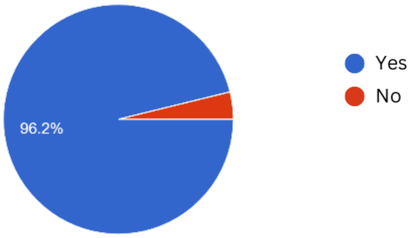
3. Is it important in architectural education to create physical models (maquette) manually to represent your building designs?

Answer:
88.5 % Important



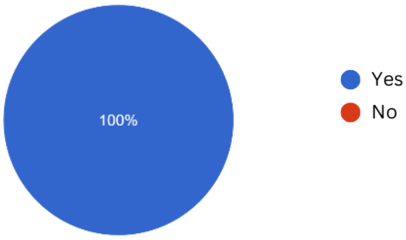
4. Do you agree that using physical models (maquette) helps in understanding proportions and scale in architectural design?

Answer
96.2% Agree



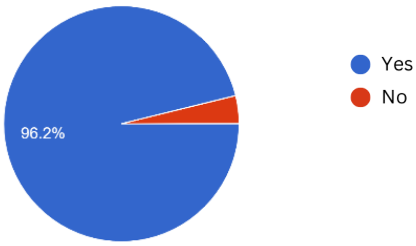
Do you feel that digital technology can improve efficiency and accuracy in the design process?

Answer:
100% Agree



5. Do you feel that creating 3D modeling of building designs takes a long time?

Answer:
96.2% Agree



Data from the questionnaire results contained 28 respondents who were architecture students and discussed the experiences that had been done in the traditional to digital design process. Respondents argue that analysing a location is very important for designing because it can discover the responses that arise and help find ideas suitable for the area. It can determine the process of designing an efficient building system and choosing the right materials for the location.

Modelling, such as mockups, is a meaningful design process, especially in the early planning stages. However, to achieve more optimal or maximum results, it is necessary to create an ideal model by combining it with digital technology. Using digital technology such as simulation software, 3D design, and the like can help the design process very effectively and does not take a long time. The benefits of doing this process are that the designer can obtain a detailed model, the flexibility provided by the mockup model, and the accuracy offered by the digital technology, and then can develop creative innovations in finding design solutions.

In question 1, the analytical process is essential and imperative. With an analysis-based approach, architects can reduce the risk of inefficient design and improve building performance in the long term. It is increasingly relevant in the modern era, demanding a balance between aesthetics, function, and sustainability [9].

Overall, in the questionnaire, 88,5% of respondents believe that modelling or mockups can help show a visualisation in capturing and producing ideas made by designers in more detail, so that clients can understand what architects make. In addition, the clients can also understand mockup modelling in the use of materials. However, 11,5% of respondents disagree that mockup modelling is less efficient and unnecessary because as the era develops, more and more are utilising technological advances.

It can encourage designers to expand the use of technology, which can integrate manual mockup modelling and digital modelling. 96,2% of respondents agreed with this idea, as technology can effectively support the design process and offer excellent visualisation [10].

3.2. Analysis of Findings

The evolution of architectural design from traditional methods to digital technology, including Augmented Reality (AR), has revolutionised how architects analyse, design, and visualise projects. Conventional approaches rely on manual tools such as pencils and drafting paper, but are limited in terms of time efficiency and accuracy, especially in understanding environmental conditions and building scale. Digital technologies like AutoCAD, Revit, SketchUp, and AR-based simulations offer more effective solutions by enhancing accuracy, real-time visualisation, and interactivity in design.

