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Research Article

Analysis of Smart Labelling Solutions in the Construction Industry Using Automatic Identification Technology

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ABSTRACT: The construction industry, known for its complexity and dynamic environment, demands efficient, accurate, and reliable methods for tracking materials, tools, and components across various project phases. This paper explores the use of automatic identification technologies in the construction sector, focusing on their application in product labelling and inventory management. The technologies evaluated include: barcodes, Radio Frequency Identification, Bluetooth Low Energy beacons, and vision-based identification systems using computer vision and artificial intelligence. Each technology is assessed based on key factors such as cost, ease of implementation, range, accuracy, durability, automation potential, and integration with digital platforms like Building Information Modeling. Among these technologies, the paper presents a comparative analysis highlighting the unique advantages and limitations of each system. Particular attention is given to barcodes, which are ultimately identified as the most practical solution for widespread use in construction due to their low cost, simplicity, and scalability. While advanced systems like BLE and vision-based AI offer sophisticated features, they often come with higher costs and infrastructure requirements. The study concludes that barcode technology offers a balanced, cost-effective approach suitable for many construction environments, making it an ideal choice for organizations beginning their journey toward digital transformation and smarter site management.

KEYWORDS: Concrete Tiles, Barcode Label, Automatic Identification Technology, RFID, BLE Beacons, Computer Vision, Construction Industry.

INTRODUCTION

The construction industry significantly contributes to the development of built spaces, which drives global economic growth (Rashmit *et al*., 2024). Produced building materials serve as the foundation for any construction project, providing structural integrity, durability, and aesthetic appeal. These materials vary based on the type of structure being constructed, environmental conditions, and specific project requirements. Concrete is among the most widely used building materials due to its strength, durability, and versatility. It is produced by mixing cement, water, sand, and gravel or crushed stone. Reinforced concrete, which incorporates steel bars (rebar), enhances its load-bearing capacity, making it suitable for foundations, bridges, and high-rise buildings.

This research focuses on concrete tiles-behaton products and automatic identification technology used for labelling these products. Behaton is a type of interlocking concrete paving block widely used for outdoor surfaces such as sidewalks, driveways, parking lots, and industrial areas. One of the most popular products are behaton bricks. Behaton products come in a variety of shapes, sizes, and colors, offering endless possibilities for design and customization. Among the most commonly used are Behaton bricks, which are available in various shapes such as square, rectangular, and rhomboid, with different dimensions and colors to suit a wide range of applications (Joudah *et al*., 2024). Smaller Behaton bricks are perfect for intricate and detailed surfaces, making them ideal for decorative paving and complex patterns.

Decorative elements are specifically designed to enhance outdoor spaces, adding a unique touch to paved areas. Bricks play an essential role in marking boundaries between different surfaces, such as sidewalks and roads, ensuring both functionality and aesthetic appeal. For added durability, coated and impregnated slabs feature protective layers that shield against weather conditions and physical damage, significantly extending their lifespan.

AUTOMATIC IDENTIFICATION TECHNOLOGY

Automatic identification technologies have transformative potential in the construction industry, especially when it comes to labelling products and materials. These technologies help automate tracking, improve inventory accuracy, enhance site logistics, and reduce errors in handling and installation. Here's an overview of the key technologies and their uses in construction:

- RFID (Radio Frequency Identification)
- Barcodes
- BLE (Bluetooth Low Energy) Beacons
- Vision-Based Identification (Computer Vision + Artificial Intelligence)

Radio Frequency Identification

RFID technology is increasingly gaining traction in the construction industry due to its ability to automate the identification, tracking, and management of materials and components across various stages of construction projects. The traditional methods of labelling and tracking products using manual logs or barcodes have limitations such as the need for line-of-sight and vulnerability to environmental factors (Lazarevic *et al*., 2011). RFID overcomes many of these limitations and introduces greater efficiency, accuracy, and reliability in labelling and managing construction materials. RFID uses electromagnetic fields to automatically identify and track tags attached to objects. Each RFID tag contains a unique identifier and can store additional information about the tagged object. In the construction industry, RFID tags are typically attached to building materials, prefabricated components, tools, equipment, and even worker safety gear.

