Enhancing the Syrian Construction Industry through Augmented Reality: Applications and Challenges

Mirna Hammoudi[*1], Abdussalam Shibani[2]

[1] Building Information Modelling and Management Master Program student at Syrian Virtual University, Syria
[2]Assistant professor in construction and project management, school of energy, construction and environment, Coventry university, Coventry, United Kingdom
Emails: mirna_180052@svuonline.org; ab1732@coventry.ac.uk

Abstract

The Syrian construction industry faces numerous challenges that hinder its efficiency and productivity, including outdated practices and a lack of modern technological integration. This study explores the potential of Augmented Reality (AR) to enhance industry practices through a descriptive analytical approach using surveys and case studies. Key findings indicate a growing awareness and favorable perception of AR among construction professionals, pinpointing substantial benefits such as enhanced project visualization, safety, and resource management. Despite these positives, significant barriers such as technological infrastructure and expertise gaps limit AR's widespread adoption. The study concludes that AR offers significant potential to revolutionize the Syrian construction industry, recommending focused governmental and private sector investment in technological training and infrastructure to leverage these benefits fully. These findings suggest that AR could be pivotal in transforming construction practices in emerging markets like Syria.

Keywords: AR (Augmented Reality); BIM (Building information modeling); AEC (Architecture; Engineering; and Construction); MR (Mixed Reality); VR (Virtual Reality); MEP (Mechanical; electrical and plumbing).

1. Introduction

Building Information Modelling (BIM) is transforming the Architecture, Engineering, and Construction (AEC) industry by addressing chronic inefficiencies such as cost overruns and scheduling delays, which are particularly acute in large-scale projects [2][4]. This model provides comprehensive building details including engineering dimensions, quantities, and properties, making it an essential tool in contemporary project management [6][12]. Due to its potential to streamline operations and enhance coordination, BIM is becoming increasingly crucial and is now being incorporated into academic programs to prepare future professionals [17].

Globally, the benefits of BIM have led to its broad endorsement by governments and industry practitioners, who recognize its advantages in improving project outcomes [8][14]. BIM facilitates a collaborative environment that aligns the interests of all stakeholders throughout various project phases, ultimately resulting in innovative, functional products that meet project goals [4]. This integration of new tools, data, and concepts with traditional construction processes brings about not only financial gains and loss reduction but also significant time savings and improved quality of

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projects [15]. Additionally, BIM enhances overall project performance and efficiency, a critical factor in today's fast-paced construction environments [10][18].

Despite these advantages, the adoption rate of BIM is uneven across the globe. Developing countries are particularly slow to adopt this technology due to a combination of factors, including limited awareness about BIM and a lack of specialized training and infrastructure [19]. In many developing countries, the traditional methods still dominate, with governmental adoption of BIM being particularly rare, further exacerbating the gap in technology application between developed and developing nations [20][21].

In the context of Syria, reliance on conventional construction methods has led to numerous issues including frequent conflicts, changes in project scope, and misalignment of time and cost objectives [22]. These problems are compounded by factors such as short design phases, inadequate design processes, a traditional bidding system that often prioritizes the lowest cost over quality, increasing project complexity, multiple stakeholders with conflicting interests, delayed material supplies, poor coordination among subcontractors, and significant wastage of resources due to repeated reworks or corrections of design defects. BIM's role as a centralized and clear source of design information is seen as a transformative solution for these challenges, providing a platform for better accuracy in project estimations and enhanced dynamic interaction in construction processes [6][21].

As BIM technology continues to evolve, it is proving essential for nations like Syria to transition from conventional CAD systems to more advanced BIM solutions [16]. The ongoing global shift towards BIM underscores the necessity for Syrian government agencies, construction companies, and engineering professionals to actively promote and adopt this technology to align with international standards and embrace the benefits of digital transformation in construction.

