Addressing Tool Loss for Construction SMEs: Investigating the Implementation of Bluetooth Low Energy (BLE) for Tool Tracking in the Australian Construction Industry.

ABSTRACT

If a tool goes missing, it is written off as overhead costs for large, established construction firms, but for small-to-medium-sized construction enterprises (SMEs), the culmination of these losses is severe. Tool loss and theft constitute one of the largest concerns for SMEs, as it leads to avertable financial strain and wasted time. Technologies such as Global Positioning System (GPS) and Radio Frequency Identification (RFID) currently serve as solutions; however, these current models are inapt for SMEs as they rely on complex networks and specialised hardware. Hence, these services are exclusively employed by large construction firms that have ample capital. This paper accentuates the capabilities of Bluetooth Low Energy (BLE) technology as a more feasible alternative for tool and asset tracking due to its accessibility and scalability, tailored to the needs of SMEs. Through a structured literature review, complemented by insights from independent contractors gathered through online interviews, current systems' shortcomings are identified and compared with BLE technology across key areas such as affordability, live-tracking accuracy, read range, and ease of use and deployment. It is concluded that the BLE-centric model offers an optimal value proposition for SMEs with the balance between affordability and tracking capacity, with its future potential augmented with opportunities such as geofencing and personnel tracking/logging. Therefore, this research spotlights the untapped market opportunity for a low-friction, cost-efficient tool tracking solution that is intentionally geared toward small-scale construction operations.

KEYWORDS: Construction SMEs, real-time tracking, tool loss, cost efficiency, RFID/BLE technology

INTRODUCTION

1.1 Overview of Industry Landscape

In Australia, at least AUD 650M worth of high-cost equipment is lost through theft annually from construction sites, a significant figure that rises further when cases of misplacement and undocumented losses are considered (National Equipment Register n.d.). Despite the accelerated development of digital systems and processes across other sectors, the construction industry is notorious for its resistance to adopting emerging technologies, with a 2017 McKinsey report placing agriculture as the only other industry below construction that lacks digitisation and innovation (Dewhurst 2017).

A potential root for this stagnancy lies within the traditional mental framework and outdated workflows that construction workers operate under, highlighted when examining the demographic profile of construction workers across major construction hubs and the average ages, indicating high levels of experience. The average age of a construction worker in North America is 42 (Klocek 2024); in Australia, it is 38 (Department of Employment and Workplace Relations 2024); in the UK, it is over 50 (CITB 2023); and in China, the median age is now 47, with recent trends suggesting that China's figure is projected to increase in the future.

The effect of this age distribution is an evident resistance to deviating from established and dated workflows. This is due to the minimal margin for error that discourages experimentation, due to the economic and time sensitivity of this industry. Moreover, as small-to-medium-sized construction enterprises (SMEs) continue to solidify their presence as the backbone of the construction industry due to the increasing demand for residential and commercial infrastructure—such as the surging demand for housing in Australia—businesses require seamless and intuitive solutions that will aid in overcoming problems and enhance coordination when completing tasks by trimming idle or wasted time.

1.2 Context

According to Australia's enterprise classification model, small-to-medium-sized construction enterprises, or construction SMEs, are defined as having fewer than 200 FTEs (full-time equivalent employees) (NSW 2021), a unit of measurement to evaluate a company's full-time employees, while considering part-time employees, to standardise the number of working hours into full-time positions (Valier 2025). Moreover, another metric that is acknowledged when calculating a business's size in Australia is the turnover-based ladder, where businesses that have annual aggregated turnover of up to 10M (million) AUD are deemed 'small', between 10M AUD and 250M AUD are classified as 'medium', and above 250M AUD are labeled 'large' (Australian Taxation Office 2024). This paper's business proposition will have a scope of SMEs that make less than 10M AUD per year, with the following example business types listed below in Figure 1.

Employee Number	Turnover Category (AUD)	Example Business Types
Micro Enterprise (0–4)	Small Business (≤ $10 M)	sole-trader plumber; solo electrician
Small Enterprise (5–19)	Small Business (≤ $10 M)	12-person concrete finisher; electrical subcontractor
Medium Enterprise (20–199)	Small Business (≤ $10 M)	30-person carpentry subcontractor; 60-person commercial painter

Figure 1: Table of the types of businesses that are classified as SMEs in Australia.

On average, a construction worker will lose 38 hours annually in search of absent tools (Berntsen 2025), averaging to approximately 10 minutes per day. Due to the fast-paced nature of construction and the multiple job sites that tools are often shared across, this pain point is common across mobile construction businesses such as local plumbing, electrician, and paving services. Construction SMEs operate in complex environments that demand competence and productivity, resulting in documentation and ordered tracking systems commonly being neglected. The compounding of these seemingly insignificant gaps frequently leads to 'ghost assets', which are tools that are documented but don't exist physically; repeated delays, hurting budgets as schedules are not time-efficient, leading to project extensions and overtime pay; reputation damage due to tardiness; heightened tensions and widespread frustration.

