

Article

Developing an IoT-Enabled Smart Helmet for Worker Safety: Technical Feasibility and Business Model

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Highlights

- Development of an IoT-enabled smart helmet for construction workers.
- Real-life feasibility of using IoT technology in construction safety.
- Ability to convert the idea into a viable business in the UAE.

Abstract

This paper presents the development and evaluation of an IoT-enabled smart helmet designed to enhance worker safety and site productivity in high-risk construction environments. The primary objective is to mitigate fall-related and heat-related risks commonly faced by laborers in the Gulf region. The proposed system integrates GPS, temperature–humidity (DHT11), and motion sensors (MPU6050 gyroscope and accelerometer) into a compact, wearable unit capable of real-time data transmission. A key technological novelty is the embedded fall detection mechanism, which analyzes sudden movement patterns to trigger instant alerts, enhancing response times during critical incidents. A fall detection algorithm was developed to identify abnormal movement patterns and trigger instant alerts, while continuous temperature monitoring addresses risks of heat stress in extreme climatic conditions such as Dubai, where temperatures exceed 45 °C. Field trials and simulations confirmed the feasibility of the system, demonstrating reliable data transmission, accurate fall detection, and effective remote monitoring. The solution is coupled with a rental-based business model, making it cost-effective and scalable for contractors. The findings suggest that the proposed helmet provides a practical and scalable safety solution.

Keywords: IoT; smart helmet; business model; construction; health and safety



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1. Introduction

It is essential that every workspace, no matter what sector, provides a safe and positive working environment for its employees. It is also quite evident that the construction sector is one of the most dangerous environments to work in. For the purpose of this study, a workplace accident is defined according to the International Labour Organization (ILO) as an occurrence arising out of or in the course of work which results in fatal or non-fatal injury. Over 30% of annual deaths are due to accidents and falls on construction sites, which is equal to around 108,000 fatalities globally each year. This means that construction workers are 3 to 4 times more likely to suffer death at work as compared to other workers [1]. A study from the World Health Organization (WHO) 2024 [2] suggested that approximately

489,000 heat-related deaths occur each year, with 45% of these in Asia alone. While heat-related issues are a global concern, regions like the UAE face particularly harsh environmental conditions, with temperatures exceeding 45 °C during summer [3,4]. This increases the chances of heat-related illness, like heat stroke, which can be fatal if not monitored. Even though Federal Law No. 8 (UAE Labor Code) and Ministerial Order No. 32 of 1982 [5] clearly highlight the role of employers to take necessary action to protect the employees from any kind of occupational illness or work-related accidents, incidents can still happen despite the implementation of safety measures. This highlights the limitations of safety measures even in a robust regulatory environment. Since Middle Eastern regions such as the UAE always experience extreme temperatures during summer, it can significantly elevate the risk of heat stroke, which is a potentially life-threatening condition associated with body overheating. If not treated in time, it can lead to multi-organ dysfunction and even failure [6].

Despite current safety regulations aiming to reduce risks associated with construction, their effectiveness is often limited by the absence of real-time monitoring. This is where new technologies, especially the Internet of Things (IoT), can provide a disruptive solution by continuously tracking environmental factors, such as temperature and humidity, thereby improving worker safety and lowering occupational risks [7–9].

The Internet of Things (IoT) refers to a network of objects that are embedded with sensors that can connect to the internet and share data. These IoT-enabled devices have the potential to revolutionize various industries like construction, manufacturing, and even healthcare. For instance, Emirates Health Services (EHS) has incorporated IoT into the healthcare industry through the EHS intelligence platform, which collects and analyzes data from IoT-based medical devices, such as patients' pulse and blood pressure, to improve patient health monitoring in real time and predictive diagnostics [10]. In manufacturing, Emirates Global Aluminum (EGA) uses IoT-driven predictive maintenance systems to optimize production efficiency by monitoring the machines and equipment in real time [11].

In construction, IoT is required due to the need for real-time on-site data, worker safety, and equipment monitoring. By collecting data like environmental conditions, IoT helps address key issues in this field, mainly health and safety. There have been efforts from researchers and academia to develop a smart safety helmet for construction workers due to the benefits it gives [8]. However, several challenges persist during its development and implementation phases. These include coding the sensors, installing and configuring the setup, and collecting information from the sensors [9]. Furthermore, the deployment of the device must comply with all the legal and regulatory requirements to ensure they are acceptable on construction sites [12,13]. The adoption of IoT in China's construction sector faces several barriers, notably high capital investment and lack of governance and top management support [14]. From a business standpoint, smart helmets seem advantageous as they help meet economic and operational objectives alongside improving safety [9]. In regions like the UAE, where large-scale developments are dominating the industry, the smart helmets could redefine safety protocols by incorporating a real-time monitoring system [15,16]. Moreover, the adoption of IoT technologies in construction supports the objectives of the Dubai Research, Development, and Innovation Program (Dubai RDI) [10,11], where its priority research sectors are Cognitive cities and Health and Life Sciences, aiming to drive smart infrastructure and healthcare solutions with disruptive technologies like IoT. Although initial adoption of this technology may be constrained by high implementation costs, a feasible and demonstrable return on investment (ROI) provides a baseline justification for its business development [17].

In addition to technical aspects, the study also considers business implications, specifically the scalability and practical application of the prototype within construction compa-

nies. These considerations are intended to demonstrate the potential for implementation beyond the experimental phase. The research is structured into four key phases. First, a real-life prototype model of the helmet was made to test and analyze the accuracy and reliability of the sensors, such as GPS, temperature, humidity, and fall detection sensors [18]. Second, the practicality and impact of using the smart helmet in real construction sites were explored, aligning with the growing emphasis on digital transformation in the construction sector [19]. The following phase focused on developing a business strategy to transform the idea of developing a smart helmet into a viable business in the UAE. Subsequently, a financial cost estimate was prepared to understand expenses associated with importing the IoT sensors, assembling the helmet, and legally registering a company in the Emirates.

2. Methodology

This study takes a mixed-method approach, integrating qualitative and quantitative research to assess the development of IoT based smart helmet. The research approach is illustrated in Figure 1. The quantitative approach comprises testing the prototype in real construction sites to gather live sensor readings. This data is used to assess the safety and productivity improvements. The qualitative approach comprises questionnaires and interviews with experts and key stakeholders including industry professionals to gather information about the helmet's real-life implications and challenges associated with developing a business model. By combining both types of data, the study provides a full assessment of helmets' impact on construction safety and practical use.