The construction industry significantly contributes to global economic development, offering substantial employment opportunities and driving growth. As the sector faces increasing demands for efficiency and innovation, technological advancements such as Augmented Reality (AR) have begun to play a pivotal role. AR offers transformative potential in construction, enhancing visualization, communication, and project management [23].

Despite its global rise, the Syrian construction industry remains challenged by outdated practices and technologies, exacerbated by a protracted period of conflict and economic instability. These factors contribute to reduced productivity and a slower pace of recovery and reconstruction. This backdrop creates a compelling case for exploring advanced technological solutions like AR to leapfrog traditional barriers and drive industry modernization [24].

This study aims to bridge the research gap by evaluating the application of AR in the Syrian construction industry. It investigates AR's potential benefits to project efficiency and safety while assessing the awareness and readiness of local professionals to adopt such technologies. By identifying the existing barriers to AR adoption and proposing strategic recommendations, this research seeks to provide a roadmap for integrating AR technologies into Syrian construction practices.

The significance of this study lies in its potential to inform policy-makers and industry stakeholders about the benefits and prerequisites of adopting AR in construction, thereby fostering a more innovative and efficient industry. This paper is structured to first review the literature on AR in construction, followed by a methodology section that outlines the approach for data collection and analysis. The results section presents the findings related to AR's potential impacts and adoption barriers, followed by a discussion that interprets these findings in the context of Syria's unique challenges. Finally, the paper concludes with strategic recommendations for harnessing AR in Syrian construction, aiming to contribute both to academic research and practical implementation strategies.

This structured introduction sets the stage for your research by providing the necessary background, stating the problem, and highlighting the research's relevance and objectives, ensuring that the reader understands the importance of your study and its implications for the Syrian construction industry.

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2. Literature Review

Augmented Reality (AR) has been increasingly recognized for its potential to revolutionize the construction industry by enhancing visualization, accuracy, and project management. Peeters S. T. [1] provides a comprehensive review of AR applications in the Dutch construction industry, focusing on its integration at various stages of construction to improve efficiency and accuracy. The study emphasizes the importance of AR in overcoming traditional barriers to communication and project visualization, highlighting the initial steps toward its successful adoption and wider use in the industry.

Čabala J. et al. [3] discuss the integration of AR with Building Information Modeling (BIM), describing how this combination enhances the preparation and execution phases of construction projects. By creating a dynamic information model, BIM technology serves as a backbone for AR applications, enabling more informed decision-making and efficient project management. The paper also explores the use of mixed reality, an extension of AR, which further expands the capabilities of BIM by providing workers with immersive, real-time insights into the construction process.

The contribution of AR to safety and health management in construction is explored by Lim K. F. [5], who conducted a study in the Malaysian construction industry. This research highlights the role of AR in enhancing hazard identification, improving safety planning, and intensifying safety inspections. Despite recognizing substantial benefits, Lim identifies significant barriers such as additional costs, the need for extensive training, and a lack of support from top management, which could hinder the adoption of AR technologies.

Innovative uses of AR for design communication are detailed by Rajaratnam D. et al. [9], who illustrate how AR can facilitate the proactive management of design, minimizing errors and changes during the construction phase. Similarly, Ratajczak J. et al. [7] propose a novel AR tool, AR4C, which integrates BIM and Location-Based Management Systems to monitor construction performance and progress effectively. Both studies underscore AR's potential to enhance communication and reduce misunderstandings in project designs and execution.

Yoon J. W. et al. [11] and Gilson K. et al. [13] provide practical insights into the application of AR in construction. Yoon et al. develop a BIM-marker-based AR system for construction site support, proving that marker-based AR improves implementation accuracy and reduces manual data collection efforts. Gilson et al. focus on the use of AR in highway construction projects, discussing how AR can assist in the design, construction, and inspection phases to enhance safety, reduce costs, and improve project management through real-time monitoring and visual feedback.