Larger construction businesses leverage enterprise tool-management software that provides intricate information about assets through the utilisation of Radio Frequency Identification (RFID) technology, barcode scanning, and/or Global Positioning System (GPS) tracking. Additionally, larger companies employ "kit rooms", a designated space in high-value areas that store and manage tools and equipment, where dedicated staff members manage audit trails, maintenance cycles, and check-in/out timings to optimise tool effectiveness. These sophisticated systems typically require major upfront investment, both time and capital, creating a high barrier to use for construction SMEs, who account for a large proportion of all construction companies registered globally, such as in the United Kingdom, where 97% of all construction companies registered are SMEs (Ali 2025).

1.3 Scoping Tool Loss within the Construction Industry

Although technologies such as passive RFID are affordable at a per-unit cost, ~<$1 per tag, the infrastructure that is required to exploit its benefits, such as obtaining specialised readers, dedicated IT support, and building a broad network, does not make it a viable solution for SMEs' limited budget. The restraint that hinders construction SMEs from replicating the current solutions utilised by dominant construction firms is tight cash flow, due to competitive thin margins and their unique placement within the industry: too small for enterprise strategies, but too large for manual methods. Each model available in the market mandates a compromise from SMEs. In the case of conserving costs, SMEs would be trading their time and labour for manually tracking equipment and tools with the use of cumbersome spreadsheets and barcode systems. Alternatively, SMEs could use enterprise solutions; however, a system costing typically tens of thousands of dollars exceeds their allocated budget for tool replacement.

Newer construction SMEs that have limited capital often resort to labour-intensive and monotonous methods for tool logging, such as paper-based checking systems, online spreadsheets, visual boards, verbal communication, and/or basic scanning technologies such as barcodes. The paper-and-pen method is appealing to cash-tight and early-stage SMEs, given the cultural inertia and cost-effectiveness of a universally understood method; however, its fundamental drawbacks lie in its vulnerability to damage and inaccuracy due to the rugged environment of construction, as well as its inability to be shared across digital platforms.

A substitute many SMEs employ includes utilising spreadsheet platforms such as Excel, addressing the latter issue raised with the clipboard method. This solution can be shared across many teams through inexpensive, cloud-based software, as well as offering a simple interface where it can be customised to suit individual and specific workflows. Nevertheless, its flaws share overlap with the clipboard approach, where it lacks entry automation, real-time tracking, and is prone to inconsistencies and errors. Another distinct issue includes the possibility of data loss in the case of file corruption. Furthermore, the oral, trust-based communication system is ubiquitous in the industry, attributed to its speed and informality; however, similar issues, such as the opportunity for discrepancies and loss of information, persist.

1.4 Competitor Technology Analysis and Comparison with BLE

Technologies such as barcode scanning are increasingly entering the market, oriented toward construction firms that emphasise cost-efficient solutions. This product is being marketed as an SME-friendly alternative to enterprise-grade asset management solutions, offering benefits such as instant digitalisation across online applications/websites through its low upfront costs and ease of integration. This approach functions with site employees manually scanning the tool's unique barcode in combination with their ID badge, creating instant digital logs that incorporate user identity, time/date stamps, and location of pickup/drop-off, promoting personnel accountability.

Yet, this approach shares a similar pain point that is present in manual tracking systems: it is reliant on high user input from workers who must document each stage of the tools' usage, creating an opportunity for gaps in tracking as well as friction in workflows. Furthermore, businesses such as GigaTrak offer this barcode-based service starting from just USD 75 per month. However, this exhibits the second issue that lies with companies that offer barcode-based tool tracking services; this cost is strictly limited to software license, access to cloud hosting, support, and automatic tool upgrades, excluding barcode printers, specialised scanners, and other essential hardware components, which would collectively inflate the cost of implementation (AssetRun, n.d.).

Other issues include durability concerns, where the tag is invalid if scratched or dirtied, and read range, as barcode scanning requires a direct line of sight to be read. Moreover, workers face a steep learning curve, as manually documenting an abundance of tools leads to low field adoption and a high abandonment rate in the industry for human-dependent, tool-tracking services. Therefore, these limitations accentuate the growing demand for automated, straightforward asset management systems that are tailored for the pace and structure of SME operations. This paper acknowledges the unmet need, which serves as the underlying rationale proposing the incorporation of alternative technology infrastructure, such as Bluetooth Low Energy (BLE), to replace present-day market solutions.

Radio Frequency Identification (RFID) technology is disruptive within the construction industry, with larger firms beginning to utilise it to modernise asset management. Dating back to its first use case to track aircraft in WWII, RFID’s purpose has evolved to be an integral component within the industry of asset tracking, with retailers such as Walmart investing USD 500 million into an RFID system in 2024 and River Island improving their stock accuracy from 78% to 98% through the deployment of RFID tags (Comparesoft, n.d.).

RFID functions through two main components: the tag, which is attached to the tracked item; and the reader, which transmits radio waves that directly communicate and receive data from the tags through the assistance of antennas (Goodrum, McLaren, and Durfee 2005, 2). RFID tags are available in two forms, passive or active, with prices for each tag ranging from 0.10–5 USD and 15-50 USD, respectively. The underlying reason for the considerable price difference for passive RFID tags is the absence of a power source, as depicted in Figure 2, extending their operational life as they draw their power from the electromagnetic force emitted from the RFID scanner. Its lightweight and inexpensive nature deems it ideal for businesses that must track large inventories.