Table 2. Analysis Advantage and Deficiencies

Architecture Analysis	Advantage	Deficiencies
Manual	1. Traditionally, designers sketch a lot in the early stages of designing, until their ideas become solid enough to be created using formal orthogonal projections. That manual sketching has cognitive benefits that computational tools cannot easily replace, and therefore sketching continues to be a viable thing to do alongside computational tools, particularly at the "front end" of design and in design studios in school [11].	1. Low time effectiveness and efficiency, resulting in less than optimal analysis. 2. Frequent trial and error in making physical models (mockups) to get the best response to the design. If the model created does not match the analysis results, it must be revised many times. 3. Architectural education still relies on manual mockups to represent ideas or concepts more concretely, including teaching about scale, space proportions, and simple mathematical basics to be more easily understood by the public or clients who do not have an architectural background.
Digital	1. Simulation can speed up the design process, increase efficiency, and allow comparison of more design variants [12]. 2. Can help architects design more functional, sustainable and attractive buildings by modelling complex dynamic systems [13] 3. The application of virtual simulation technology in architectural engineering design can build a special simulation model to conduct simulation experiments on architectural engineering design, make modifications in time, reduce costs and risks, and improve overall design quality [14]. Students have difficulty applying 3d simulation modelling in architectural design because it is perceived as a constraint on their conceptual creativity [15].	1. The complexity of data representation, software interfaces, and simulation software is being targeted more for detailed design stages and engineering use rather than early architectural design [16]. Most of the simulations do not pay attention to the metrics used and require the most significant effort to achieve the objectives of the access and methodology aspects [17].

The findings from this study highlight the crucial role of integrating traditional and digital design methodologies in architectural education. Based on literature analysis and case studies, several key themes emerged:

1. **Bridging the Gap Between Traditional and Digital Design Methods**

   Traditional architectural design relies heavily on manually sketching and physical mockups, which encourages creativity and spatial awareness but often involves a lot of trial and error. The introduction of digital tools such as AR reduces inefficiencies by providing real-time visualisation and interactive simulations, allowing students to test various design iterations without needing physical reconstruction. Combining the LEGO House approach and AR technology creates a learning model that enhances tactile and digital skills, offering a balanced approach to design exploration.

2. **Improving Spatial Visualisation and Design Efficiency**
   Literature shows that AR significantly improves spatial understanding by placing digital data into a real-world context, helping students better understand proportion, scale, and materiality. Findings from the LEGO House show that multimodal interactions, including AR-enriched model building, improve cognitive engagement and retention, aligning with contemporary pedagogical approaches. The ability to overlay digital elements onto physical models provides students with new opportunities to think iteratively and evaluate designs in real-time, bridging the gap between conceptualisation and execution.

3. **Reduce Trial and Error in Architectural Design**
   One of the significant drawbacks of manual mockups is the need for repeated revisions when the design does not match the site analysis requirements. The integration of AR in the design process allows architects and students to simulate environmental factors, such as lighting conditions, airflow, and structural stability, before physical construction. The LEGO House study supports this approach by showing how an AR-based feedback system can assist in minimising errors and optimising design decisions in the early stages of the process.

4. **Implications for Architecture Pedagogy**
   The findings confirm that experiential learning models, such as those observed in LEGO House, can be adopted in architectural education to enhance student engagement and understanding. Interactive tools such as AR and multimodal technologies align with the evolving landscape of architecture pedagogy, where hybrid learning environments (digital and physical) are increasingly important. By integrating AR into design studios, students can develop critical problem-solving skills, adapt to real-world design challenges, and enhance their ability to communicate ideas to clients and stakeholders effectively.

Good innovation in digital technology is needed to assist in the design process and strengthen mockup creation to avoid trial and error [18]. So, Augmented Reality (AR) has a particular and deep connection to the design process. This technology has revolutionised the way architects visualise and plan designs. AR technology integrates virtual elements into a real environment in real-time. This technology enables users to interact with digital objects as part of the physical world, creating an immersive experience [19]. The effectiveness of using Augmented Reality (AR) in the architecture industry includes several key points [20]:

1. **Client Participation:** AR can enhance client involvement in projects, which is crucial for design success. AR allows users to interact directly with design elements, providing quicker and more accurate feedback. It reduces misunderstandings often associated with traditional 2D plans or 3D models.
2. **Interactivity and Visualisation:** AR enables users to interact with virtual components added to the real environment, giving the impression that the objects are physically present. It helps in visualising designs and better understanding the planned space and structure.
3. **Accuracy:** AR allows architects to display virtual models of designs within real environments. It aids in evaluating design elements such as proportions, scale, and context more accurately, thereby reducing the likelihood of errors in design interpretation.