Zaher M. et al. [15] investigate the role of AR in improving resource management and training within the construction industry. They highlight a system that utilizes AR for real-time, on-site training and guidance of construction workers, reducing errors and increasing efficiency. The system allows for the overlay of digital information onto real-world objects, providing workers with immediate access to detailed instructions and safety protocols. This use of AR not only improves the accuracy of work performed but also enhances the training process by providing a hands-on learning experience that traditional methods cannot match.

3. Methodology

***Research Design*:**
The study employed a descriptive analytical research design aimed at capturing detailed insights into the current state and potential applications of AR technology in construction. This approach facilitated a thorough analysis of both qualitative and quantitative data.

Participants and Sampling:
the research targeted professionals within the Syrian construction industry, including engineers, project managers, and technical staff involved in the adoption and implementation of AR technologies. The sampling method focus on a representative mix of roles and experiences to ensure diverse insights into the usage and perception of AR in construction.

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Data Collection Methods:

The primary data collection involved the use of surveys, which were likely distributed electronically given the context. The surveys included a range of question types to gauge both the subjective perceptions of AR technology and more objective measures of its implementation and impact.

Additionally, case studies were used to provide in-depth analysis of specific instances of AR application in construction projects. These helped to illustrate the practical benefits and challenges faced during real-world implementation.

Survey Questions`

What is your age?	Under 25	25-34	35-44	45-55	
	4.7%	**60.5%**	**30.2%**	**4.7%**	
What is your gender?	Male		Female		
	37.2%		**62.8%**		
What is the highest level of education?	Ph.D.	Master	B.S.	Diploma	
	2%	**44%**	**51%**	**2%**	
What is your role?	Technician	**2%**			
	Supervisor	**2%**			
	Engineer	**47%**			
	Project Manager	**9%**			
	General Manager	**9%**			
	Consultant	**2%**			
	Construction Manager	**2%**			
	Architects	**25%**			
What is the main sector of the company you work for?	Business Manager	**2%**			
	Educational	**4%**			
	Engineering Studies	**26%**			
	Contracting	**9%**			
	Procurement	**2%**			
	Consulting	**4%**			
	Project Management	**14%**			
	Facility Management	**33%**			
	Communications	**7%**			
How many years of experience do you have in the construction industry?	1-3 years	4-5 years	6-10 years	10+ years	
	26%	**14%**	**30%**	**30%**	
Are you familiar with augmented reality (AR) technology?	Yes		No		
	81%		**19%**		
How would you rate your understanding of AR technology on a scale of 1 to 5 (1 very bad, 5 excellent)?	1	2	3	4	5
	11%	**7%**	**46%**	**20%**	**14%**

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Have you ever used AR technology in any context (e.g. personal, professional, educational)?	Yes		No
	17%		**26%**
Are you aware of any applications of augmented reality technology in the construction industry?	Yes		No
	25%		**18%**
Which phase of the project life cycle do you think augmented reality can benefit the most from?	Design and visualization		**69%**
	On-site construction		**20%**
	Maintenance and facility management		**18%**
	At all stages of the project		**2%**
Do you think there are potential benefits of using augmented reality technology in the construction industry?	Yes		No
	42%		**1%**
Which stakeholders do you think will benefit most from the adoption of AR in the construction industry?	Architects		**37%**
	Consultants		**28%**
	Contractors		**19%**
	Engineers		**12%**
	Owners/Developers		**4%**
what are the top three potential benefits of using AR technology in the construction industry?	Improving design accuracy		**83%**
	Increasing work efficiency		**69.8%**
	Reducing material waste		**53.5%**
	Improving safety on site		**41.9%**
	Improving client experience		**37.2%**
	Improving collaboration		**27.9%**
What are your expectations regarding the impact of augmented reality on project efficiency in the construction industry?	Big	Moderate	None
	58.1%	**41.9%**	**0%**
What are the 3 most important obstacles that prevent the adoption of augmented reality technology in the Syrian construction industry?	Cost		**58.1%**
	Lack of infrastructure		**51.2%**
	Resistance to change		**44.2%**
	Government support		**44.2%**
	Lack of experts		**53.5%**
How important is training and skills development for the successful adoption of AR tools in the Syrian advanced construction industry?	Very important	Important	Not Important
	83.7%	**16.3%**	**0%**
Do you think the availability of affordable augmented reality tools and software is a decisive factor for its adoption?	Yes		No
	90.7%		**9.3%**
	Yes		No