That said, this structure results in a significantly shorter read range—as great as 4 metres—and is diminished when scanned through industrial materials such as metal, requiring the proximity of the reader to be within a few centimetres to successfully read the tag. Its counterpart, active RFID tags, do not suffer from this issue as their internal battery allows them to autonomously transmit information to the reader without the presence electromagnetic field, as depicted in Figure 3. The effect of this point of difference is improved speed and accuracy in scanning assets when compared to passive RFID tags. Active RFID tags’ read ranges are consistently observed to be between 15-25 metres; albeit, this technology suffers from the same issue of a degradation in read range when interfered with by dense industrial infrastructure (Andoh 2012, 12).

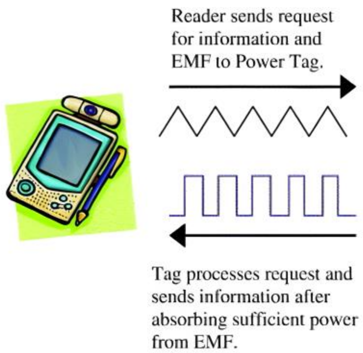

Figure 2: Diagrammatic representation of passive RFID technology. Goodrum, Paul M., Matt A. McLaren, and Adam Durfee. "The Application of Active Radio Frequency Identification Technology for Tool Tracking on Construction Job Sites." *Automation in Construction* 15, no. 3 (2006): 292–302. https://doi.org/10.1016/j.autcon.2005.06.004.

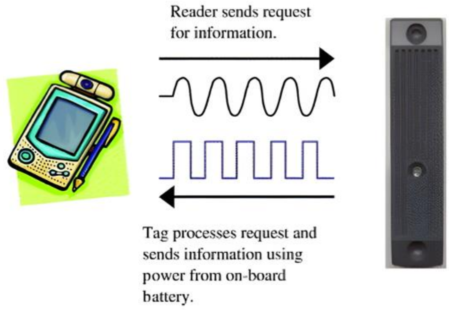

Figure 3: Diagrammatic representation of active RFID technology. Goodrum, Paul M., Matt A. McLaren, and Adam Durfee. "The Application of Active Radio Frequency Identification Technology for Tool Tracking on Construction Job Sites." *Automation in Construction* 15, no. 3 (2006): 292–302. https://doi.org/10.1016/j.autcon.2005.06.004.

Yet, its comprehensiveness is also its setback, as advanced infrastructure installation demands extensive capital investment, segmenting the market of potential consumers to only large construction enterprises. With readers costing thousands of dollars, coupled with strategic placement of antennas and cable infrastructure, the accumulation of these expenses deters construction SMEs that lack sufficient capital to execute such a large-scale system.

A competing technology experimented with in the construction industry that aims to provide the live tracking ability of RFID is the Global Positioning System (GPS) technology. GPS technology leverages the constellation of satellites that orbit Earth, providing real-time location data through a process of triangulation. It requires a minimum of four satellites for 3D positioning, with the process determining the exact longitude, latitude, and altitude coordinates (Crato, 2010). While GPS excels in outdoor environments, due to the nature of the technology, accuracy and reliability deteriorate indoors, around bridges, and under tree canopies, all of which are conditions common on worksites. Hence, GPS has been restricted in most cases to outdoor, high-value assets, such as forklifts and excavators, where its placement aligns with the strengths of the technology.

This raises the overarching question: how can the live-tracking abilities and automation of RFID and GPS be intuitively incorporated in an SME-focused system, whilst eliminating the prerequisite of intensive infrastructure?

Bluetooth Low Energy, abbreviated to BLE, operates through the interaction of beacons and Bluetooth-enabled devices, such as smartphones, making it ideal for indoor environments where its location can be shared with surrounding technology. It is a wireless communication protocol that operates in the 2.4 GHz ISM band, purposely designed for low-energy, short-range data transmission. In a typical setup, beacons will periodically broadcast a unique identifier signal that will be interpreted by receivers, which are smartphones or other Bluetooth-enabled devices/gateways, establishing logs that provide real-time tracking of assets, which can be accessed seamlessly through interfaces such as mobile applications. This signal transmission process, as well as low latency, justifies BLE's competence within indoor settings, areas where systems such as GPS may be unreliable.

BLE beacons contain a battery that remains idle unless a connection is initiated, thus making it impressively power-efficient and extending each beacon's lifespan to up to 5-10 years. Moreover, BLE beacons have a read range of up to 100 metres in open conditions, speeding up the implementation process and future scaling. Additionally, its interaction with existing IT infrastructure is attractive to SMEs with budget restraints, as there is no need for extra network installations, dedicated scanners, antennas, and other system-specific equipment.

Nonetheless, BLE is inferior in location precision when compared with GPS, as it does not offer exact coordinates, but rather an approximate area, with an average accuracy distance of up to 5m in optimal conditions (inpixon, n.d.). To add on, a beacon may display 'nearby' or 'last seen at' in certain situations rather than live location, as it relies on the presence of receivers.

