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Benefits and Challenges of Building Information Modelling (BIM) in Enhancing Occupational Safety and Health (OSH) in Construction Project

Indrajid Nagendran[1], Sushilawati Ismail[2]

[1] *Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA*

*Corresponding Author: sushila@uthm.edu.my
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BIM- Building Information Modelling, OSH-Occupational Safety and Health, AEC- Architectural Engineering and Constrcution, CITP- Construction Industry Transformation Plan, AI-Average Index, SPSS- Statistical Package for Social Science

Abstract

This study explores the use of Building Information Modelling (BIM) to improve Occupational Safety and Health (OSH) in the Malaysian construction industry. Despite the sector's economic significance, accidents are prevalent. The hypothesis suggests that BIM, a cutting-edge tool in architecture, engineering, and construction, can elevate safety standards. However, challenges like skill gaps and technological limitations hinder full BIM integration. The study aims to identify BIM's benefits for OSH and recognize adoption barriers focusing on G7 contractors in Malaysia. A questionnaire surveyed 34 respondents, and the results highlight BIM's potential in safety enhancement, providing insights into safety visualization, coordination, communication, and predictive analysis. Challenges include resistance to technological change, complexity, and cost concerns. This research is vital for ensuring OSH regulations, improving construction site safety, and overcoming BIM implementation barriers.

1. Introduction

The construction industry, a significant contributor to economic growth, is unfortunately characterized by a high incidence of accidents and injuries. Despite advancements in technology and procedures, safety remains a concern [1]. OSHA (Occupational Safety and Health) planning is the duty of contractors under the Factory and Machinery Act of 1967 and the Occupational Safety and Health Act of 1994 (Act 514), which highlight the significance of workplace safety [39]. The technology known as Building Information Modelling (BIM) is developed to improve safety in building projects. Benefits of BIM, a more recent innovation in the AEC (Architectural, Engineering, and Construction) sector, include lower costs, more productivity, and better safety planning [2]. Using BIM at every stage of a project can help with efficient management, teamwork, and dispute resolution [3].

1.1 Objective

i. To identify the benefits of BIM for OSH in construction projects.
ii. To recognise the challenges of BIM adoption for OSH in construction project.

1.2 Scope of study

i. Benefits and challenges faced by construction practitioners on BIM technology for OSH in Malaysia.
ii. G7 contractors, that implement BIM technology in construction projects.
iii. The data was collected through questionnaires survey form.
iv. The data was analysed using average index.

1.3 Significance of research

This research contributes to increased safety on construction sites, identifies obstacles to BIM adoption, and ensures compliance with safety regulations. It seeks to determine potential benefits of BIM for OSH and assess obstacles in its adoption [39]. The study aids in clash detection, visual communication, and scenario planning, ultimately enhancing health and safety in the construction industry. Contractors can benefit by developing strategies to integrate BIM and adhere to safety standards, thereby increasing safety on building sites.

2. Building Information Modelling (BIM) in Occupational Safety and Health (OSH)

2.1 Overview of BIM Technology

The evolution of BIM technology, stemming from the origins of computer-aided design (CAD) in the 1970s, has been highlighted by [4]. Since the development of this technology, stakeholders in a project may now effectively collaborate by using a comprehensive virtual model that combines structural, architectural, and MEP (mechanical, electrical, and plumbing) information. With a goal of 50% of projects using BIM by 2020, the Malaysian Construction Industry Transformation Plan (CITP) highlights the government's commitment to BIM adoption. But problems still exist, as [5] points out, mentioning a lack of knowledge and insufficient training in the Malaysian building industry. In spite of these obstacles, BIM's revolutionary potential is clear from its capacity to produce 3D models—which outperform conventional 2D drawings—which improve project visibility, collision detection, and interdisciplinary cooperation. Because BIM is all-inclusive, it enables stakeholders to model and evaluate a project's lifecycle, incorporating factors like time and cost to support well-informed decision-making.