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Can experimentally projects and successful case studies influence the adoption of AR technology?	**40%**	**3%**
What are the three most important factors helping to overcome the obstacles to implementing AR in the Syrian construction industry?	Creating innovation culture	**81.4%**
	P.P technology providers	**55.8%**
	Government support	**53.5%**
	Data security and privacy	**34.9%**
Do you think AR and BIM integration can help in visualizing the project progress in real-time?	Yes	No
	97.7%	**2.3%**
Do you think AR and BIM integration can help in identifying potential clashes between different elements of the project?	Yes	No
	100%	**0%**
Do you think AR and BIM integration can help in enhance communication between project stakeholders?	Yes	No
	93%	**7%**
Do you think AR and BIM integration can help in provide accurate data about the project progress?	Yes	No
	97.7%	**2.3%**

Data Analysis Techniques:

Data from surveys were analyzed quantitatively. This included analysis of variance, correlation, and regression analyses to understand the relationships and impacts of AR technology.

Qualitative data from case studies were analyzed to extract themes and insights about the practical applications and effectiveness of AR. This involved a thematic analysis approach, synthesizing qualitative data into coherent themes that reflect the broader implications of AR in construction.

4. Results

Awareness and Perception of AR:

- The research found a moderate level of awareness about AR among Syrian construction professionals. Most respondents recognized the potential of AR to enhance project visualization and management but lacked comprehensive knowledge about its implementation and full capabilities.

Benefits of AR in Construction:

- Significant benefits of AR identified through the survey and case studies included improved accuracy in project execution, enhanced safety on construction sites, and better communication and collaboration among project teams.
- AR applications were particularly valued for their ability to overlay digital information onto physical construction sites, aiding in tasks such as inspection, maintenance, and complex component assembly.

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Challenges and Barriers to Adoption:

- Major barriers to the adoption of AR technology in the Syrian construction industry were identified as the high cost of AR equipment, lack of technical expertise, and the infrastructural limitations in deploying advanced technologies.
- Resistance to change within organizational cultures and the need for substantial training and support were also noted as significant hurdles.

Impact on Project Outcomes:

- Case studies demonstrated that AR could significantly reduce errors and rework in construction projects, leading to cost savings and time efficiency. Projects that integrated AR tools from the planning phase reported better adherence to schedules and budgets.

Integration of AR and BIM:

- The survey results indicated a positive outlook among Syrian construction professionals of both AR and BIM technologies. However, the integration of AR with BIM is still at a nascent stage, with few examples of full implementation. Respondents showed a keen interest in exploring how AR could complement BIM in project management and execution.

Benefits of Combining AR with BIM:

- The combined use of AR and BIM was found to enhance visualization and accuracy in construction projects significantly. This integration allows for real-time, on-site visualization of BIM models, facilitating better decision-making and adjustments during the construction phase.
- Benefits specifically highlighted included improved spatial understanding, error reduction in the installation of complex systems, and enhanced communication between onsite workers and project managers through real-time data updates and visual feedback.

Future Prospects and Recommendations:

- The study concluded with a positive outlook on the future integration of AR in Syrian construction, recommending strategic investments in technology infrastructure and professional training programs.
- It was suggested that pilot projects could be instrumental in demonstrating the benefits and building a case for broader adoption across the industry.