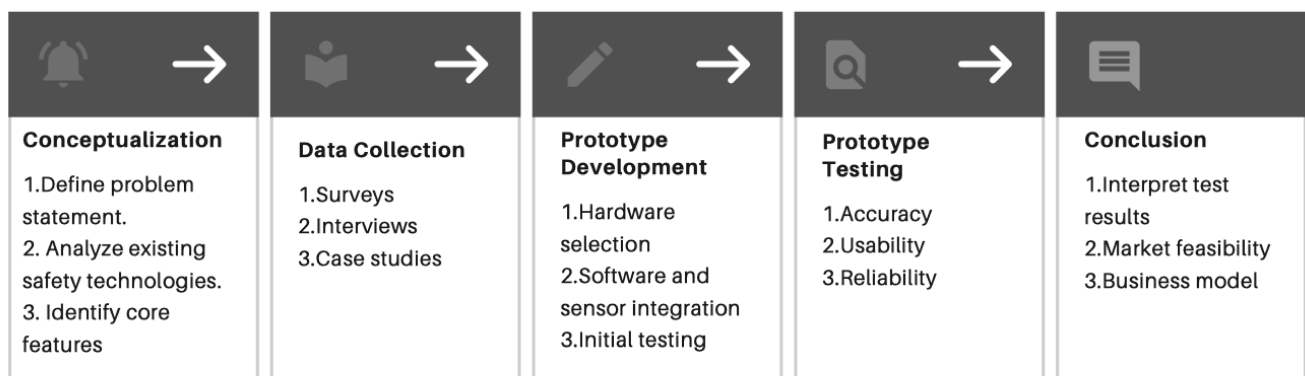


Figure 1. Research approach.

2.1. Interviews

Seven key stakeholders participated in structured interviews to obtain qualitative insights. In the context of the active construction industry, these interviews were intended to analyze real-world obstacles and determine the practicality of implementing smart helmets. Professionals engaged in the stakeholder interviews are listed in Table 1. The Co-founder and Chief executive officer of a Saudi Arabia-based Construction technology startup was one prominent participant. Since this stakeholder had expertise in introducing a technology-based startup, the discussion was based entirely on obstacles faced by the company in developing a technology product, designing a business model, marketing the product, and eventually making a quantifiable impact in the construction industry.

Table 1. Professionals engaged in stakeholder interviews.

Code	Designation	Organization	Location	Years of Experience
CEO	Chief Executive Officer	Construction technology startup	UAE	12
AVP	Vice President	Leading construction company	UAE	18
EE	Executive Engineer	Urban development	India	20
AEE1	Asst. Executive Engineer	City municipal council	India	20
AEE2	Asst. Executive Engineer	City municipal council	India	15
AEE3	Asst. Executive Engineer	City municipal council	India	13
HSSE	Senior Officer—Safety	Construction company	UAE	15

2.2. Online Survey—Questionnaire

To gather data from a wider group of construction professionals, an online survey was conducted. Ten structured questions were included in the survey to investigate and collect opinions from industry professionals regarding Internet of Things technology and its potential to enhance health and safety on a construction site. To reach a large number of industry professionals, the poll was disseminated online. A total of 38 replies were gathered, including a wide variety of viewpoints from individuals with different responsibilities and degrees of expertise. The survey was designed to understand the participants' perspectives on IoT's impact on worker safety, efficiency, and overall site management. Among the key questions were the following:

1. What do you think the future holds for IoT in construction?
2. Do you believe IoT helmets can enhance safety and efficiency on construction sites?
3. Would you recommend IoT-enabled construction safety helmets for laborers?

2.3. Helmet Setup

The helmet's key components were sourced from AliExpress, an online marketplace renowned for providing a large selection of electronic components and sensors from reputable Chinese vendors [20]. AliExpress was chosen due to its vast catalog of IoT components, ease of access, and competitive pricing, making it an ideal choice for sourcing hardware. The smart helmet incorporates many components in the setup, as shown in Figure 2, mainly the following: (1) ESP-32 (sourced from a local electronics shop, Bangalore, India), an advanced microcontroller with Wi-Fi and Bluetooth capabilities that connects all the following IoT sensors and transmits the sensor readings to the cloud using the internet. (2) DHT22 (sourced from a local electronics shop, Bangalore, India), a sensor that reads temperature and humidity of the environment. It is often chosen because of its considerably low cost and ease of use. DHT22 is capable of reading temperatures ranging from -40 to 80 °C and relative humidity ranging from 0% to 100%. (3) GPS module (sourced from a local electronics shop, Bangalore, India), a sensor that receives signals from GPS satellites to determine the exact location of the module using its coordinates—latitude and longitude. Its accuracy is typically within 3–5 m. (4) MPU6050 (sourced from a local electronics shop, Bangalore, India), a sensor module that integrates accelerometer and gyroscope, making it ideal for motion tracking applications. The accelerometer can detect movement and tilt, while the gyroscope helps in determining the velocity. By combining both, the module can detect any sudden falls or abnormal movement. The code for integrating these sensors to the microcontroller was developed using the assistance of ChatGPT (GPT-3.5, released November 2022). The AI was used for writing and debugging the code to interface DHT22, GPS, and MPU6050 with the ESP-32 microcontroller. The code was then uploaded

using Arduino IDE, an open-source software that is used to transfer the code directly into the microcontroller. This approach helped streamline the coding process and reduce development time significantly. A breadboard was used to hold all the components in place and intact, providing a platform for testing. The breadboard's ability to support quick and easy connections via jumper cables enabled seamless integration of the sensors with the ESP-32 microcontroller. The prototype was assembled by integrating multiple sensors onto the helmet to capture real-time data from workers during construction activities. Figure 3 illustrates the real-life images of the sensor and helmet setup.

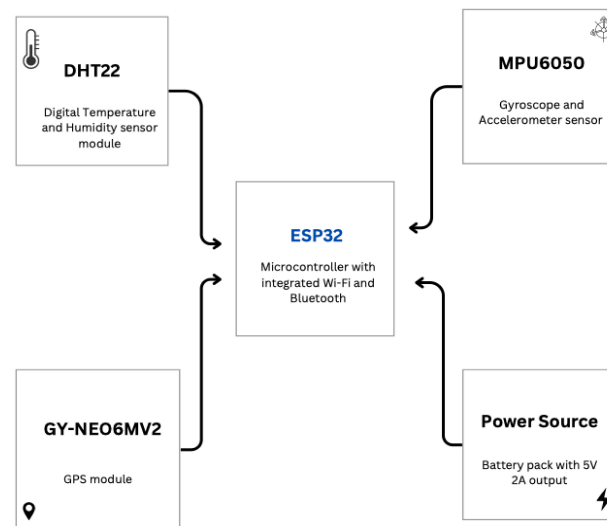


Figure 2. Sensor module setup.