2.2 Benefits of BIM Technology in OSH

The literature review reveals several key advantages of Building Information Modelling (BIM) technology in enhancing Occupational Safety and Health (OSH) within the construction sector. BIM facilitates improved safety visualization and simulation, allowing stakeholders to assess and address potential risks through real-time digital representations [4]and [5]. Virtual walkthroughs based on BIM models enable proactive safety planning, aiding in the identification and mitigation of safety issues before construction begins [6], and [7]. The integration of safety parameters into BIM models enhances safety studies by automating hazard assessments using design data [8], and [9].

Additionally, data-driven safety analytics is made possible by BIM technology, giving stakeholders the ability to examine safety trends and patterns in order to make more accurate safety assessments and decisions [10], [11], and [12]. Construction professionals can enhance risk management by adapting safety precautions dynamically as work continues, thanks to real-time dynamic hazard analysis enabled by BIM-based simulations [13] and [12]. The use of BIM in site layout planning reduces hazards, expedites OSH procedures, and optimises the deployment of resources [14], and [15]. Stakeholder participation facilitated by BIM facilitates collaborative safety planning, which improves coordination and communication and facilitates the implementation of preventive safety measures and risk mitigation [16], [19], and [20].

Additionally, BIM facilitates safety training simulations, which give construction workers a safe environment in which to explore possible risks and enhance their knowledge and practical skills [12], and [17]. BIM's incorporation of safety equipment and local safety regulations guarantees adherence to OSH regulations, expediting the verification procedure and lowering the possibility of non-compliance penalties [18], [19], and [20]. Based on historical data and trends, predictive safety analytics in conjunction with BIM provide a proactive approach to hazard prevention, improving overall project safety [20], and [10]. With the help of sensor integration and real-time safety monitoring via BIM, decisions and actions to ensure a safe working environment may be made quickly and effectively [21], [22].

2.3 Challenges in Applying BIM Technology in OSH

Implementing Building Information Modelling (BIM) for Occupational Safety and Health (OSH) encounters several challenges. Firstly, contractors' resistance to BIM adoption, rooted in a lack of experience and reluctance to change, poses a significant obstacle [5], and [7]. Overcoming this resistance demands a holistic approach addressing cultural and psychological factors to foster a more accepting attitude toward technological advancements. Secondly, the complexity of BIM systems complicates their effective use in construction projects, necessitating simplified techniques and specialized training for proficient application [28], and [12].

Financial constraints constitute a third challenge, with insufficient resources hindering widespread BIM acceptance for OSH enhancement [11], and [23]. The absence of standardized rules for integrating safety-specific data into BIM models is the fourth challenge, resulting in discrepancies and impeding seamless safety factor incorporation [24], and [7]. Moreover, a shortage of qualified individuals familiar with both BIM tools and safety procedures in construction poses a fifth challenge, potentially leading to ineffective BIM usage for OSH management [3], and [25]. Addressing these challenges is crucial to fully leverage BIM's potential for enhancing OSH in construction projects [14], [15], and [9].

2.4 Recognition of BIM into OSH Practices

Contractors' awareness of BIM's potential for enhancing Occupational Safety and Health (OSH) is crucial for successful deployment [7], and [26]. Experience with BIM projects positively correlates with better awareness among contractors [27], and [12]. Bridging knowledge gaps through targeted educational initiatives is essential to empower contractors in making informed decisions.

BIM utilization for OSH practices is influenced by organizational size, resource availability, project type, and complexity [6], [4], and [29]. Contractors recognize benefits such as improved risk identification but face challenges like interoperability issues [30], and [24]. Effective education and training programs play a crucial role in enhancing contractors' skills for BIM-driven OSH practices [31], and [32]. The legal environment and industry standards significantly impact BIM-OSH integration, emphasizing the need for alignment with construction safety rules and global BIM standards [22], and [33]. Best practices include fostering collaboration between OSH and BIM specialists, supported by successful case studies [34], and [18]. Future directions involve exploring augmented reality, virtual reality, artificial intelligence, and machine learning in BIM-OSH integration [35], and [14]. Measuring and evaluating BIM's effectiveness requires quantitative analysis, as demonstrated by previous studies [36], and [8]. Identifying and addressing barriers, such as reluctance to change, and providing BIM training for contractors are crucial aspects for successful integration into OSH practices [11], and [8].