A summary of the competing technologies' application uses, advantages, and disadvantages is displayed in Figure 4.

Technology	Application Uses	Advantages	Disadvantages
Barcodes	- Inventory tracking - Tool check-in/check-out - Simple asset logging	- Relatively low cost - Straightforward implementation process - Intuitive for most users	- Requires manual scanning and line of sight - No live tracking or location data - Prone to human error
BLE (Bluetooth Low Energy)	- Live tracking of tools on job sites, indoors and outdoors - Geofencing capabilities and push notifications controls when items leave their zone	- Real-time tracking - Long battery life (5–10 years) - Smartphone-compatible - Cost-effective and scalable - Minimal infrastructure required	- Fluctuating range (10–100m) - Susceptible to signal interference (e.g., metal) - Slightly lower precision than GPS - May require additional installation of beacons for increased accuracy
Passive RFID	- High-volume, enterprise inventory control - Fixed checkpoint scanning - Bulk tool authentication and processing - Entry/exit scanning	- Inexpensive tags (USD 0.10–5) - No battery required - Durable and compact - High reliability - Fast and efficient scanning	- Limited range (~1–4m) - Requires dedicated readers and antennas - High infrastructure setup and costs - Signal blocked by metal/liquid - Limited to checkpoint-based tracking - Occasional battery replacement
Active RFID	- Real-time tracking of high-value assets - Site-wide, long-range applications - Automated inventory systems	- Longer read range (30-150m) - Continuous and automatic transmission - Works without reader proximity - High accuracy and reliability	- Expensive tags (USD 15–50+) - Requires battery replacements - Requires dedicated IT support - Infrastructure is complex and capital-intensive

GPS	- Outdoor tracking of large vehicles and heavy equipment - Mobile asset monitoring - Theft prevention/recovery	- High location accuracy - True real-time tracking - Suitable for remote locations - Established and reputable technology	- Poor indoor performance - High power consumption - Costly hardware and subscriptions - Not suitable for smaller tools

Figure 4: Table highlighting the major points of difference in each competing technology.

Therefore, this paper will examine how BLE technology can address construction SMEs' two valued resources, cost and time efficiency, by automating the management of tools and assets, and as a result, decrease the unnecessary expenditure on restoring lost equipment. The proposed business model's unique value proposition will be its objective to incorporate the advantages of high-infrastructure and complex technologies, such as the reliability of active RFID, without its tie to heavy, up-front capital investment, instead offering a more flexible structure that is accessible for all-sized businesses. Potential customers for this hypothesised business model will be gauged through primary and secondary methods of data collection, detailed below.

METHODOLOGY

2.1 PRIMARY DATA COLLECTION - INTERVIEWS

During the interview process, judgmental and convenience sampling methods were implemented, as this approach would allow for authentic insight within the demographic in the construction industry that experiences the repercussions of persistent tool loss on a micro and macro scale. Judgmental sampling was utilised when restricting the scope of interviewees to the type of people who would consistently experience tool and equipment loss during their workflow, which included tradespeople and subcontractors.

In a similar vein, convenience sampling effectively complemented the selection process by electing to contact local and available people out of the candidate pool. This approach is conducive to receiving more detailed responses and ideas, as interviewees who entered the discussion with an innate eagerness to express their concerns rather than feeling pressured would be more inclined to respond openly and genuinely. With this paper's focus on Australia's construction industry, emphasis was placed on interviewing Australian-based construction workers, specifically in Brisbane, as Australia's fastest-growing capital city (Philip, 2024).

Six interviews were conducted with the age range being 23-52 years, aiming to discern whether differing levels of experience impacted perceived problem severity. Each interview had a duration of 20-35 minutes, with most participants sharing anecdotes and detailing related issues of concern. A few participants curbed their responses to the specifics of the questions, shortening the length of the discussion to 1-2 sentence responses. To compensate for the lack of initial detail, further follow-up questions were asked and recorded, encouraging the interviewee to elaborate on key themes that were brought up. All interviews were facilitated through Microsoft Teams, a video conferencing platform. Prior to any information being shared, consent was granted by the interviewee to include their responses within this paper. A persisting obstacle that arose was due to a misunderstanding of the questions, participants commonly deviated from the key ideas that were in the question, and hence, follow-up clarifications brought their responses back to the essence of the question.

Listed below in Figure 5 are the questions each interviewee was asked.

#	Topic	Interview Question
1	*Nature of Work*	Tell me more about the nature of your work and the key differences it has when compared to other professions.
2	*Problem Areas*	What areas or aspects within your work do you believe the most problems arise from?
3	*Recurring Frustrations*	Across multiple projects, are there any common and persistent nuisances that cause consistent frustration among managers and colleagues? If so, what are some specific examples you would be comfortable sharing?
4	*Current Solutions & Improvements*	Regarding [*problem raised*], what are the current workarounds or solutions your company has been using? If relevant, what improvements would you like to see in these solutions?
5	*Decision-Making Factors*	In your line of work, what factor do you consider to be the most important when determining whether there is a need to address a problem, or when comparing competitors' solutions to an issue?
6	*Tool Tracking for SMEs*	Research shows that due to the fast-paced nature of construction, managing tools' locations to prevent misplacement is a tedious and often manual task that is a large and growing pain point within the industry. Current solutions are often not a proper fit for small- to medium-sized construction businesses. To what extent do you believe this is true? Have you had personal experience with this problem, and if so, how are you overcoming it?