One of the primary benefits of using RFID for labelling in construction is enhanced traceability. Materials and components can be tracked from their point of origin (such as a manufacturing facility) to the construction site, and even during on-site movements. This ensures that the right materials are delivered to the right place at the right time, reducing delays caused by misplaced or mislabelled items. For example, precast concrete segments can be tagged with RFID, allowing contractors to verify delivery, check quality assurance documentation, and track installation progress in real-time.

Another key advantage is anti-collision. RFID readers can scan multiple tags simultaneously without requiring line-of-sight. This is particularly useful in large-scale applications where thousands of products/pallets are handled daily. With strategically placed RFID readers at entry/exit points or manipulators, the system can automatically log material movements, which reduces manual labour and minimizes human errors. Automated tracking helps maintain up-to-date inventory records and supports just-in-time delivery practices, which are vital for efficient project management. RFID also supports real-time inventory and asset management. RFID tags can be affixed to valuable machinery to monitor their usage and location, reducing the risk of loss or theft. This capability extends to reusable formwork systems, scaffolding, and even shipping containers, allowing project managers to monitor usage cycles and streamline logistics.

Furthermore, RFID can be integrated with Building Information Modeling (BIM) systems to create a digital twin of the physical site. Tagged components can be linked to their digital counterparts in BIM models, providing insights into their installation status, maintenance history, and compliance records. This integration supports better coordination between design, procurement, and construction teams, enhancing project transparency and quality control. Despite its advantages, RFID adoption in construction does face certain challenges. Environmental conditions such as dust, moisture, and extreme temperatures can affect tag performance. Moreover, metallic materials commonly used in construction can interfere with radio frequencies, requiring specialized tag designs. Cost is another consideration, especially for small-scale projects where the return on investment may not be immediately evident. However, as RFID technology becomes more affordable and robust, its adoption is expected to rise.

Barcodes

Barcodes are one of the most widely used and cost-effective automatic identification technologies across various industries, including construction. They serve as a practical solution for labelling and tracking products, components, and materials throughout the lifecycle of a construction project. A barcode is a visual, machine-readable representation of data that encodes information related to the object it is attached to (Tarjan *et al*., 2014). In the construction industry, barcodes are typically printed on adhesive labels or directly onto packaging and components to help streamline logistics, inventory control, and on-site operations.

One of the major advantages of using barcodes in the construction industry is simplicity and low cost. Barcode systems are relatively inexpensive to implement compared to more advanced technologies such as RFID. Barcode printers and scanners are widely available and easy to use. This makes barcode systems accessible even for small and medium-sized construction firms that may not have the budget or technical capacity to deploy complex tracking solutions.

Barcodes are commonly used to label and track materials (Tarjan *et al*., 2011). When these materials are delivered to a construction site, workers can scan the barcode on each item to verify delivery, check against purchase orders, and update inventory systems. This process improves accuracy and reduces errors caused by manual data entry or misidentification of materials. In addition to materials, barcodes are also used for tool and equipment tracking.

Each piece of equipment or tool can be tagged with a barcode that identifies it uniquely. By scanning these barcodes at tool stations or storage areas, construction managers can keep records of which tools are in use, where they are located, and who last used them. This helps prevent loss or theft, improves accountability, and ensures that tools are returned and maintained properly.

Another significant use of barcodes in construction is their integration with digital systems, such as Enterprise Resource Planning (ERP) and BIM. When scanned, a barcode can link directly to a digital database containing detailed information about the component, including manufacturer details, installation instructions, safety information, and maintenance records. This integration allows for real-time data exchange between the field and the office, improving decision-making and project coordination.