2.5 Optimizing and Managing Construction Safety through BIM Technology

Building Information Modelling (BIM) technology has emerged as a powerful tool for optimizing construction safety management. Integration of BIM into various construction processes enables proactive safety planning and hazard prevention. Notably, [4] emphasize the 3D visualization and conflict detection capabilities of BIM, which facilitate early hazard identification and contribute to a reduction in safety risks on construction sites. The combination of BIM with Geographic Information System (GIS), as suggested by [5], enhances risk evaluation and hazard detection, allowing construction teams to develop effective safety planning strategies by merging spatial data and BIM models.

In addition to improving safety outcomes, BIM significantly enhances quality control procedures in the construction industry. [29] highlight BIM's role in minimizing errors and rework through clash identification and resolution capabilities. Automation of quality control processes using BIM, as advocated by [23], involves incorporating data validation approaches and rule-based algorithms into BIM models, ensuring continuous adherence to safety regulations and decreasing human error. The integration of BIM with other technologies, such as Augmented Reality (AR), as proposed by [7], further enhances quality control inspections, facilitating thorough assessments and real-time repairs. These advancements in quality control, coupled with BIM's integration with safety monitoring systems and RFID technology [37], contribute to more efficient safety management, allowing for real-time movement tracking of workers and better monitoring of access to hazardous areas. The overall impact of BIM on construction safety is further underscored by its integration with Artificial Intelligence (AI) and Machine Learning (ML) approaches, as discussed by [12], enabling early detection of potential safety issues and efficient risk reduction strategies. Thus, the adoption of BIM in construction projects enhances both safety management efficiency and quality control processes, leading to improved occupational safety and health outcomes.

3. Methodology

The primary data collection method was a questionnaire survey, aligning with the study's goal. A meticulously crafted questionnaire, divided into three parts, focused on respondent demographics, benefits of BIM for OSH, and challenges of BIM implementation in OSH among construction contractors. The survey aimed to assess the level of expertise of G7 contractors in using BIM for OSH in Malaysian construction projects [7]. The surveying process, involved the development of the questionnaire, content validity assessment, pilot testing, determination of respondents, defining the research population, determining sample size, distributing the questionnaire, collecting responses, and data analysis.

3.1 Development of questionnaire

The questionnaire comprises three parts:

- Part A: Respondent Demography - Collects vital information such as gender, educational background, career experience, and expertise with BIM to aid in selecting study volunteers.
- Part B: Benefits of BIM for OSH in Construction Projects - Contains structured questions to validate predicted variables related to the advantages of using BIM for OSH in construction.
- Part C: Challenges of BIM Implementation in OSH among Construction Contractors - Aims to gather accurate data to evaluate the challenges associated with BIM adoption for OSH in construction projects.

The structured questionnaire is designed to efficiently collect data for a comprehensive analysis of the benefits and challenges related to BIM in enhancing OSH within the construction industry.

3.2 Content Validity Assessment

To ensure the questionnaire's efficacy and quality, civil engineering experts, including lecturers, were involved in the validation process. The finalized questions were shared with a research team comprising four lecturers and an academic advisor. The primary objectives were to confirm the questions' relevance to the construction sector and alignment with the research objectives. Expert comments and suggestions were carefully considered before distributing the questionnaire to respondents.

3.3 Determination of Respondent

A suitable reply had been found by this point. The respondents in this study's construction industry were G7 contractors in Malaysia. To ensure that the goals of the research are accomplished, the company's contractor needs to have expertise implementing BIM in Malaysian OSH building construction. This allowed them to deliver more reliable data and information. This study required many respondents in order to be conducted.

3.4 Research Population and Sample Size

The study focused on G7 contractors experienced in implementing Building Information Modelling (BIM) for Occupational Safety and Health (OSH) in Malaysian construction projects. Due to practical constraints, a sampling approach was employed. The study aimed for 96 respondents using the Cochran equation due to the absence of direct database information [15] but received 34 completed questionnaires within the time constraints. While below the initial target, the sample size was deemed sufficient based on guidelines by [40] suggesting a range of 30 to 500 respondents for a study of this nature.

$$Population\ of\ unknown\ (n_o) = \frac{z^3 p(1-p)}{e^2} \qquad \text{(Eq 1)}$$

Where;

no = The population of unknown sample
z^2 = The value of standard normal distribution according to z table.
p = The number of maximum variability of population
e = The number of acceptable margin error in social research

$$(n_o) = \frac{1.96^3 x\ 0.5(1-0.5)}{0.1^2}$$
$$= 96.04 \approx 96\ respondents$$

3.5 Distribution of questionnaire

After the content validity process, the next was choosing a qualified respondent. 100 questionnaires were sent to the prospective respondent. Time constraints meant that this step required roughly four weeks. The questionnaire was sent online via email, a Google form, a link shared via a mobile device, or any similar method, at the respondent's discretion. There were two weeks left to fill out the form.