Figure 5: Table categorising each question asked to interviewees into distinct topics.

2.2 SECONDARY DATA COLLECTION

During this paper's literature review, quantitative metrics that were sought were exact figures that depicted the average annual cost of tool loss/theft within the construction industry, whether it be national estimates or whole industry statistics. However, reports, such as construction crime indexes, were more available than specific measures of tool loss, as cases are typically not reported sufficiently for accurate tracking. Moreover, the exact costs of the integration of competing systems, such as RFID, were challenging to obtain, as each technology system is case-specific, and no company would have a 1:1 cost to another; therefore, cost ranges were presented instead. More quantitative data that were researched were the differences in read range, cost, and lifespan in the major tracking technologies in this paper: GPS, Passive RFID, Active RFID, and BLE.

Qualitative data, such as case studies of existing competitors offering solutions for tool and asset tracking, were analysed to outline the limitations of current technologies and to observe if any SME-focused solutions were available on the market. Peer-reviewed academic papers were key sources that were used to compare and contrast the leading technologies for asset tracking: GPS, BLE, RFID, and Barcode systems. Trade publications and news sites, covering the implementation of RFID and other technologies, were used to strengthen the reputation and legitimacy of tool tracking solutions by highlighting the effectiveness seen within other industries. White papers from established organisations were utilised to understand the current models that are on offer for construction businesses. Government websites, such as the Australian Taxation Office, were referred to when delineating the scope of the issue and to clarify the definitions that were stated earlier in the paper.

One of the major challenges when researching BLE was the scarcity of scholarly research detailing BLE's specific usages within small-scale construction contexts. Repeatedly, most resources would explore its benefits in healthcare and logistics, leaving its value for construction SMEs to be underexplored, ergo increasing reliance on vendor case studies, which lack objectivity. Another barrier when evaluating current technologies was the fluctuation in price and performance. This is because most companies offer modular solutions that differ in value proposition, depending on the use case, and hence make it difficult to form standardised comparisons.

RESULTS

3.1 QUALITATIVE ANALYSIS – DATA VISUALISATION

Question	Sentiment Statement	Avg. Rating (1-5)	Visual Scale
Tell me more about the nature of your work and the key differences it has when compared to other professions.	Pride in work identity	4	★★★★☆
What areas or aspects within your work do you believe the most problems arise from?	Perceived problem severity	3	★★★☆☆
Across multiple projects, are there any common and persistent nuisances that cause consistent frustration among managers and colleagues? If so, what are some specific examples you would be comfortable sharing?	Frustration with recurring issues	4	★★★★☆
Regarding [*problem raised*], what are the current workarounds or solutions your company has been using? If relevant, what improvements would you like to see in these solutions?	Satisfaction with existing solutions/methods	3	★★★☆☆
In your line of work, what factor do you consider to be the most important when determining whether there is a need to address a problem, or when comparing competitors' solutions to an issue?	Priorities during the decision-making process	2	★★☆☆☆

Research shows that due to the fast-paced nature of construction, managing tools' locations to prevent misplacement is a tedious and often manual task that is a large and growing pain point within the industry. Current solutions are often not a proper fit for small- to medium-sized construction businesses. To what extent do you believe this is true? Have you had personal experience with this problem, and if so, how are you overcoming it?	Concern and awareness about tool loss within small scale construction contexts.	5	★★★★★

Figure 6: Table presenting the responses received and sentiment average calculations.

3.2 PRIMARY DATA ANALYSIS – PROFESSIONAL TRADE TRENDS

Across all interviews conducted, there was a prominent convergence in mindsets, specifically the emphasis on quality over speed. Whilst efficiency is aimed for in all construction operations, most respondents stressed that quality shouldn't be sacrificed, as a rushed job would set off a cascade of subsequent delays. A consistent theme in responses regarding decision-making was the prioritisation of overall customer satisfaction and long-term cost benefits, which aid in delivering the finished project punctually and thoroughly. A recurring cause for tight deadlines and loss of time is miscommunication between trades (horizontal) and management-to-tradespeople (vertical), with challenges such as critical measurement and planning errors. Although the age range of the interviewees was 29, no apparent connections were evident between their experience level and perceived problem severity.

Participants stated that the compounding of minor disruptions and lapses across different departments increases workload and pressure during the final stages of development. Candidates further elaborated by stating that sub-targets can be delayed, but the final deadline is fixed, and there are significant repercussions for overruns, with a participant giving the example of penalties starting from thousands of dollars being applied per day the project is extended. These anecdotes correspond with previously observed patterns within the construction industry, where evident worksite inefficiencies disrupt workflows and thus compromise productivity and overall project coherence.