Barcodes also play a role in quality control and compliance. For example, when components such as electrical panels, plumbing fittings, or structural steel elements are delivered to the site, barcode scanning can ensure that only certified and approved products are used. In the event of a defect or recall, the barcode data provides a clear trace of where the component was sourced and where it was installed, supporting faster response and mitigation. Despite their benefits, barcodes do have some limitations. The most notable is the requirement for line-of-sight scanning. Unlike RFID, barcodes must be visible and accessible to be read, which can be challenging in cluttered, dirty, or poorly lit environments typical of construction sites. Additionally, barcode labels may become damaged due to exposure to water, dust, and abrasion, rendering them unreadable (Todorovic and Lazarevic, 2018). To address these issues, durable labels with protective coatings or labels etched directly onto materials can be used.

BLE Beacons

BLE beacons are emerging as a powerful tool for product labelling and tracking in the construction industry. These compact, battery-powered devices transmit signals at regular intervals, enabling real-time identification and location tracking of tagged items, materials, and even personnel. Compared to traditional barcodes and even RFID in some contexts, BLE beacons offer enhanced capabilities for automated tracking, real-time location monitoring, and wireless communication across large construction sites. BLE beacons work by continuously broadcasting a unique identifier via Bluetooth. This signal can be received by BLE-enabled devices, such as smartphones, tablets, or fixed scanners known as BLE gateways. When multiple gateways are placed strategically across a construction site, they can detect the proximity of BLE beacons and triangulate their location with high accuracy. This allows for precise tracking of tagged materials and components as they move throughout the site (Prodanoff *et al*., 2025).

In construction, BLE beacons are used to label and monitor building materials, tools, equipment, and prefabricated assemblies. For instance, a concrete beam delivered to the site can have a BLE beacon attached that transmits its ID and status to a central monitoring system. As the beam is moved and installed, its location is updated automatically without manual intervention. This provides accurate, real-time inventory control and reduces delays caused by misplaced or misidentified materials.

Another significant application of BLE beacons is in tool and equipment tracking. Construction sites are dynamic environments where tools frequently change hands and move across locations. By tagging high-value tools and machinery with BLE beacons, project managers can continuously monitor their location and usage. This minimizes the risk of theft, loss, and underutilization. In addition, usage data collected via BLE can support predictive maintenance schedules and improve asset lifecycle management. BLE beacons also enhance worksite safety and personnel management. Workers can carry wearable BLE tags that enable site managers to monitor their real-time location, especially in hazardous zones. In the event of an emergency, such as a collapse or fire, the system can quickly identify who is on-site and where they are located, supporting faster and more effective emergency response. Geofencing features can be implemented to restrict access to certain areas, with alerts triggered when unauthorized entry occurs.

A key strength of BLE beacons is their low power consumption, which allows them to operate for months or even years on a single coin-cell battery. This makes them practical for long-term deployments without frequent maintenance. Furthermore, BLE is supported by virtually all modern smartphones and tablets, allowing for wide compatibility and integration without specialized scanning hardware (Tian *et al*., 2020). However, there are some challenges and limitations to consider. BLE signal strength can be affected by obstacles such as metal structures, concrete walls, and machinery, which may reduce accuracy in certain conditions. The system also requires a well-designed network of BLE gateways to ensure consistent coverage across the site. Proper planning and calibration are necessary to maintain location accuracy and avoid blind spots.

Despite these challenges, the benefits of using BLE beacons in the construction industry are substantial. They offer an efficient, scalable, and cost-effective solution for product labelling, inventory management, and operational oversight. As construction companies continue to embrace digital transformation and smart construction practices, BLE beacons are likely to play a central role in enabling real-time visibility, automation, and control across complex project environments.