5. Discussion

Technological Integration and Practical Implications:

The integration of AR with BIM has shown significant promise in enhancing the construction process by providing real-time, immersive visualization and accurate project tracking capabilities. According to the findings of this research, the implementation of AR and BIM technologies not only facilitates a deeper understanding of project specifications among workers on-site but also enhances communication between different stakeholders, leading to more efficient project execution and reduced incidences of costly errors. This observation aligns with those reported by Yoon J. W. et al. (2023), who noted substantial improvements in precision during the construction phases when AR is integrated with BIM systems.

In the context of Syria, where reconstruction efforts are imperative yet fraught with challenges such as limited resources and outdated construction practices, the application of AR and BIM could revolutionize the industry. The Syrian construction sector, primarily relying on traditional methods, faces issues of inefficiencies and project delays. Implementing advanced technologies such as AR linked with BIM could mitigate these issues by providing a more streamlined, accurate, and efficient workflow, thus addressing both the economic pressures and the urgent need for infrastructure rebuilding.

Comparison with Global Practices and Local Feasibility:

Globally, countries like Germany and Singapore have leveraged AR and BIM integration to great effect, standardizing their use in public and private sector projects to optimize construction outcomes.

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For instance, Singapore's Building and Construction Authority (BCA) has mandated BIM for all large-scale projects, which has significantly improved project delivery times and cost efficiency. However, while these examples provide a roadmap, the adaptation of such practices in Syria must consider local challenges, including the availability of skilled professionals trained in these technologies and the current technological infrastructure, which may not support such advanced implementations.

Socio-Economic Implications and Policy Recommendations:
Adopting AR and BIM technologies in Syrian construction could serve as a catalyst for economic growth, not only by streamlining construction processes but also by fostering a technology-driven refurbishment of the industry. This technological shift could lead to job creation, particularly in tech-oriented roles, and require a re-skilling of the current workforce, thus contributing to human capital development in the country.
For such a transformation to be successful, policy interventions are crucial. The government could initiate programs for the training of construction professionals and engineers in AR and BIM, perhaps supported by international partnerships with countries that have successfully implemented these technologies. Furthermore, incentives for construction companies to adopt these technologies, such as tax breaks or subsidies for AR and BIM software and hardware, could accelerate their uptake.

Limitations and Future Research Directions:
While the potential for AR and BIM in the Syrian construction industry is evident, this study recognizes limitations such as the representativeness of the sample and the need for more extensive case studies to validate the findings fully. Future research should focus on longitudinal studies that can assess the long-term benefits and ROI of integrating AR and BIM in construction projects across different regions in Syria. Additionally, experimental designs could be employed to test the effectiveness of various AR and BIM applications in real-time on construction sites, providing more empirical data to support the findings presented.

6. Conclusion

This research has rigorously investigated the integration of Augmented Reality (AR) and Building Information Modeling (BIM) within the Syrian construction industry, revealing transformative potentials and notable challenges. The findings clearly demonstrate that AR and BIM can significantly enhance project visualization, improve accuracy in construction processes, and foster better communication among project teams. Notably, the use of AR in conjunction with BIM has shown to reduce errors, enhance operational efficiency, and improve safety on construction sites, which are critical outcomes for an industry often plagued by costly delays and safety issues.

The implications of these technologies extend beyond mere technological advancements; they offer a pathway to revitalize the Syrian construction industry, especially crucial in a period where the country faces the colossal task of reconstruction. By adopting AR and BIM, the industry can leapfrog traditional barriers, adopting modern methods that ensure projects are not only completed faster but also with greater precision and lower costs. Such advancements are particularly pertinent in Syria’s context, where efficient resource management and rapid project turnaround are essential to address the extensive infrastructural damage and prepare for future development needs.

Given these insights, it is recommended that key stakeholders within the Syrian construction sector—ranging from government bodies to private construction firms—embrace these technologies. Construction companies should consider investing in AR and BIM technologies and initiate pilot projects to showcase their benefits across various construction phases. These projects can serve as benchmarks for wider implementation across the industry. Furthermore, governmental support is crucial in fostering this technological adoption. Policies aimed at subsidizing the cost of AR and BIM technologies, coupled with incentives for training the workforce in these advanced tools, could accelerate their uptake.