When focusing the discussion on tool loss, there appeared to be a subtle divergence in the data. Whilst all participants acknowledged the prevalence of tool theft across colleagues and similar projects across the region, only a few respondents felt it was a primary concern for themselves, as others reported minimal experience with site break-ins, downplaying the severity of the issue. This is credited to the variation of projects that the tradespeople have been involved in, as those who claimed to have little to no first-hand experiences of theft noted that the smaller and secure sites they have been accustomed to often have 'site boxes', which are locked overnight and store all equipment needed by site-workers. Those familiar with tool theft mentioned that larger, multi-site projects present multiple opportunities for tools and equipment to be left behind or misplaced and never to be seen again, due to the more frequent travelling between work locations. Surprisingly, all participants shared a common, persisting nuisance that they felt was common within the industry: high-value batteries going 'missing', often being taken and used by workers who do not own them.

The root of this problem lies within the structure of how power tools are organised within construction sites. Most tradespeople possess personal ‘kits’ and ‘tool bags’; however, the charging station for their equipment lies in a shared space where surveillance is absent. Thus, the high volume of batteries entering/exiting charging ‘zones’ often leads to the availability of batteries declining over time. Moreover, whilst experience with tool theft is closely tied to worksite scale and the frequency of moving tools, nearly all respondents claimed to have instances of misplacing equipment, small or large, due to their own fault. An outlier that emerged during this topic was Interviewee 4, who stated they had never lost equipment due to personal mistakes. This participant attributed this to mitigation strategies that were implemented, such as returning all personal equipment to their vehicle and not relying on shared storage spaces, effectively eliminating the risk for tool loss. This stance aligns with previous research, as larger and time-consuming projects entail frequent travelling for construction SME workers, thereby allowing more cases for tools to be forgotten, misplaced, or go ‘missing’.

Overall, the qualitative data from the interviews presented parallels with the research outlined above, how the accumulation of disruptions in productivity contributed to disorder in the workplace, complemented by the pressure inflicted by rigid deadlines. Furthermore, participants revealed a varying sense of urgency to address tool loss/theft, suggesting that widespread adoption of BLE technology within construction SMEs will require messaging tailored to the differing profiles of tradespeople.

3.3 QUANTITATIVE DATA ANALYSIS – MARKET DATA

This research is contextualised within the Information and Communication Technology (ICT) sector, located within the Internet of Things (IoT) branch. The proposed solution is placed in the Construction Technology (ConTech) industry, with the target market encompassing construction SMEs. Submarkets comprise independent contractors, residential builders, tool rental companies, and subcontractors that rely on portable equipment, such as plumbers, cabinetry installers, electricians, and carpenters.

In 2024, the global asset tracking market was valued at an estimated USD 23.42 billion, with a projected growth of 12.6% CAGR (Compound Annual Growth Rate), as illustrated in Figure 7. This market is expected to reach USD 59.64 billion by 2032 (Fortune Business Reports, 2025). Factors that are driving the proliferation of asset-tracking solutions include the increasing demand for IoT-based asset tracking solutions, as they support manufacturers in monitoring real-time data that prolongs the lifespan of machinery. Moreover, the transition from retail to e-commerce, with projections that 53% of all purchases will be facilitated online in 2029, imposes pressure on businesses to deliver a seamless consumer experience and thus, digitalise their production pipeline through the usage of asset tracking systems. Another market growth factor is the appealing nature of Software-as-a-Service (SaaS) subscription models, as it diminishes the need for significant, up-front capital investment and proposes a more predictable expenditure layout. This paper’s target of utilising technologies such as BLE is supported through the rising ubiquity of smartphones and IoT-enabled devices, which strengthens the reliability of the infrastructure that BLE beacons depend on.

Figure 7: A chart displaying the expected trajectory of the Global Asset Tracking Market. "Asset Tracking Market Size & Trends | Research Report [2032]." August 11, 2025. https://www.fortunebusinessinsights.com/asset-tracking-market-109490.

The global ConTech market is expected to reach USD 7,032.9 million in 2025, with a growth rate of 17.5% CAGR up to 2034, with a value of approximately USD 30,086.9 million (Dimension Market Research, 2025), depicted below in Figure 8. Several growth factors for the ConTech market include skilled labour shortages, incentivising companies to automate tasks and systems to reduce required labour; the emergence of AI/ML, which analyses datasets to predict and prevent overruns and budgeting errors; and the inefficiencies of traditional methods, such as miscommunication and wasted time/materials. In 2024, the largest categories for investment in ConTech, in respective order, were productivity tools (e.g., management software and AI), green construction technology (e.g., solutions/materials to reduce carbon emissions), and future tech (e.g., robotics and 3D printing) (Proptech Jobs, n.d.).