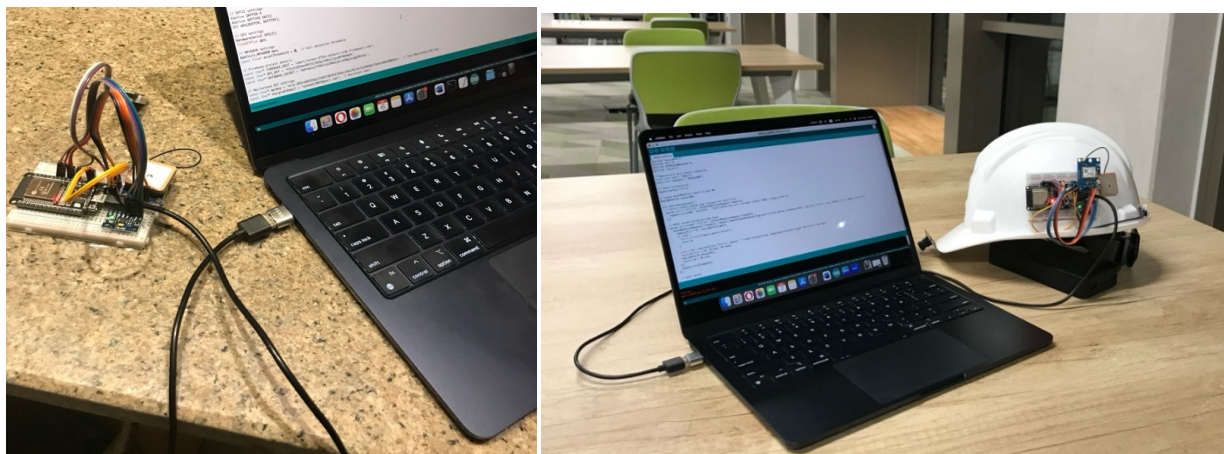


Figure 3. Real-life images of the sensor and helmet setup.

To power the setup during testing, a typical 5 V portable power bank was used. This external power source was connected to the ESP-32 microcontroller via a USB cable, ensuring a consistent and controlled voltage supply for the entire system. The battery bank was neatly put in the user's pocket to prevent adding weight to the helmet, ensuring the user's comfort and mobility. This configuration allowed for continuous testing of sensor performance and data transfer without the use of sophisticated power management circuitry. Although this strategy was suitable for prototype validation, future iterations could include unique battery solutions for integrated and field-deployable designs.

2.4. Operational Mechanism of the Smart Helmet

Following the initial setup, the next essential phase was to read real-time data collected from the IoT sensors, as shown in Figure 4. This method consisted of sending data from IoT sensors (DHT22, MPU6050, and GPS) to the ESP-32, which then used the internet from Wi-Fi to upload sensor readings to Google Firebase (Firebase SDK v10.5.0), a cloud-based platform used for storing, synchronizing, and viewing real-time data. The data was then made available via the Firebase dashboard, allowing real-time monitoring on various devices such as PCs and mobile phones. Additionally, in the event of a fall, the MPU6050 sensor detects the unusual movement and triggers an alarm. The ESP-32 microcontroller processes this alarm and turns on the Mailer send function, an email service that facilitates the automatic dispatch of notifications to designated personnel. The microcontroller sends an HTTP request to the Mailer Send API (Application Programming Interface), a set of protocols that allows different software to communicate with each other, allowing an email notice to be automatically distributed to the designated staff.

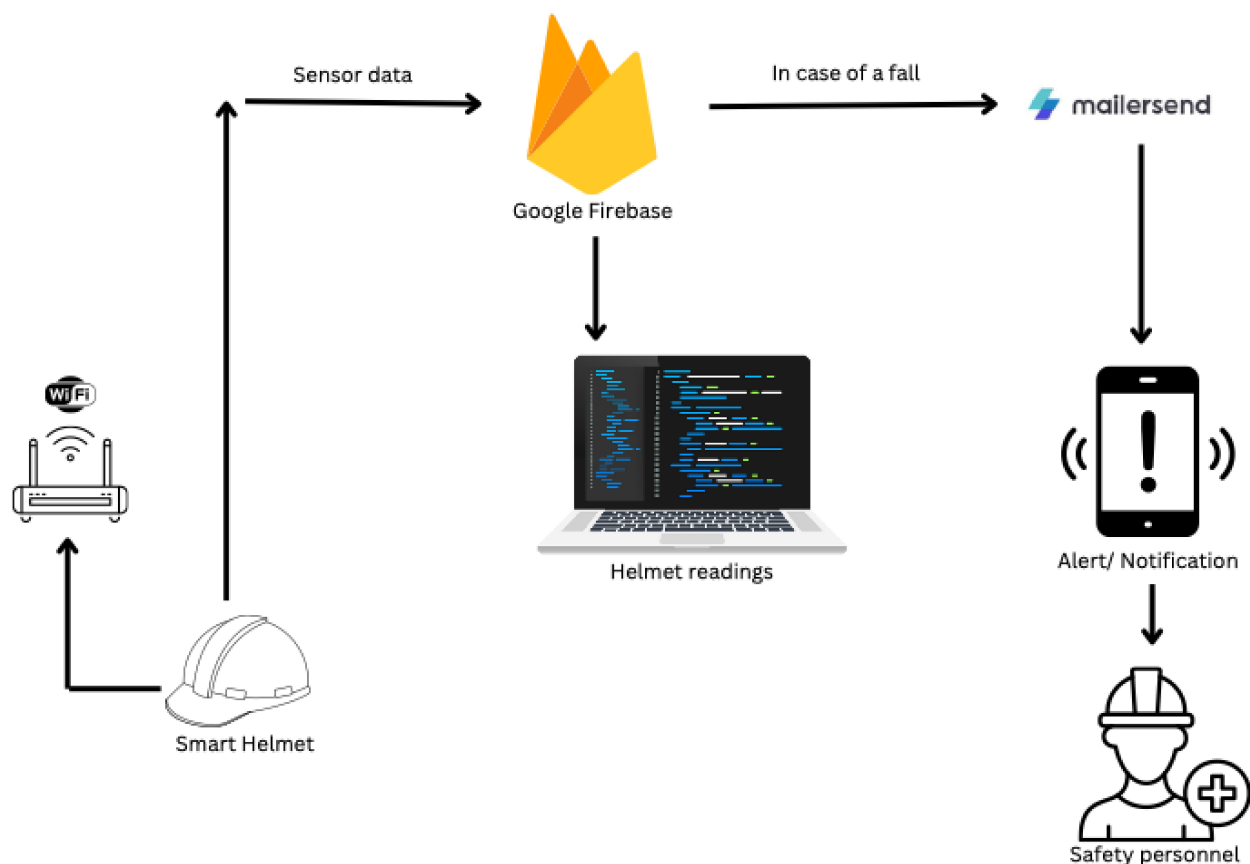


Figure 4. Flow model of the smart helmet.

3. Limitations of the Safety Helmet Prototype

Several limitations affected the smart helmet's feasibility. The helmet's weight was a major drawback since the setup weighed between 700 and 750 g, including the battery and cables. To guarantee user comfort and safety, it had to meet safety regulations such as EN 397 [21]. These guidelines state that the helmet's weight cannot go over 600 g. In order to overcome this restriction, the battery was moved from the helmet and relocated to the worker's pocket, connected via a USB cable, which brought down the weight to 550 g, making it meet EN 397 regulation. Personal Protection Equipment certification is subject to strict Dubai Municipality (DM) regulations, which mostly focus on physical safety requirements, including durability and impact resistance. IoT-enabled smart helmets may

need more testing to meet these conventional criteria because they use additional physical sensors attached to the helmet. The changing regulatory environment for tech-enhanced PPE offers a chance for safety equipment approval procedures to be updated and innovated in the future.