By using Augmented Reality in the field of architectural design, several benefits can be created, namely, time savings that are raised by better visualisation and detecting errors earlier, AR provides more complete information to architects and clients so that better decisions emerge, opening new design innovations that previously architectural designers had to imagine the designated building.

Integrating Augmented Reality (AR) technology in architecture has opened up new opportunities in the design process. AR in architecture can be incorporated into various design stages, from initial planning to presenting the final design. By applying AR systems, architects can visualise designs in real time in a real environment. It allows the design process to consider more in-depth comprehensive evaluations, such as knowing the natural and artificial lighting that can affect when designing the interior and exterior of the building, determining the proportion and scale in the surrounding environment, and being able to interact spatially in the room.

The main benefits of Augmented Reality (AR) technology include improving efficiency and accuracy in the design process. Architects can test faster with various design alternatives to identify potential problems earlier and make more informed decisions and solutions for the design process. In addition, Augmented Reality (AR) can improve the quality of presentations to clients and make it easier to understand the design concepts designed by a complex architect. The application of Augmented Reality (AR) technology in architectural design has several challenges, such as relatively high hardware and software costs, complex 3D models (detailed and accurate) that require a long time, combining AR data with the building data, and limited compatibility with various platforms.

Based on the explanation of Augmented Reality (AR) Technology, it is recommended that the world of architectural education implement Augmented Reality (AR) technology into the curriculum. Students or the world of education can enrich material related to site analysis using Augmented Reality (AR), making digital and physical (manual) models that can integrate with technology and be used in the design presentation process using Augmented Reality (AR). Then, it can develop students' Augmented Reality (AR) technology skills. It should also focus on students who can be trained to operate Augmented Reality (AR) software by creating 3D models and integrating spatial data into Augmented Reality (AR) models.

With a case study using the LEGO House in Denmark that successfully integrates Augmented Reality (AR) technology with physical elements (LEGO), the concept of the "interactive table" can be an interesting model to be applied in architectural education. By using an interactive table that is connected to AR, students can use the interactive table as a model for architectural education.

Integrating physical models with AR technology offers a revolutionary approach to architectural education. By combining the tactile experience of building physical models with the immersive capabilities of AR, students can gain a deeper understanding of architectural concepts and design principles. Students begin by constructing physical models of buildings using various materials, fostering hands-on learning and creativity. These tangible models serve as the foundation for the AR experience. When placed on an interactive table, the physical model seamlessly integrates with the AR system, triggering a dynamic and interactive visualisation.

The AR system generates a real-time 3D model of the building, allowing students to explore and manipulate the design from various perspectives. They can virtually walk through the building, examine details, and even make modifications in real time. This interactive experience provides valuable insights into spatial relationships, proportions, and overall design aesthetics. Furthermore, the AR system can conduct simulations, such as lighting and air circulation studies, enabling students to assess the performance of their designs. Students can make informed choices and refine their proposals by visualising the impact of design decisions on environmental factors.

The AR system also provides access to relevant data, including site analysis, solar studies, and visual analysis. This data-driven approach empowers students to make evidence-based decisions and develop aesthetically pleasing and functionally efficient designs. This innovative approach fosters a more engaging and practical learning experience by combining the physical and digital realms. Students develop critical thinking, problem-solving, and technical skills essential for success in the architectural field. As technology advances, the integration of AR in architectural education holds the potential to revolutionise the way students learn and design, preparing them for the challenges and opportunities of the future..