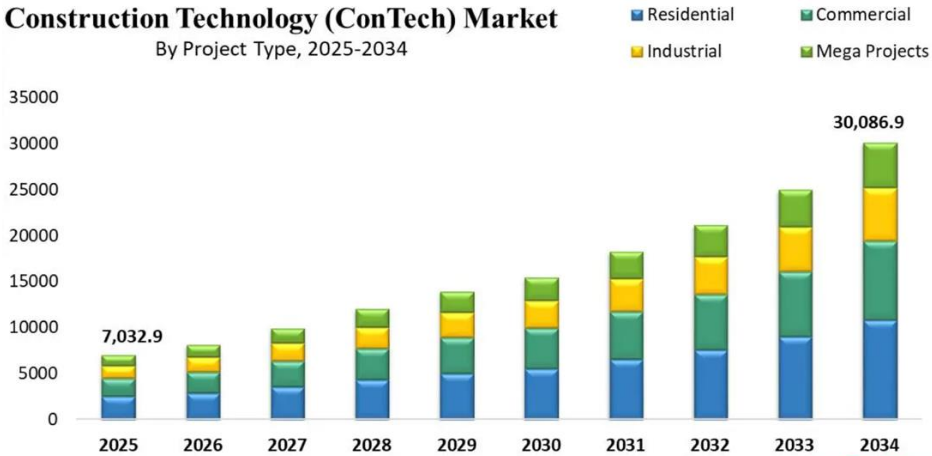

Figure 8: Projected global ConTech market growth up to 2034. Dimension Market Research. "Construction Technology (ConTech) Market to Reach USD 30,086.9 Mn By 2034." Accessed August 23, 2025. https://dimensionmarketresearch.com/report/construction-technology-market/.

3.4 QUALITATIVE DATA – CASE STUDY

In the construction landscape in Australia, Milwaukee One-Key is currently the most reputable tool tracking solution, with the technology first introduced in 2015. It leverages the established Milwaukee name and ecosystem and is available free of cost on applicable Milwaukee-branded products. The mobile application offers a polished user interface, with features such as geofencing alerts, cloud-based tracing, and theft-detection notifications. The large-scale promotional campaigns, accompanied by its prominent distribution network in tool retailers such as Bunnings Warehouse, strengthen awareness within the construction community, with multiple interview participants praising its practicality.

However, One-Key's attempt to create an *ecosystem lock-in* through its restriction to Milwaukee equipment is its core limitation, as it neglects the reality of many SMEs who utilise a variety of brands for their tools as a strategy to optimise cost-efficiency. In contrast, the proposed leaner business model that incorporates BLE-architecture for tool tracking will be designed to work on any tool/asset, regardless of manufacturer, in a more affordable and streamlined manner. By emphasising the integral aspects of well-known tracking solutions, such as live-accuracy, and excluding irrelevant feature sets for SMEs, such as barcode scanning capabilities, the proposed solution will permit deeper collaboration with construction SMEs and a more straightforward onboarding process. This balance will allow for personalised support and quicker product iteration through feedback received by early clients, a clear advantage over One-Key, where feedback loops are longer and product roadmaps are more extensive, which hinders Milwaukee's ability to pivot swiftly.

DISCUSSION

4.1 BIAS ASSESSMENT AND PRIMARY RESEARCH ANALYSIS

The primary data from the interviews yielded valuable insights within the construction industry, with the interviewees detailing the most forefront pain points in their respective workflows and how it is currently being addressed. This open-ended format allowed more candid discussion and deeper exploration into the nuanced day-to-day realities faced by the construction workforce, which would not have been expressed through other mediums, such as surveys or phone calls, as non-verbal cues, such as body language and pauses in their speech, proved substantial when responding. However, the small sample size and confined geographical focus on Brisbane limited the scope of results that were possible.

If reconducted, the results would benefit from having input from a larger participant pool that encompasses a wider spread of construction disciplines and locations, domestic and international. Moreover, crucial feedback from other members of the construction process, such as SME owners, site supervisors, managers, and board members, was absent and would have further contextualised the status quo and what influences shape purchasing decisions.

The underrepresentation of authoritative roles and the overemphasis on tradespeople skewed the data that was collected, as concerns such as long-term maintenance and return on investment (ROI) calculations were not adequately represented. Furthermore, by omitting a diversity of subcontractors, sufficient data was not provided to conclude whether tool tracking remains a significant issue across all trades. This issue of focusing on depth instead of breadth risks potentially amplifying trade-specific problems that may not be common in other lines of work, further skewing the dataset.

A notable obstacle that arose when facilitating the interviews was the differing levels of engagement that respondents exhibited, with some demonstrating a willingness to elaborate and others requiring additional probing. This fundamental difference lies within the communication styles that were evident within the interviewees, such as the usage of hand gestures and varying personality types (e.g., introverted vs extroverted). Thus, the answers ranged from concise and purposeful to those who openly digressed into other topics. The effect of these inconsistencies led to lost moments that could have elevated the richness of their replies. If repeated, the uneven depth of responses could be mitigated if questions were supplied beforehand, thereby encouraging deeper thought and preventing valuable insight from emerging after the discussion has concluded.