4. Results and Discussion

4.1. Qualitative Insights—Stakeholder Perspectives

The insights obtained from industry professionals provided critical viewpoints and perspectives on the feasibility, possible obstacles, and potential for using IoT-enabled smart helmets in the construction industry. While there was agreement on the helmet's potential benefits, perspectives differed on the factors influencing adoption and market success. The gap demonstrates the complexities of incorporating such technology into the sector, with diverse stakeholders prioritizing cost, regulatory compliance, and the technology's unique applications. The Vice President (VP) of a well-known UAE construction company expressed profound worries about the smart helmet, questioning its usefulness and feasibility. He emphasized that his organization currently has solid safety measures in place, which reduces the necessity for such a device. He also mentioned practical challenges and probable legal limits, as Dubai Municipality requires tight safety standards for any new technology used on construction sites. These concerns provide vital insights into future challenges, such as regulatory obstacles and the necessity to align the smart helmet with existing safety requirements. By identifying these constraints, the project scope can be shifted to focus on tailoring the helmet's features to meet regulatory standards and demonstrating its additional value in an already well-regulated safety environment.

In contrast, the Executive Engineer from Bangalore, India, offered a very optimistic outlook on the potential of IoT-enabled smart helmets, particularly in terms of worker safety and project tracking. As the Head of the Engineering Wing for local urban bodies under the Urban Development Department, responsible for planning and carrying out all civil works, he provides vast expertise in construction management and regulatory compliance. He highlighted that when government agencies issue tenders, contractors must adhere to strict deadlines or face penalties. Contractors frequently blame delays on low productivity, unfavorable weather, and workforce shortages, which can lead to disagreements and conflicts between the contractor and client. The Executive Engineer proposed that IoT-enabled smart helmets may assist in reducing these disputes by giving real-time data on worker activities and project progress, assuring better transparency and accountability. He also stated that government agencies are inclined to sponsor such programs, particularly if they contribute to saving lives and improving worker safety. Programs such as the Startup India Seed provide financial support to startups for proof of concept, prototype development, product trials, market entry, and commercialization.

Supporting this optimistic view, a Health, Safety, Security, and Environment (HSSE) officer from a construction company in Dubai shared valuable operational insights into the smart helmet's potential. He emphasized that the ability to monitor the live heat index for each individual worker—especially in labor-dense zones—could be extremely valuable for preventing heat-related incidents. In environments where a high concentration of laborers is working simultaneously, site supervisors often struggle to assess real-time conditions for every worker. The smart helmet could provide individualized environmental data, enabling prompt interventions and improving overall safety management. This feature becomes even more critical considering Dubai Municipality's regulations, which mandate work stoppages during extreme heat to protect worker health, such as the annual midday break rule enforced from 15 June to 15 September [22]. Real-time heat index data from the

smart helmets can help organizations ensure compliance with these legal requirements, thus avoiding penalties while safeguarding worker well-being.

One of the most significant revelations came from the CEO of a Saudi Arabian construction technology business. He discussed his experience developing a smart helmet outfitted with a full suite of various sensors available at the market, an initiative that originally experienced hurdles due to its broad and unfocused capabilities. Due to this, the helmet struggled to gain traction as it attempted to serve multiple purposes—safety, data collection, project management, etc.—without a clear primary goal. Recognizing this difficulty, they changed their approach to focus on boosting productivity in mega projects, specifically by monitoring labor productivity and automating timekeeping. The helmet tracked workers' location in real time, computed actual man-hours spent on the assigned activity, and calculated the time wasted when workers are involved in non-productive activities such as waiting for supervisors. This strategic change presented the product with a clearer purpose, making it more desirable to construction companies looking to optimize worker management. The key learning from this experience is that for an IoT-enabled smart helmet to be effective, it must have a well-defined and industry-relevant goal rather than being a generic tech-heavy solution.

4.2. Quantitative Analysis of Survey Data

The survey generated 38 responses from construction professionals with varying levels of experience and expertise, with the majority of them having a basic understanding of Internet of Things technology. About 95% of the respondents expressed the belief that IoT holds a promising future in the construction industry. The overall opinions of these stakeholders on IoT implementation in the construction sector are summarized in Figures 5 and 6. However, multiple concerns have been expressed about the viability of the suggested smart helmet.

What do you think the future holds for IoT in construction?

38 responses

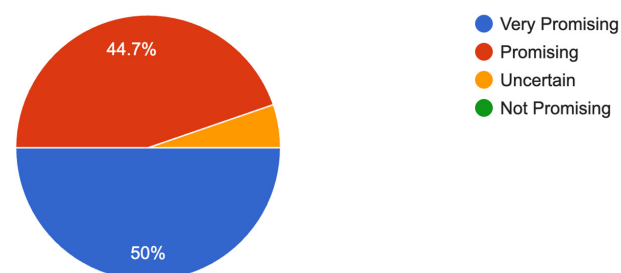


Figure 5. Stakeholders' opinion on IoT implementation in the construction sector.

Do you believe IoT helmets can enhance safety and efficiency on construction sites?

38 responses

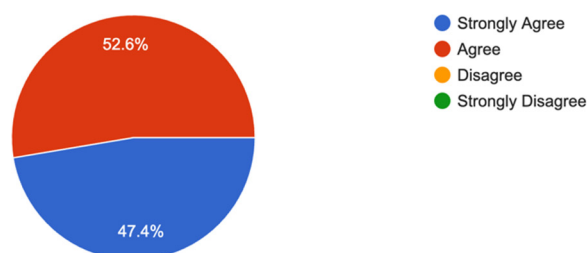


Figure 6. Stakeholders' opinion on IoT smart helmet and their potential in increasing safety.

1. Cost concerns were frequently raised, with one respondent mentioning that the helmet might be “too expensive for smaller projects.” This feedback suggests that while the smart helmet could offer substantial benefits for large-scale projects, it may not be financially viable for smaller businesses or projects, where budget constraints are more pronounced.
2. Battery life and wearability concerns emerged from a few respondents. These concerns echoed the feedback received from Assistant Executive Engineers (AEEs), who questioned the practicality of maintaining long battery life while ensuring worker comfort. Despite these concerns, prototype testing showed that the helmet was well-received in terms of comfort, with no significant issues reported regarding the helmet’s weight or wearability.

4.3. Outcomes of On-Site Prototype Testing

The IoT-enabled smart helmet prototype was developed and tested to enhance worker safety on construction sites. It incorporated a temperature and humidity sensor, a GPS sensor, and a fall detection sensor. The smart helmet was coupled with a web-based monitoring dashboard made with Google Firebase, allowing for real-time visualization of crucial information such as worker position (GPS), fall detection alarms, temperature, and humidity. The technology was meant to transmit real-time data and provide alerts in the case of an accident. The data was structured in the following format for ease of monitoring:

- Timestamp: dd/mm/yyyy_hh: mm: ss;
- Temperature (°C): [value];
- Humidity (%RH);
- Longitude: [value];
- Latitude: [value].