3.6 Collecting the Respond from Respondent

The distributed questionnaire was successfully collected upon completion by the respondents, who displayed strong commitment and timely participation. Out of 100 distributed questionnaires, 34 responses were received and recorded. Ensuring each participant filled out the form was crucial for reliable results. The researcher-maintained focus on precise question definition to avoid overlooking any valuable information from the responder data. This step was essential to fulfill the study's goals during the analysis stage.

3.7 Analysis of Data

The collected data was processed using Microsoft Excel and SPSS, and the results were compared against established specifications. The Average Index (AI) was employed for data analysis, utilizing a formula that considered respondents' scales from "Strongly Disagree" to "Strongly Agree." Two evaluation tables, Table 1 and Table 2, were used to assess the benefits and challenges of using BIM in OSH construction projects.

$$Average\ Index\ (A.I) = \frac{\sum(1X_1+2X_2+3X_3+4X_4+5X_5)}{\sum(X_1+X_2+X_3+X_4+X_5)} \qquad (Eq\ 2)$$

X1 = Number of respondents for scale “Strongly Disagree”
X2 = Number of respondents for scale “Disagree”
X3 = Number of respondents for scale “Neutral”
X4 = Number of respondents for scale “Agree”
X5 = Number of respondents for scale “Strongly Agree”

Table 1 *Level of agreement of Average Index Analysis (A.I)*

Average Index	Level of Agreement
1.00 ≤ Average Index ≤ 1.50	Strongly Disagree
1.50 ≤ Average Index ≤ 2.50	Disagree
2.50 ≤ Average Index ≤ 3.50	Neutral
3.50 ≤ Average Index ≤ 4.50	Agree
4.50 ≤ Average Index ≤ 5.00	Strongly Agree

Table 2 *Level of Agreement of Average Index Analysis (A.I)*

Average Index	Level of Agreement
1.00 ≤ Average Index ≤ 1.50	No idea at all
1.50 ≤ Average Index ≤ 2.50	No idea
2.50 ≤ Average Index ≤ 3.50	Neutral
3.50 ≤ Average Index ≤ 4.50	Agree
4.50 ≤ Average Index ≤ 5.00	Absolutely Agree

3.8 Reliability Test

Reliability, the consistency of measurements or tools, was assessed using Cronbach Alpha coefficient in SPSS. A value of ≥ 0.7 indicates good internal consistency. Results for the actual study involving BIM construction site contractors are presented in Table 3. Cronbach Alpha scores above 0.7 for both sections signify excellent internal consistency. The study establishes a high degree of internal consistency, confirming the reliability of measurements and tools in the experimental setting.

Table 3 *Results of Cronbach's Alpha for actual study*

Actual Study	Cronbach’s Alpha Score	Number of Questions Tested	Total Number of Respondent
Benefits of BIM for OSH	0.966	13	34
Challenges of BIM implementation in OSH	0.875	9	34

4. Result and Discussion

This chapter delves into the results of the survey conducted with 34 G7 contractors in Malaysia, exploring the impact of Building Information Modelling (BIM) on Occupational Safety and Health (OSH) in construction projects. Statistical Package for Social Science (SPSS) software and Microsoft Excel were employed for data analysis, with a focus on reliability testing and Average Index Analysis. This section concludes with a summary of key findings.