Applying Augmented Reality (AR) technology in design processes, especially architecture, has opened new avenues for creating more innovative and efficient designs. This process begins with collecting detailed data about the project site, such as geospatial data, environmental data, surrounding building data, and infrastructure data, for example, knowing the project site's coordinates, elevation, topography, wind direction, rainfall, temperature, air quality, building data, and the surrounding environment. Information about utilities and other infrastructure. This data is converted into digital and read by augmented reality (AR) software. Then, the data will be processed into an Augmented Reality (AR) engine system such as Unity or Unreal Engine.

When a designer creates a physical model or mockup of a building, AR tools can bring it to life, displaying a highly realistic 3d visualisation. It allows designers to see how the building will appear in its actual environment, considering factors like sunlight, wind patterns, and surrounding structures. This immersive experience empowers designers to make informed decisions and fine-tune their designs in real-time.

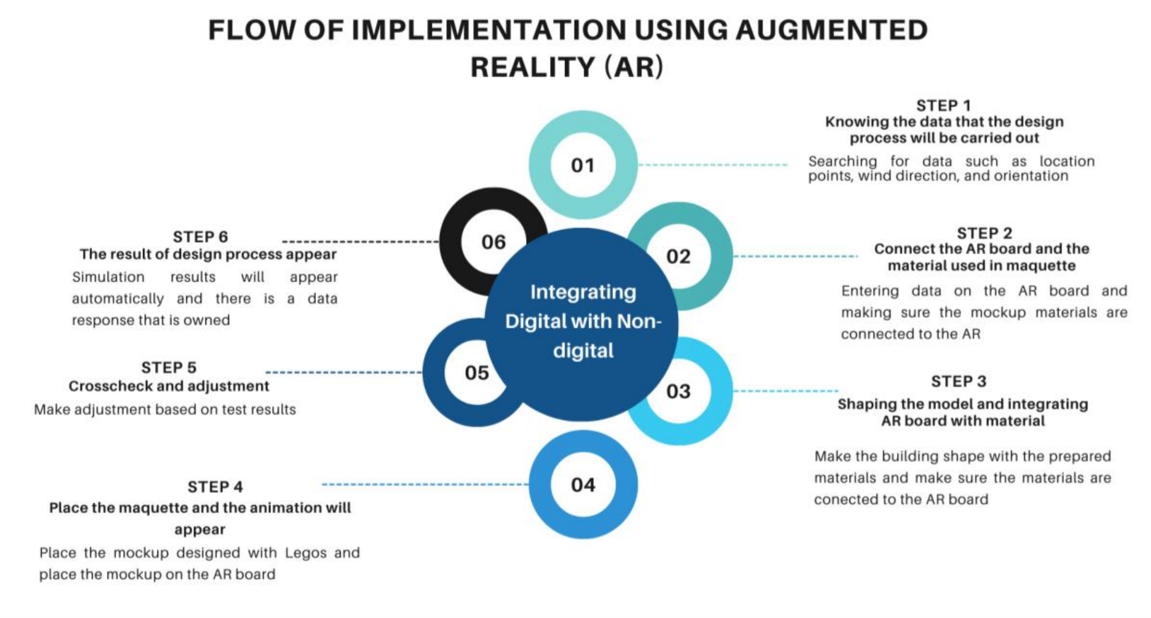


Figure 3. Flow of Implementation Using AR

By simulating various scenarios, such as how sunlight enters a room or how wind flows around a building, designers can ensure that their designs are visually appealing but also functional and user-friendly. This data-driven approach leads to more efficient and innovative designs. As AR technology evolves, designers can expect even greater efficiency and creativity in their work. Collaborative efforts between designers, clients, and other stakeholders can be significantly enhanced through AR, fostering a more streamlined and effective design process.