The helmet was deployed at a construction site in Dubai, UAE; the system recorded data for two hours. The average temperature recorded on 9 May 2024 was 36.5 °C, with 71.4% humidity. The heat index (HI) was estimated using the Rothfus regression equation [23,24], which takes into account the effects of humidity on felt temperature. The equation is presented as follows:

$$HI = -8.7847 + 1.6114T + 2.3385RH - 0.1461T \cdot RH - 0.0123T^2 - 0.0164RH^2 + 0.0022T^2 \cdot RH + 0.0007T \cdot RH^2 - 0.0003 T^2 \cdot RH^2$$

where

- HI = Heat Index in °C;
- T = Ambient temperature in °C;
- RH = Relative humidity in %.

Thus, the computed heat index was roughly 57 °C, placing the working conditions in the “**Death Danger**” zone according to the Dubai Municipality Health & Safety Department [3]. This heat stress condition is illustrated in the Heat Stress Matrix shown in Figure 7, adapted from Dubai Municipality guidelines. Workers are at greater risk of heat-related illnesses, including heat stroke; thus, frequent hydration, shaded rest breaks, and shorter exposure hours are required.

The prototype uses a triaxial accelerometer (MPU6050) to track worker movements and detect falls based on acceleration thresholds. A fall was detected when the resultant acceleration magnitude exceeded 2.5 g, followed by a deceleration of less than 0.5 g within a 500 milli second window, a typical pattern of free-fall and collision [25,26]. This 2.5 g threshold was calibrated based on industry research to ensure an appropriate balance of sensitivity (detecting actual falls) and specificity (reducing false positives caused by normal

movements such as jumping or bending) [27]. According to studies, falls with impact pressures of more than 3 g to 4 g are considered hazardous, frequently resulting in serious injuries such as fractures or concussions [28]. Fatal falls often have acceleration maxima that exceed 6 g to 8 g, depending on the height and surface of impact [29]. Given that the majority of falls in construction occur at modest heights (e.g., scaffolding or ladders), the 2.5 g threshold was selected to detect high-risk falls while avoiding false triggers from minor stumbles. When the system detected a fall, it quickly sent a “fall detected!” message to the web-based monitoring dashboard, which was shown in real time. Simultaneously, an automated email notification was triggered using *mailer send* [30] to a specified email address, detailing the occurrence. The GPS module built inside the helmet captured the worker’s precise coordinates at the point of impact. These coordinates were displayed on the monitoring website in real time, allowing us to identify the impact location on the site. The prototype also included GPS and fall detection sensors. The fall detection sensor triggered an immediate alert on the webpage and sent an automated email for emergency response. The GPS sensor tracked the worker’s location, helping supervisors in case of an accident. A screenshot of the “Fall detection alert” email notification is shown in Figure 8.

		Relative Humidity															
		25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
Temperature, °C	42°	48	50	52	55	57	59	62	64	66	68	71	73	75	77	80	82
	41°	46	48	51	53	55	57	59	61	64	66	68	70	72	74	76	79
	40°	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75
	39°	43	45	47	49	51	53	55	57	59	61	63	65	66	68	70	72
	38°	42	44	45	47	49	51	53	55	56	59	60	62	64	66	67	69
	37°	40	42	44	45	47	49	51	52	54	56	58	59	61	63	65	66
	36°	39	40	42	44	45	47	49	50	52	54	55	57	59	60	62	63
	35°	37	39	40	42	44	45	47	48	50	51	53	54	56	58	59	61
	34°	36	37	39	40	42	43	45	46	48	49	51	52	54	55	57	58
	33°	34	36	37	39	40	41	43	44	46	47	48	50	51	53	54	55
	32°	33	34	36	37	38	40	41	42	44	45	46	48	49	50	52	53
	31°	32	33	34	35	37	38	39	40	42	43	44	45	47	48	49	50
	30°	30	32	33	34	35	36	37	39	40	41	42	43	45	46	47	48
	29°	29	30	31	32	33	35	36	37	38	39	40	41	42	43	45	46
	28°	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43

Legend:

Up to 29°C	No discomfort
From 30 to 34°C	Slight discomfort sensation
From 35 to 39°C	Strong discomfort. Caution: limit the heaviest physical activities
From 40 to 45°C	Strong indisposition sensation. Danger: Avoid efforts
From 46 to 53°C	Serious danger: stop all physical activities
Over 54°C	Death danger: imminent heat stroke

Figure 7. Heat Stress Matrix showing a Heat Index value of 57 °C, highlighted from IoT helmet data. **Source:** Adapted from heat stress guidelines published by Dubai Municipality (Public Health & Safety Department).

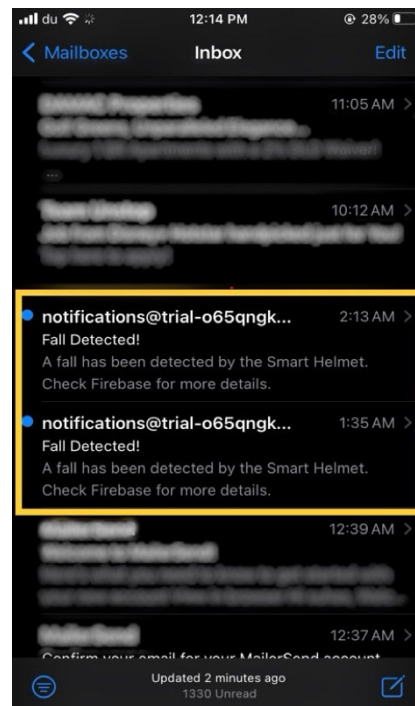


Figure 8. Screenshot of “Fall detection alert” triggered via e-mail.

4.3.1. Business Model

Based on the interviews with industry experts and survey data, a thorough business model for the IoT-enabled smart helmet was developed. Figure 9 summarizes this Business model, which tries to address the technology’s commercial viability by concentrating on prospective market segments, value proposition, revenue sources, cost structure, and implementation plan required for successful market entry [10,11,15].