4.1 Part A - Demographic Information

Part A delves into the demographic characteristics of the 34 respondents, shedding light on their educational backgrounds, current job positions, organizational affiliations, and years of experience in the construction industry and with BIM applications. Most respondents (76%) were associated with G7 contractors, and 55% of them reported expertise with BIM. Educational backgrounds were diverse, with 8 having diplomas, 17 degrees, 3 master's, and 1 PhD. Job positions included project managers, engineers, site supervisors, safety officers, and others, offering a representative sample of roles within construction projects. Contractors/subcontractors constituted the predominant group (20 out of 34). This comprehensive demographic analysis establishes a solid foundation for exploring how various factors may influence perceptions and experiences related to BIM and OSH.

Table 4 Demographic Information

Description		Frequency	Percentage (%)
Highest Education Level	Diploma	8	23.5
	Degree	17	50
	Master	3	8.8
	PhD	1	3
	SPM	5	14.7
Current Job Position	Site Supervisor	10	29
	Engineer	10	29
	Safety Officer	5	15
	Project Manager	7	21
	Others	2	6
Current Organization	Client	7	20.6
	Architect	1	3
	Consultant	6	17.6
	Contractor / Sub-Con	20	58.8
Years of experience in construction industry	1-5 years	6	18
	6-10 years	17	50
	11-15 years	8	23
	More than 15 years	3	9
Years of experience with BIM application	1-5 years	29	85.3
	6-10 years	2	5.9
	11-15 years	2	5.9
	More than 15 years	1	2.9

4.2 Part B - Benefits of BIM for OSH in Construction Projects

In Part B, we explore in-depth the perceived benefits of integrating Building Information Modelling (BIM) in Occupational Safety and Health (OSH) within construction projects. Utilizing Likert scales for evaluation, the study investigates 13 specific benefits to discern the impact of BIM on safety protocols. The highest-rated benefit, with an average index of 4, is the enhancement of safety visualization and simulation on construction projects (B1). This underscores BIM's pivotal role in providing a clear visual representation of potential risks, aligning with findings by [4] that emphasize the importance of BIM's visualization capabilities in safety planning.

Following closely, the second highest-rated benefit, with an average index of 3.97, highlights BIM's effectiveness in improving safety communication in construction projects (B10). This finding underscores the pivotal role BIM plays in promoting effective communication and disseminating safety information among project teams, echoing the research of [5].

Collaborative construction site safety planning (B7) emerged as the third highest-rated benefit, with an average index of 3.88. This finding aligns with research by [6], emphasizing the critical role collaborative planning plays in enhancing overall safety performance on construction sites. The study indicates that BIM facilitates effective communication and coordination between project participants, leading to the implementation of risk mitigation and preventative safety measures.

Furthermore, the study explores a spectrum of benefits, including but not limited to safety coordination (B9), integration of safety equipment (B11), and real-time safety monitoring (B13), each contributing to a comprehensive understanding of how BIM can be a catalyst for improved safety practices in construction projects. The diverse range of benefits uncovered in this section provides a nuanced perspective on the multifaceted advantages of BIM integration, guiding future strategies for enhancing OSH within the construction industry. These findings collectively reinforce the notion that BIM, with its visual, collaborative, and predictive capabilities, can significantly elevate safety management practices in construction projects.

Table 5 Benefits of BIM for OSH in Construction Projects

Benefits of BIM for OSH in construction project	AI	Rank
B1: Enhancing safety visualization and simulation on construction projects.	4	1
B2: Facilitating virtual walkthroughs that aid in safety planning.	3.68	9
B3: Integrates safety parameters for OSH in construction projects.	3.71	8
B4: Aid in safety data analytics in construction projects.	3.62	10
B5: Providing dynamic hazard analysis for construction site safety.	3.56	12
B6: Enhances site layout planning for safety in construction projects.	3.59	11
B7: Provide collaborative construction site safety planning.	3.88	3
B8: Enhance effectiveness of safety training simulations in the construction project.	3.50	13
B9: Support safety coordination on construction projects.	3.82	4
B10: Enhances safety communication in construction project.	3.97	2
B11: BIM has been effective in integrating safety equipment into construction projects.	3.79	5
B12: Provide effective prediction on safety issues and incidents on construction sites.	3.76	6
B13: Support real time safety monitoring on construction projects.	3.74	7

4.3 Part C - Challenges of BIM Implementation in OSH Among Construction Contractors

Part C systematically addresses the challenges associated with implementing BIM for OSH within construction projects. The identified challenges encompass resistance to technological change (C1), emphasizing the industry's reluctance to adopt new technologies [4], and [12]. The complexity of BIM systems (C2) and the lack of standardization in BIM practices (C4) highlight the need for simplified strategies and standardized training for contractors to confidently use BIM systems in strengthening safety practices, according to past studies like [12], and [20]. Cost concerns (C3) emerge as a prominent difficulty, echoing concerns raised in the literature about the financial implications of BIM implementation [28], and [22].