Vision-Based Identification

Vision-based identification, powered by computer vision and artificial intelligence (AI), is an innovative approach increasingly being adopted in the construction industry for labelling, tracking, and managing products and materials. Unlike traditional methods such as barcodes or RFID, vision-based identification does not require physical tags or direct interaction. Instead, it relies on cameras and AI algorithms to detect, recognize, and track materials, components, and tools by analyzing visual features such as shape, size, texture, color, and contextual placement. This technology is particularly well-suited for the dynamic and often harsh environments found on construction sites. Vision-based systems can operate passively and continuously, using cameras installed around the site to monitor incoming materials, tools, and structural elements. With the help of AI algorithms, these systems can classify objects, detect anomalies, match materials with digital models, and provide real-time updates to project management software (Irshad *et al*., 2025).

One of the primary applications of vision-based identification in construction is automated material recognition and verification. As materials arrive on-site, cameras can scan and identify items such as steel beams, pipes, bricks, or prefabricated panels without requiring any human intervention. By comparing the visual characteristics of the items with known templates in a database or BIM system, the technology can confirm if the correct materials have been delivered. This reduces the risk of errors and ensures compliance with specifications.

Another valuable use case is in progress monitoring and quality assurance. Cameras equipped with AI can analyze the ongoing work on a construction site to verify if materials have been installed correctly and according to the design plan (Urgo and Terkaj, 2025). For example, the system can detect whether electrical conduits are in the right position, or whether a wall has been constructed to the correct height and thickness. This helps identify issues early, reducing the cost and time associated with rework. Vision-based systems are also beneficial for inventory management. By continuously scanning storage areas, these systems can automatically count and log the quantity of materials on hand. This data can be integrated with supply chain and procurement systems to ensure timely reordering and delivery of materials, minimizing project delays caused by shortages. A significant advantage of vision-based identification is that it does not depend on physical tags, which can be damaged, lost, or become unreadable due to dirt, moisture, or rough handling — all common on construction sites. Cameras can capture and process images in real-time, even from a distance or under low-light conditions, making this a highly efficient and resilient solution.

Furthermore, computer vision and AI can be used to enhance site safety. By monitoring the movements of workers and machinery, these systems can identify unsafe practices, detect unauthorized access to restricted areas, and alert supervisors to potential hazards. This proactive approach contributes to a safer working environment and helps ensure compliance with health and safety regulations. However, the implementation of vision-based systems comes with some challenges. High-quality image recognition requires robust algorithms trained on large datasets specific to the construction environment. Camera placement must be optimized to avoid blind spots, and sufficient computing power must be available on-site or via cloud services to process the video data in real-time. Privacy concerns and data security must also be addressed, particularly when monitoring personnel.

CHOOSING THE BEST AUTOMATIC IDENTIFICATION TECHNOLOGY

Automatic identification technologies play a transformative role in the construction industry by streamlining material handling, improving accuracy, enhancing safety, and supporting digital workflows like BIM. Among the most widely discussed automatic identification technologies are RFID, barcodes, BLE beacons, and Vision-based identification. Each of these technologies offers unique capabilities, and their effectiveness depends on specific use cases, site conditions, and budget constraints. Barcodes are the most cost-effective automatic identification technology. They require minimal infrastructure—just printers and handheld scanners or smartphones. They are ideal for small-scale projects or temporary uses such as checking deliveries, simple inventory control, or linking components to BIM data. Limitations in using barcodes include the need for manual scanning and line-of-sight, which becomes inefficient at scale or in poor site conditions (e.g., dust, mud, damage). Automation is minimal, and accuracy is user-dependent.

RFID offers a balance of automation, accuracy, and real-time tracking. Unlike barcodes, RFID does not require line-of-sight and can scan multiple items simultaneously. It is suitable for tracking high-value materials, precast elements, or equipment throughout a large site or across the supply chain. However, RFID has higher implementation costs, especially when deploying RFID with long range. It requires readers and software infrastructure. Metal and liquids can interfere with signal reliability, though specialized tags mitigate this.