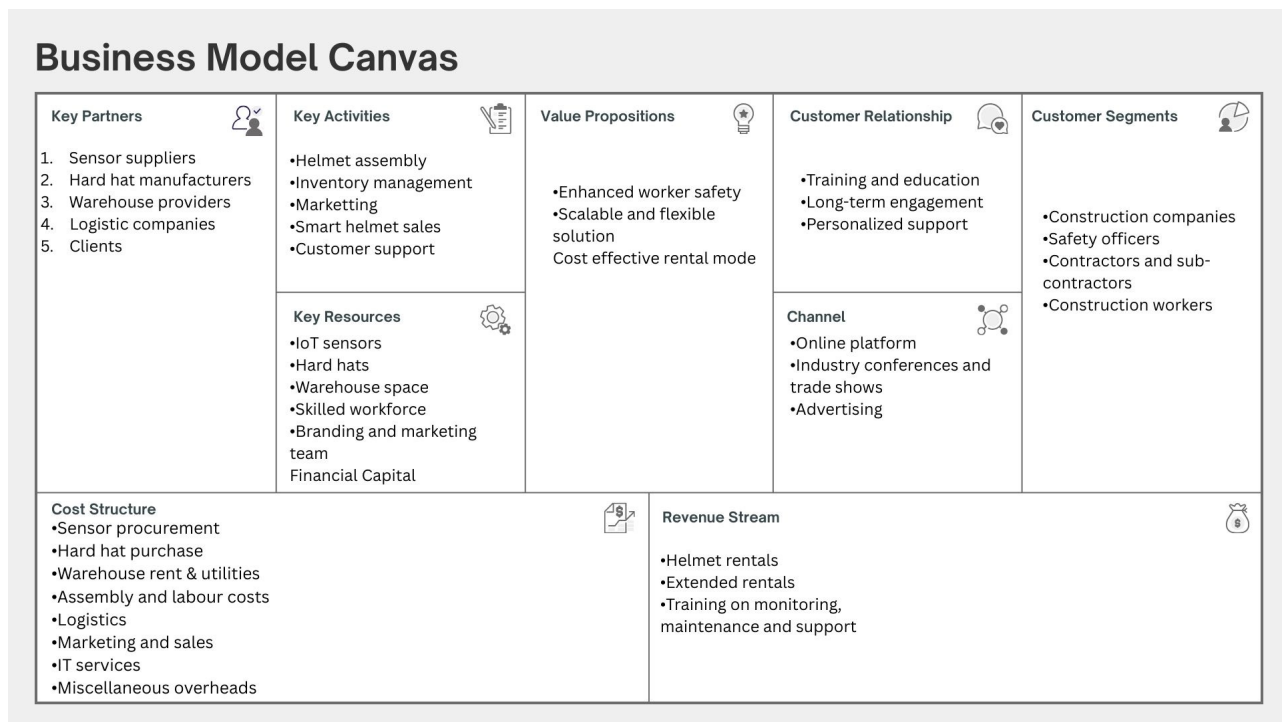


Figure 9. Business model of the proposed helmet.

To enhance long-term viability, the rental-based model can be refined through predictive maintenance (e.g., sensor-driven battery alerts and leveraging edge computing to reduce latency [31]), strategic partnerships (e.g., insurance discounts for safer sites *with demonstrated 22% claim reduction in IoT-monitored projects* [31]), and dynamic pricing (e.g., pay-per-hour for short-term projects). Modular hardware design would allow cost-effective upgrades (e.g., adding air quality sensors), while anonymized data aggregation could generate value through industry benchmarks. Partnerships with telecom providers could ensure connectivity, and integration with BIM/ERP systems like Autodesk [32] would appeal to large-scale projects. These refinements address scalability, regulatory alignment (e.g., UAE's PDPL and Blockchain Strategy 2031 for tamper-proof certifications), and adoption barriers for SMEs through free trials funded by Dubai SME grants—balancing profitability with broader market penetration.

4.3.2. Estimated Monthly Savings per Worker

To quantify the financial benefits of deploying IoT-enabled smart helmets, a study of expected monthly savings per worker was conducted. These savings are determined using regular conditions found in Dubai's building sector and are a conservative estimate based on industry reports and actual site data. The breakdown of estimated savings is summarized in Table 2.

Table 2. Breakdown of the estimated savings to the consumer after using the helmet.

Category	Description	Estimated Savings (EUR/Month)	Underlying Assumptions
Overtime (OT) Misuse Reduction	Eliminating inflated or fraudulent overtime claims through helmet usage tracking	EUR 11.30 (AED 48)	Based on site data, average misuse estimated at 2 h/month per worker. Considering an overtime (OT) rate of EUR 5.6/hour, the monthly saving per worker is EUR 11.30 [33–35]
Safety Compliance (Fine Avoidance)	Ensuring mandatory helmet usage to avoid regulatory fines and site penalties	EUR 1.64 (AED 7.00)	Industry data suggests approx. 1 PPE violation fine per 25 workers per month (avg. AED 1800 per fine). Pro-rated saving per helmet: AED 1800 ÷ 25 = AED 72 ; applying a 10% risk-adjusted factor gives AED 7 (EUR 1.64) [12,13,36,37]
Productivity Enhancement	Improved time efficiency through real-time location and motion monitoring	EUR 5.87 (AED 25.00)	Estimated time saved: 10 min/day/worker due to optimized supervision. Over 22 workdays: ≈3.6 h saved. Valued at EUR 5.87/hour, yields EUR 21.14; conservatively adjusted to EUR 5.87 [16,38–41]
Health Incident Reduction (Heat Stress)	Reducing lost workdays through early detection of heat stress.	EUR 7.05 (AED 30.00)	Based on prevention of lost workdays/month. At EUR 7/day (avg. wage), monthly saving is EUR 7 [6,42–45]
Labor Accountability	Reduced absenteeism and medical leaves via DHT-based heat stress alerts	EUR 3.52 (AED 15.00)	Based on prevention of 0.5 lost workday/month. At EUR 7/day (avg. wage + indirect productivity loss), the monthly saving is EUR 3.52 [46–48]
Total Estimated Savings		EUR 29.3 (AED 125.00)	

It is worth noting that the cost savings outlined in Table 2 have been estimated based on standard Dubai construction site conditions, where labor OT rates range around EUR 4.7–5.87 per hour and daily wages are approximately EUR 7–9.40. The figures are conservative and derived from practical observation of common inefficiencies (e.g., overtime misuse, lack of PPE compliance, absenteeism). These direct savings, totaling

EUR 29.3 per worker/month, establish a baseline for ROI calculations and justify the economic feasibility of the proposed solution.

4.3.3. Financial Projection

A financial income statement for the first year of operations was investigated to validate the profitability of the business model. Table 3 summarizes the revenue assumptions, costs, and projected profits based on realistic operational parameters.

Table 3. Year 1 income statement for IoT-enabled smart helmet business.

Item	Amount (AED)	Remarks/Justifications
Revenue		
Helmet rental income	EUR 70,469 (AED 300,000.00)	Assuming 500 helmets are rented for 12 months at EUR 11.74/month (500 helmets × EUR 11.74 × 12 months)
COGS (cost of goods sold)		
Business setup fee	EUR 3523 (AED 15,000.00)	Business license in UAE [49,50]
Hard hat cost	EUR 1174 (AED 5000.00)	Based on EUR 2.35/helmet in bulk order from local supplier
IoT sensors		
• DHT22	EUR 840 (AED 3578.25)	Based on bulk orders (500 units) from a Chinese supplier, <i>Electro Peak</i> [51]
• MPU6050	EUR 1939 (AED 8257.50)	
• ESP32	EUR 2133 (AED 9083.25)	
• GY Neo 6M	EUR 1185 (AED 5046.25)	
Operating expenses		
Warehouse rent	EUR 9395 (AED 40,000.00)	720 sqft of warehouse space being rented annually in the UAE.
Labor salaries	EUR 6215 (AED 26,460.00)	A total of 3 technicians with EUR 635 per month salaries has been considered [52].
Logistics (Shipping)	EUR 234 (AED 1000.00)	Local shipping partner <i>Aramex</i> has been considered, shipping 500 helmets with a total of 200 KG
DEWA	EUR 1174 (AED 5000.00)	Utility estimate for 12 months
Taxes		
VAT (value added tax) 5%	EUR 0 (AED 0.00)	Applicable only to the sales
Corporate tax 9%	EUR 0 (AED 0.00)	Applicable only if net profits exceed EUR 88,086.11 (AED 375,000) in the UAE
Gross Profit	EUR 59,671 (AED 254,034.75)	(Revenue—COGS)
Operating Profit	EUR 42,651.24 (AED 181,574.75)	(Gross Profit—Operating expenses)
Net Profit	EUR 42,651.24 (AED 181,574.75)	(Operating Profit—Taxes)