Education and training represent another critical area for action. Technical and vocational education programs in Syria must evolve to include AR and BIM training, equipping the next generation of construction professionals with the skills necessary to operate in a modernized construction

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environment. Collaborations with international tech firms could also facilitate knowledge transfer and technical training, ensuring that the Syrian workforce is proficient in these cutting-edge technologies.

In conclusion, while the road to widespread adoption of AR and BIM in Syria's construction industry may be fraught with challenges, the potential benefits are too significant to overlook. These technologies not only promise to enhance the efficiency and safety of construction projects but also align with broader goals of economic recovery and sustainable development. The future of construction in Syria could be markedly improved through the strategic adoption of AR and BIM, setting a precedent for innovation and excellence in the region.

Future research should focus on longitudinal studies to track the implementation of AR and BIM over multiple projects to better understand their long-term impacts on project efficiency and cost-effectiveness. Additionally, comparative studies examining the effects of these technologies in different regions within Syria could provide deeper insights into localized challenges and benefits, helping tailor implementation strategies to specific needs.

7. Recommendations

For Government and Policy Makers:

- Develop Incentive Programs: Implement financial incentives such as tax breaks, subsidies, or grants specifically designed for construction firms that invest in AR and BIM technologies. These incentives could reduce the initial cost barrier associated with adopting new technologies.
- Establish Regulatory Frameworks: Create and enforce regulations that encourage or require the use of BIM and AR in large public and private construction projects. This could include mandating BIM for all government-funded construction projects to ensure consistency and quality.
- Invest in Infrastructure: Strengthen the digital infrastructure of the country to support the widespread use of high-tech tools like AR and BIM. This includes improving internet accessibility and speed, particularly in rural or war-affected areas, to ensure that all construction sites can benefit from these technologies.

For Construction Companies and Industry Stakeholders:

- Pilot Projects: Initiate pilot projects that integrate AR and BIM to demonstrate their practical benefits. These projects can serve as case studies or models for broader implementation and help to quantify the return on investment.
- Training Programs: Invest in continuous professional development programs for employees at all levels to ensure they have the skills necessary to utilize AR and BIM effectively. Partner with technology providers to create customized training sessions that are directly relevant to the tools being implemented.
- Collaboration and Partnerships: Engage in partnerships with technology firms, universities, and international construction companies that have expertise in AR and BIM. These collaborations can facilitate technology transfer, provide access to cutting-edge practices, and help adapt these technologies to the Syrian context.

For Educational Institutions:

- Curriculum Development: Update and adapt the curriculum in engineering and construction management programs to include comprehensive training in AR and BIM. This could involve both theoretical courses and practical, hands-on training that reflects the current technological advancements in construction.
- Research and Development: Encourage and support research in AR and BIM applications in construction, offering grants or funding opportunities for innovative projects. Facilitate partnerships between academia and industry to ensure that research outcomes are practical and applicable in real-world settings.

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For International and Local NGOs:

- Capacity Building: Focus on capacity-building initiatives that equip local construction firms and workers with the knowledge and tools to implement AR and BIM. This could include workshops, seminars, and on-site training programs that are tailored to the specific needs of the Syrian construction industry.
- Support for Innovation: Fund and support innovative projects that explore the use of AR and BIM in rebuilding and development efforts in Syria. This can help to catalyze the adoption of these technologies and showcase their benefits to a broader audience.

By following these recommendations, stakeholders across the Syrian construction industry can effectively leverage AR and BIM technologies to enhance construction processes, improve project outcomes, and ultimately contribute to the nation's economic recovery and development. Embracing these technologies not only promises substantial improvements in construction practices but also aligns with broader strategic goals of modernizing the industry and rebuilding a war-torn country

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