Legal and regulatory compliance (C5) indicates that implementing BIM for safety in construction is hampered by the need to comply with legal and regulatory standards [24], and [30]. Concerns about privacy and security (C7) emphasize the delicate balance between leveraging BIM's benefits and safeguarding sensitive data [8], and [23]. Lastly, the issues related to collaboration and communication (C8) highlight how challenging it is to have successful stakeholder collaboration and communication in BIM-based safety assessment. This is consistent with research by [37], and [10] that highlights the value of efficient communication in BIM systems.

Table 6 Average Index for challenges of BIM implementation in OSH construction project

Challenges of BIM implementation in OSH among construction contractors		AI	Rank
Resistance and Adoption	C1: Resistance to technological change is a significant obstacle to implementing BIM for safety improvements in construction projects.	4.0	2
	C9: Limited familiarity with BIM among construction workers is a significant challenge in promoting safety and health in construction through BIM.	3.71	6
	C6. Cultural and organizational change is a significant challenge when implementing BIM technology for occupational safety and health in construction.	3.56	9

Challenges of BIM implementation in OSH among construction contractors		AI	Rank
Complexity and Standardization	C2: BIM systems are too complex for practical use in the construction industry.	3.74	5
	C4: The lack of standardization in BIM practices is a barrier to safety improvements in construction.	3.76	4
Cost Concerns	C3: The cost of implementing BIM technology in construction is a major concern.	4.2	1
Legal and Regulatory Compliance	C5: Legal and regulatory compliance is a concern when implementing BIM for safety in construction.	3.68	7
Privacy and Security	C7: Privacy and data security concerns are significant barriers to using BIM for safety in construction	3.59	8
Collaboration and Communication	C8: Effective collaboration and communication among stakeholders in BIM-based safety assessment is challenging	3.79	3

5. Conclusion

Chapter 5 serves as the culmination of an in-depth exploration into the benefits and challenges of Building Information Modelling (BIM) to enhance Occupational Safety and Health (OSH) in the construction sector. Drawing upon the comprehensive findings presented in Chapter 4, the study elucidates the substantial advantages conferred by BIM. These include the augmentation of safety visualization, facilitation of virtual walkthroughs, and the promotion of collaborative planning within construction projects. However, the landscape is not without its challenges, as evidenced by obstacles such as resistance to technological adoption, the intricacies associated with BIM systems, financial considerations, and the imperative adherence to legal standards.

Despite the valuable insights gained, certain limitations need acknowledgment. The study primarily focuses on G7 contractors, potentially limiting the generalizability of findings. Moreover, the scope of respondent roles, predominantly Project Managers, Engineers, Site Supervisors, and Safety Officers, could have influenced the breadth of perspectives. A time constraint during data collection further accentuates the study's limitations.

To propel future research endeavors, the study advocates for expanded representation, encompassing a wider array of contractors, and diversifying respondent roles to capture a holistic understanding of BIM benefits and challenges in the Malaysian construction landscape. These recommendations aim to fortify the study's findings, providing a robust foundation for continued exploration and refinement in the integration of BIM for heightened safety and health outcomes in construction. The following suggestion for improving future research:

- Future study should be extended to all grade of contractors to gain high responses. To obtain a sufficient response, data collection must take longer.
- This study was only focused on Project Manager, Engineer, Site Supervisor, and Safety Officer. Further research can be widened up to get different perspectives of BIM benefits and challenges in Malaysia.
- There should be an equal number of respondents for each set of respondents to get precise statistics regarding the reliability of the study.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper. The research was conducted impartially and honestly, and the researchers have no personal, professional, or financial ties that could compromise the objectivity and validity of the findings that were released. This study was primarily driven by the sincere desire to learn more and advance scientific understanding in the assigned topic.

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