According to the financial analysis, the smart helmet business model provides a positive net profit margin during the first operating year, even under modest assumptions. The calculated gross profit of EUR 59,671 (AED 254,034.75) demonstrates good cost management and a high contribution margin relative to sales. Key cost components, primarily warehouse rental and IoT sensor procurement, accounted for the majority of operating expenses while remaining within acceptable levels to ensure profitability. This is consis-

tent with industry conventions, in which initial operational costs are often allocated to technology purchase and infrastructure setup, particularly in developing construction technology solutions. Despite the initial capital investments, the business generates a net operational profit of EUR 42,651.24 (AED 181,574.75), demonstrating the financial viability of the suggested model. Furthermore, the business benefits from the UAE's favorable tax climate, as corporation taxes are not levied until net profits surpass EUR 88,086.11 (AED 375,000). This policy is intended to help small and medium-sized businesses and startups, allowing for greater early-stage reinvestment opportunities. This implies a high return on investment potential, which is critical for promoting long-term sustainability and expansion in the competitive construction industry.

4.3.4. ROI and Breakeven Analysis

The return on investment (ROI) for the smart helmet business is an important metric that measures the investment's efficiency. According to the predicted estimates, the entire initial investment—including both cost of goods sold and operations expenses—is EUR 26,330.76 (AED 112,095.25). Over the course of one year, the company is predicted to have a net profit of EUR 42,651.24 (AED 181,574.75). The return on investment (ROI) is computed by dividing the net profit (EUR 42,651.24) by the total initial investment (EUR 26,330.76) and multiplying it by 100. This yields an ROI of roughly 161.94%, which is a significant return for a first-year operation. Figure 10 presents a visual representation of this break-even analysis by quantity and time.

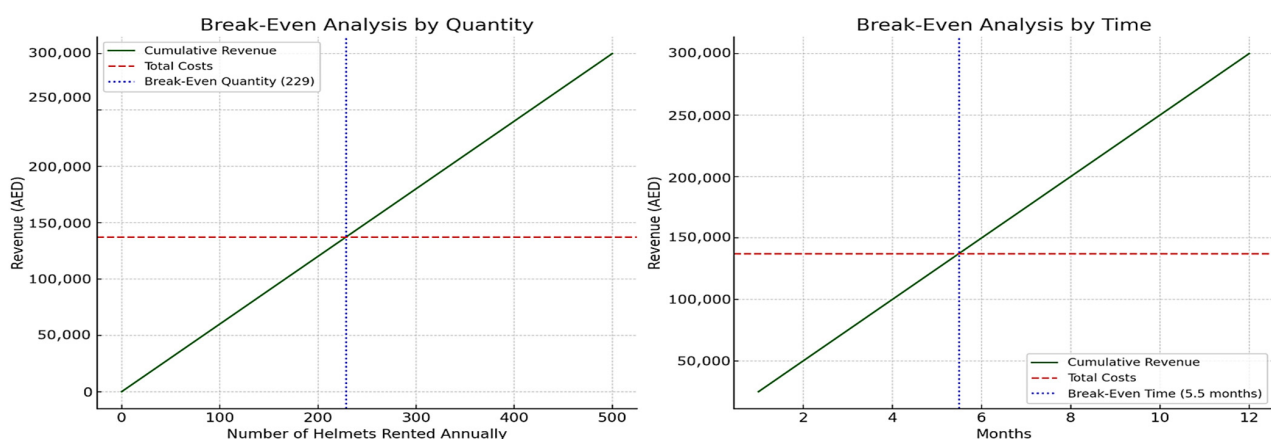


Figure 10. A visual representation break-even analysis by quantity and time.

The smart helmet business creates an annual revenue of EUR 140.88 per helmet, computed by renting each helmet for EUR 11.74 each month (EUR 11.74 multiplied by 12). To break even, the business must rent at least 229 helmets for a whole year, totaling EUR 32,203.17 ($32,203.17 \div 140.94 \approx 229$ helmets). Renting out 500 helmets would provide a monthly revenue of EUR 5872.41 (AED 25,000) ($500 \times 11.74 = \text{EUR } 5872.41$). In this case, the business would break even in around 5.5 months ($32,203.17 \div 5872.41 = 5.5$ months). As a result, the business can break even after renting 229 helmets for 12 months or after 5.5 months of renting out 500 helmets, allowing for greater flexibility in operational goals for financial sustainability.

4.4. Comparative Analysis with Existing Solutions

While several commercial smart helmets [53–55] and academic prototypes exist, this study's solution distinguishes itself through its cost-effective rental model, modular sensor integration, and focus on real-time heat-stress monitoring—a critical need in UAE construction environments. Unlike proprietary systems that require high upfront costs (e.g., Daqri's

AR-enabled helmets priced at ~USD 4000/unit), the prototype developed in this study leverages affordable, off-the-shelf sensors (e.g., DHT22 and MPU6050) and open-source software, reducing unit costs by ~80%. Additionally, while existing helmets often prioritize augmented reality (AR) or productivity tracking, our design emphasizes worker-centric safety metrics (e.g., heat index and fall detection) validated by Dubai's extreme climate conditions. However, trade-offs include limited AR functionality and shorter battery life (~8 h) compared to industrial-grade alternatives. This positions our solution as a scalable, niche tool for emerging markets where heat safety and cost sensitivity dominate.

4.5. Regulatory and Standardization Challenges

The adoption of IoT-enabled smart helmets in construction faces significant regulatory hurdles. In the United Arab Emirates (UAE), for example, regulatory bodies like Dubai Municipality (DM) enforce strict certification standards for PPE, including adherence to EN 397 for impact resistance [56]. While traditional helmets are evaluated for physical durability, IoT-integrated designs must additionally comply with data privacy laws (e.g., UAE's Personal Data Protection Law, PDPL) and wireless communication regulations (e.g., TRA compliance for IoT devices). For instance, continuous GPS tracking raises concerns about worker consent and data anonymization, necessitating clear policies to align with MOHRE (Ministry of Human Resources and Emiratization) guidelines. Furthermore, the absence of global standards for IoT-enhanced PPE complicates certification; existing frameworks (e.g., ANSI/ISEA 125 for connected safety devices) remain nascent and regionally fragmented. To address this, collaboration with regulators to develop adaptive certification pathways—such as modular approvals for sensors separate from the helmet shell—could accelerate compliance. Engaging proactively with innovation-driven public entities such as Dubai's Research, Development, and Innovation (RDI) Council and DM's Innovation Lab could facilitate regulatory sandbox testing or temporary exemptions for pilot deployments of emerging technologies [57].