BLE beacons are excellent for real-time location tracking, especially for tools, equipment, and personnel. These devices periodically broadcast signals that can be picked up by BLE-enabled smartphones or gateways. They're ideal for large, complex sites, offering better range and more granular tracking than RFID. BLE beacons strike a good balance between cost and performance. They consume low power and can last for months or years on a battery. However, accuracy may be affected by environmental interference, and triangulation infrastructure (gateways) is needed for optimal performance. This is the most advanced and automated technology. With high-definition cameras and AI models trained to recognize construction materials, tools, and components, it can track, verify, and report on construction progress without requiring any physical labels or tags. Vision systems also integrate well with BIM and safety monitoring tools. The trade-off is cost and complexity. Vision systems require cameras, computing hardware (on-site or cloud-based), and well-trained AI models. Implementation can be technically demanding, and results depend heavily on image quality, lighting conditions, and camera placement. Despite this, they offer unmatched automation and analytical capabilities, including progress tracking and quality inspection.

In order to compare these technologies effectively, an evaluation/grading on several important criteria like: cost of implementation, ease of use, range and coverage, real-time tracking, durability, automation capability, BIM/ERP integration, accuracy, infrastructure needed and scalability with adequate grades that are 1=poor, 2=below average, 3=average, 4=good, 5=excellent, has been done and are represented in Table 1.

Table 1: Grades for different criteria and automatic identification technology.

Criteria	Barcodes	RFID	BLE Beacons	Vision-Based
1. Cost of Implementation	5 (very low)	2 (moderate to high)	3(moderate)	2 (high)
2. Ease of Use	5 (very easy)	4	4	2 (complex setup)
3. Range and Coverage	2 (line-of-sight only)	4 (1–10 meters)	4 (up to 70 meters)	3 (depends on camera view)
4. Real-Time Tracking	1 (manual scanning)	4	5 (excellent)	5 (with AI processing)
5. Durability	2 (can be damaged)	4 (tags can be rugged)	3 (moderate)	3 (sensitive to lighting)
6. Automation Capability	1 (low)	4	5 (high)	5 (very high)
7. BIM/ERP Integration	3	4	4	5
8. Accuracy	3 (user-dependent)	4	4	5
9. Infrastructure Needed	2 (scanners/printers)	4 (readers, middleware)	3 (beacons + gateways)	2 (cameras + servers)
10. Scalability	4	4	4	3 (expensive to scale)

Barcodes are suitable for basic tracking and low-budget projects. RFID provides automation and is ideal for complex supply chains. BLE beacons excel in live location tracking and asset management. Vision-based systems are future-forward tools that deliver intelligent, tagless recognition and advanced analytics but at a higher cost. As the construction industry advances toward full digitization, a hybrid approach—using a combination of these technologies—may offer the most effective, scalable, and cost-efficient solution tailored to the needs of each project. Barcode technology was chosen for the project tracking Behaton products during production, storage, and distribution to customers. The main reason is that the products are inexpensive and the pallets are not returnable. Figure 1. represents how the barcode is implemented for labeling pallets with behaton products. Figure 1 shows the labels containing information about the products on the pallet (model, color, dimensions, technical specification, standards, etc., and QR and data matrix code with all needed information), which are marked with red circles.

Figure 1: Shows the Pallets of behaton with labels with barcode identification

DISCUSSION

In the evolving landscape of the construction industry, the need for effective, reliable, and cost-efficient product labelling and tracking technologies has become increasingly important. As construction projects grow in complexity and scale, the ability to accurately identify and manage materials, equipment, and components plays a crucial role in improving productivity, reducing errors, and maintaining project timelines. Among the various automatic identification technologies available—such as RFID, BLE beacons, and computer vision—barcodes and QR codes remain a practical and strategic choice, especially for many companies seeking a balance between functionality and affordability.