3.3. Case Study: LEGO House Denmark

Architectural design is increasingly linked to advancements in digital technology, opening up previously unimaginable opportunities for exploration and innovation. One architectural icon that has gained attention in this regard is the LEGO House in Denmark, which reflects the iconic tradition of LEGO play and presents new challenges and opportunities in facing the digital revolution in design [20]. The LEGO House in Denmark supports play, creativity, and learning through interactive LEGO experiences encompassing digital and non-digital forms [19][21]. LEGO House implements educational activities that foster creativity, where visitors can build and create with LEGO bricks, encouraging them to imagine and collaborate on any project [22][23]. Additionally, LEGO House promotes learning through play, supporting the development of problem-solving skills, creativity, and innovation. It provides an innovative "third space" for interaction with multimodal technology, fostering skill development and creative knowledge in an engaging way in the digital era.

The LEGO House is an example of how AR can be applied in architectural education by combining physical and digital elements. LEGO House has technological innovations that combine digital and non-digital elements to create interactive and educational play experiences. One such innovation is the use of multimodal technology. Integrating many technologies, such as cameras, scanners, and interactive tools in the LEGO bricks creates the potential for a playful experience, and users can interact in creative and mind-blowing ways. LEGO House is also developing an app that can prolong the play experience after a visit (e.g., digital animation that can turn any drawing into a virtual animation on mobile devices). LEGO House also has several devices that are connected in a publicly open creation innovation, such as:

1. Digital Camera
   Digital cameras at the LEGO House capture moments and creations made by visitors. It allows visitors to document their work in the form of photos.
2. Scanner
   Used to make digital copies of physical creations made by visitors. It allows them to store and share their work in digital format.

3. Interactive Table
   The interactive table in the LEGO House is equipped with a projector that displays a virtual cityscape on the table surface. Visitors can interact with tabletop elements to build and design their city, similar to open-ended video games like SimCity. This table allows visitors to collaborate and create simultaneously, providing a dynamic and interactive play experience. They can view their creations in a larger context and interact with the digital elements displayed.