4.6. Scalability and Generalizability

The proposed IoT-enabled smart helmet demonstrates strong potential for scalability beyond UAE construction sites, particularly in regions with extreme climates (e.g., GCC countries and Southeast Asia) or high-risk industries like oil and gas, mining, and logistics. Its modular sensor architecture allows for customization—e.g., swapping heat-stress monitoring for gas detection in confined spaces—while the rental-based business model lowers entry barriers for small-to-medium enterprises. However, scalability hinges on addressing infrastructure dependencies (e.g., stable Wi-Fi on remote sites) and local regulatory adaptations (e.g., GDPR compliance for EU deployments). Critically, the helmet's real-time analytics framework (e.g., heat index alerts) could be repurposed for disaster response or military applications, though further testing in diverse environments is needed to validate cross-sector robustness.

4.7. Future Opportunities

The integration of Internet of Things (IoT) data with Building Information Modeling (BIM) presents a promising avenue for enhancing real-time construction site monitoring and safety analytics. Utilizing Autodesk Forge—a cloud-based development platform—enables the visualization of IoT sensor outputs from smart construction helmets within a 3D BIM environment. The smart helmet is equipped with sensors such as the DHT22 for temperature and humidity monitoring, the MPU6050 for motion and fall detection, and a GPS module for real-time location tracking. Data from these sensors is transmitted via an ESP32 microcontroller with Wi-Fi capability to a cloud-based storage system. Autodesk Forge's Viewer API facilitates the overlay of this sensor data onto a Revit-based BIM model

in real time. Through the Model Derivative Application Programming Interface (API), the BIM model is converted to a format suitable for interactive rendering in web applications. Sensor streams are synchronized with specific worker IDs and their respective positions within the model, allowing for live visualization of environmental metrics and worker activity. This system supports the creation of dynamic heat maps per floor level, indicating zones of elevated temperature and humidity, thereby aiding in proactive labor reassignment and hazard mitigation. Implementing this level of digital integration can significantly enhance construction site visibility, safety compliance, and operational decision-making, aligning with the broader goals of Industry 4.0 and smart construction management. Figure 11 provides a visualization of this IoT and BIM integration, created using AI.

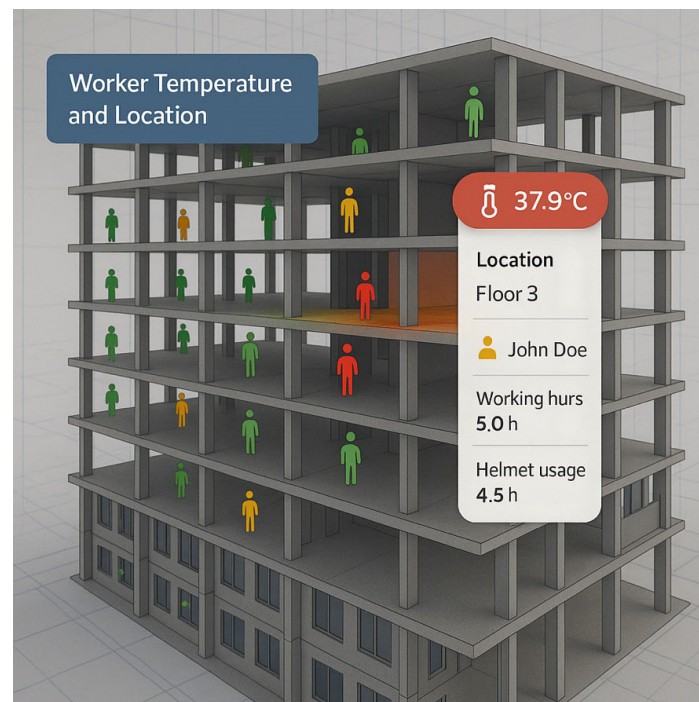


Figure 11. IOT and BIM integration, visualized using AI.

According to the *Future Opportunities Report—The Global 50* [58] published by the Dubai Future Foundation, Opportunity No. 35 emphasizes the integration of IoT technologies in various sectors, aligning perfectly with our smart helmet concept. (See attached screenshot for the relevant excerpt.) The smart helmet, which incorporates IoT-enabled components such as GPS modules, temperature and humidity sensors, and accelerometer-gyroscope units, embodies the opportunity’s core objectives of enabling real-time data monitoring, worker safety analytics, and process optimization in construction environments. This strategic alignment not only strengthens the product’s technological relevance within Dubai’s innovation ecosystem, but also positions the business to capitalize on national priorities such as access to innovation funding, regulatory facilitation, and partnerships in the UAE’s rapidly evolving smart infrastructure landscape.

5. Conclusions

This study looked at the creation and testing of an IoT-based Smart Construction Helmet intended to increase safety monitoring, personnel tracking, and operational efficiency in construction projects. Data collection included expert interviews with construction professionals in the UAE, India, and Saudi Arabia, and an industry-wide survey. A functioning prototype with a GPS module, DHT22 sensor, and MPU6050 sensor was created and

tested on an active construction site to determine its real-time performance under realistic conditions. Based on the examination of survey findings, expert input, and prototype performance, this study can derive the following precise conclusions:

1. According to survey results, 91% of construction professionals understand the need to incorporate real-time safety and tracking technology into worker equipment, indicating a high demand for smart wearable solutions in the industry.
2. Expert interviews revealed that, in addition to safety, the helmet's potential to assist in staff management and productivity tracking might provide substantial economic value by linking technology adoption with profitability goals.
3. Prototype testing demonstrated that the helmet could successfully gather and send real-time data on temperature, humidity, GPS location, and worker movement, demonstrating the proposed system's technical feasibility.
4. The study stated that a rental-based business model could increase adoption among construction businesses by allowing them to reap the benefits of smart monitoring without incurring large initial costs.
5. Heat stress monitoring capabilities based on DHT22 sensor data were particularly welcomed during field trials, proving the ability to save downtime and prevent heat-related incidents on-site.
6. Based on the business model and financial projections outlined in the cost sheet, the smart helmet rental business achieves break-even by renting 229 helmets annually or 500 helmets over 5.5 months, confirming the model's financial feasibility and sustainable revenue potential within the first year of operation.

To advance this research, subsequent phases will focus on (1) long-term field trials to evaluate sensor durability and user adoption in diverse climates, (2) AI-driven predictive analytics (e.g., early heat-stroke detection via physiological data fusion), and (3) edge-computing integration to reduce cloud dependency in connectivity-limited sites. Additionally, exploring blockchain-based data security for worker privacy and cross-sector adaptability (e.g., oil rigs and disaster response) could broaden impact. Finally, collaboration with UAE regulators to establish IoT-PPE certification standards will be critical for scalable deployment.

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