One of the most compelling reasons for choosing barcodes is their low cost of implementation. Barcode labels are inexpensive to produce, and the infrastructure required—such as handheld scanners, mobile devices with cameras, and basic printing equipment—is widely available and affordable. This makes barcodes highly accessible, even for small and medium-sized construction firms operating on tight budgets. Unlike RFID or vision-based systems that require significant investment in hardware, software, and technical expertise, barcodes can be deployed with minimal upfront costs, making them ideal for pilot projects, short-term construction jobs, or teams new to digitized tracking. Barcodes also offer excellent ease of use. Workers can quickly learn to scan materials and components using simple devices, reducing the training overhead. Because they are based on a well-established and standardized technology, barcodes integrate easily with most inventory management and procurement systems. This ensures seamless data flow from the field to the office and supports real-time project visibility and decision-making. In many cases, barcode scanning can be performed using existing smartphones or tablets, eliminating the need for specialized devices.

Despite their simplicity, barcodes offer sufficient functionality for many common construction applications. For example, they are extremely effective for tracking materials from suppliers to the job site, verifying deliveries, managing inventory in storage yards, and checking component usage during installation. A barcode scanned on-site can link to a comprehensive digital record in a BIM or ERP system, providing project managers with access to product specifications, installation guides, and compliance documentation. In terms of accuracy, barcodes are highly dependable when used correctly. Each barcode represents a unique identifier that reduces the risk of human error during manual entry. While barcodes require line-of-sight scanning and can be affected by dirt or physical damage, these challenges can be mitigated through the use of durable labels and proper handling protocols. For environments where labels are likely to be exposed to harsh conditions, laminated or etched labels can be used to improve resilience. Another important benefit of barcodes is their flexibility and scalability. Whether a project involves a few hundred components or tens of thousands, the barcode system can easily scale to meet the demand. New items can be labelled and integrated into the system with minimal effort. Additionally, barcodes support various encoding formats, such as 1D and 2D (QR codes), which can store different types and volumes of data, making them adaptable for different use cases.

When comparing barcodes to more advanced technologies like RFID, BLE, or vision-based AI systems, it's clear that each has its strengths. RFID offers hands-free scanning and bulk reading, BLE supports real-time location tracking, and computer vision enables tagless identification and automation. However, these systems often come with significantly higher costs, require technical expertise, and involve complex infrastructure setups. For many construction companies—particularly those managing standard commercial or residential projects—the benefits of these advanced systems may not justify their expense.

In contrast, barcodes provide a low-risk, high-return entry point into the world of digital construction management. They offer a proven, reliable method of improving material tracking, enhancing accountability, and streamlining workflow processes. For companies aiming to begin their digital transformation journey or optimize their current operations without heavy investment, barcodes represent a smart, strategic choice.

While the construction industry is rapidly adopting more advanced technologies, barcodes continue to be the most practical solution for many product labelling applications. Their affordability, ease of use, integration capabilities, and proven reliability make them a valuable tool for improving efficiency, accuracy, and control on construction sites. By adopting barcode systems, construction firms can lay a solid foundation for digital project management, ensuring better material handling, fewer delays, and greater confidence in operational execution—ultimately contributing to safer, faster, and more cost-effective construction outcomes.

CONCLUSION

This work concludes that the integration of automatic identification technologies represents a significant advancement in the construction industry's efforts to improve traceability, efficiency, and accuracy in material management. Among the technologies analyzed—RFID, BLE beacons, vision-based systems, and barcodes—barcodes emerge as the most practical and cost-effective solution for labelling construction products, particularly in applications like Behaton brick tracking. While more advanced systems offer greater automation and real-time data capabilities, their higher costs and complexity make them less accessible for many construction firms. By implementing barcode-based labelling systems, companies can achieve substantial improvements in logistics, inventory control, and project oversight with minimal investment. This approach also lays the groundwork for future digital transformation, enabling scalable integration with tools like BIM and ERP systems.

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