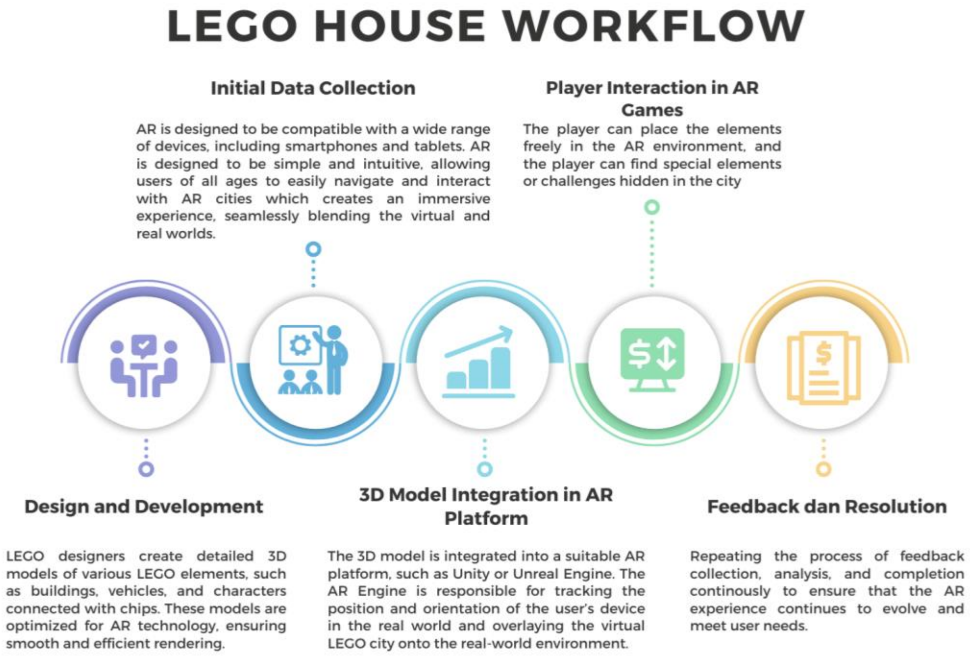


Figure 4. LEGO House Workflow

LEGO House incorporates Augmented Reality (AR) to explore the coexistence and multicultural factors through play that engages tactile, visual, and auditory stimuli. The system is based on structures built with LEGO bricks, enriched with various multimedia elements such as sound and 3D animations displayed using AR technology [16]. The concept of "innovation through tradition" proposes framing theory as an effective tool to capture the company's design traditions and reinterpret them to new technological developments so that traditional design principles can serve as a foundation for understanding emerging technologies [17]. If this technology were applied in architecture to help identify site issues and responses, it could be used to design LEGO blocks that would be translated into AR. Thus, the data generated automatically would greatly assist the design process. This process involves creating a model of the desired building using LEGO bricks, with AR technology automatically responding to the site and structure to support the design. This analysis would be available if architects provided the location coordinates for analysis. With these capabilities, designers can easily obtain responses from the existing site analysis. Therefore, this method can perform tasks such as real-time data acquisition and save time in the design process.

The integration of LEGO model-making with AR exemplifies a hybrid approach to architectural education, allowing students to bridge traditional physical modelling techniques with digital visualisation tools. In an architectural learning environment, this methodology fosters:

1. Enhanced spatial comprehension: Students can analyse and refine their designs in real time using AR overlays.
2. Iterative design processes: Just as visitors at LEGO House engage in interactive building experiences, architecture students can test multiple design variations more effectively.
3. Problem-solving and critical thinking: Exposure to physical and digital tools prepares students for real-world architectural challenges where hybrid methodologies are increasingly employed.

Integrating LEGO or model-making elements connected with chips and augmented reality is crucial in helping designers address on-site challenges. Additionally, LEGO and AR can serve as educational materials, artistic media, and modelling tools, making them an ideal subject for research (14). There is a need for a detailed implementation process using this technology. Therefore, this study aims to understand non-digital and digital technology utilisation through the LEGO House case study in architectural education. It is expected to provide insights and practical recommendations for architectural designers to support the design process by adopting LEGO in its manual form and AR as a technological tool, enhancing accessibility and efficiency, and contributing positively to technological advancements in the future.

By studying LEGO House's integration of AR, architectural pedagogy can adopt similar methodologies to enhance interactive learning, creative exploration, and digital adaptability. These findings emphasise the importance of merging physical and digital design tools to create a more engaging and effective architectural education framework.

4. CONCLUSION

4.1 Implications for Academia and Industry

This research found that Augmented Reality (AR) can improve architecture students' understanding of exploration by combining physical models and digital technology. The LEGO House case study shows that AR can help students visualise designs more interactively, reduce trial and error in making mockups, and speed up the design process.

A literature review and bibliometric analysis indicate an increasing trend in the application of AR for architectural pedagogy. Findings from the questionnaire reveal that 96.2% of respondents agree that digital technology enhances efficiency and accuracy in design. In comparison, 88.5% acknowledge the importance of physical models (maquettes) in understanding proportion and scale. However, some students still perceive digital modelling as complex. These results align with existing literature, which highlights the role of AR in bridging traditional and digital design methods.

Previous studies suggest that AR enhances spatial visualisation and is an interactive learning tool that improves engagement and retention. The LEGO House case study exemplifies how AR can be successfully integrated into design education, offering hands-on learning experiences that complement theoretical knowledge.

In the academic world, the results of this research can be used to develop a more technology-based architecture curriculum, integrating AR in design studios to enhance students' learning experience. In industry, AR has the potential to improve the efficiency of design presentations to clients and minimise errors in the planning and construction stages.

4.2. Research Limitations and Recommendations for Future Research

This study has several limitations, including a sample size limited to architecture students in a particular academic setting, so the results are not fully generalizable to professional practice. In addition, this research method focuses on a single case study, so further research with a broader scope is needed to validate the findings.

Future research could explore the long-term impact of AR in design studios to understand its influence on students' design skills over time. In addition, further studies could include a comparative analysis of different AR technologies and other learning methods in architectural education to identify the most effective approaches. A larger sample size, including professional architects, could provide a more comprehensive understanding of the effectiveness of AR in real-world applications.

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