4.2 RESEARCH GAPS AND IMPLICATIONS FOR THE BUSINESS PLAN

With additional time and resources, exact figures delineating the true costs—financial and temporal—of tool loss for construction businesses could be incorporated into future research. By segmenting this data by company size, explicit comparisons can be made to truly measure the extent of tool loss for SMEs, empirically validating the testimonials from the interviews. Furthermore, to reality test other statements in secondary research, such as the perceived ease of deployment and hypothesised reductions in lost equipment, prototyping a BLE-based solution in real-life scenarios, by partnering with construction SMEs over a prolonged period, would confirm findings and outline vital metrics, such as the frequency and type of tools that get lost. Furthermore, to recognise whether the identified pain points are region-specific or universal, it would have been advantageous to collect data outside of Brisbane, as varying construction legislation could have raised further pain points that would equally require recognition. Overall, with these amendments, not only will the results' validity be strengthened, but accurate and efficient product design could be achieved through the Minimal Viable Product (MVP) concept. This methodology focuses on delivering an early version of a product and developing it iteratively through consumer feedback; in this instance, it would be delivering core features for early adopters, construction SMEs.

It is highlighted in this paper that there are three attributes that construction SMEs place weightage on: seamlessness in its initial deployment, return on investment ratio, and friction in long-term usage. In more specificity, investment-heavy models that include specialised hardware and infrastructure create a high barrier for usage and thus deter SMEs from many high-end solutions currently on the market. Therefore, for this paper's proposed solution, a leaner business model would be implemented through the leveraging of widely available devices (e.g., smartphones and BLE-enabled devices), which will form the backbone of the technology and ultimately trim costs.

Moreover, to combat the unmet need of a competent and affordable solution, a subscription-based model or alternate price tiers can be offered to accommodate SMEs' constrained budgets and logistical requirements. From a marketing standpoint, it is imperative to also address the tangible time savings when adopting a tool tracking solution, in conjunction with the ROI benefits. These efficiencies are achieved with the technology's automated architecture, eliminating manual logging processes that are present within other forms of documentation, such as barcode scanning and spreadsheet entry. Without restricting this technology's application to specific equipment or tool size/type, this system's modularity empowers SMEs to adapt features to however it suits them, thereby circumventing the rigidity and ecosystem lock-ins that are prevalent in current solutions such as Milwaukee One-Key.

CONCLUSION

Reflecting on the primary data, in the form of video interviews with tradespeople within the industry, and the secondary data, through a comprehensive literature review, this business proposal has been refined towards the development of BLE-based architecture for small-scale construction operations. Central features include smart alerts when items exit pre-defined geofences, automated audit logging, and real-time tracking.

The competitive differentiator when compared to existing market solutions is the leveraging of smartphones and other universal devices as receivers for data transfer, diminishing infrastructure costs, whilst elevating convenience and simplicity. Beyond the construction sector, the significance of safeguarding high-value equipment and assets persists, such as in healthcare and logistics disciplines, forming opportunities for BLE systems to be utilised in endless contexts. This unique value proposition will fulfil the standing unmet needs of SMEs and ultimately address the disparity between larger and smaller enterprises regarding efficiency and security, not just in construction.

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Author 100071 - Submission 100066 - Initial Submission

Manuscript Title: Addressing Tool Loss for Construction SMEs: Investigating the Implementation of Bluetooth Low Energy (BLE) for Tool Tracking in the Australian Construction Industry

Journal: Convergence

Overall Evaluation

This paper explores how Bluetooth Low Energy (BLE) technology can be used to address tool loss among small-to-medium-sized enterprises (SMEs) in the Australian construction industry. The author combines a structured literature review with interviews of tradespeople to compare BLE with existing solutions such as Radio Frequency Identification (RFID), Global Positioning System (GPS), and barcode-based systems. The paper argues that BLE offers a cost-effective and scalable alternative suited for SMEs, who often face financial constraints and lack complex IT infrastructure.

Strengths

-Focuses on a common problem for construction SMEs.

- The paper is well-organized, moving from context and problem identification to methodology, analysis, and discussion.

-Clearly compares different tracking technologies.

-Suggests a practical and simple business model for SMEs.

Areas for Minor Improvement

Limited generalisability:

The study is based on a small sample from Brisbane, Australia, so its findings may not apply to other regions or contexts.

Suggestion: Add a “Limitations” section to clearly state this.

Clarity of language:

The writing could be simpler and easier to read.

Suggestion: Use shorter sentences and simpler words.

Example rewrite: Instead of “BLE technology utilises low-power radio waves to establish proximity-based connections between tags and receivers, enabling continuous real-time tracking of tools within a defined radius,” say “BLE uses low-power radio waves to connect tags and receivers, allowing tools to be tracked in real time within a set area.”

Lack of perspectives from decision-makers:

All participants were tradespeople; no managers, owners, or decision-makers were included.

Suggestion: Acknowledge this as a limitation and suggest that future studies include managers or business owners for a more complete view.

Lack of supporting data for claims:

The paper states that BLE can reduce tool loss and improve productivity but does not provide data, costs, or test results.

Suggestion: Clarify that this is a prediction and that future studies should test this or provide cost analysis to support the claim. This will make the claims more realistic.

Recommendation

Accept with Minor Revisions.

Addressing Tool Loss for Construction SMEs: Investigating the Implementation of Bluetooth Low Energy (BLE) for Tool Tracking in the Australian Construction Industry.

Originality & Significance

- This paper uses a mixed-methods approach (qualitative and quantitative) to explore whether Bluetooth Low Energy can be used to prevent tool theft or misplacement in small to medium construction companies in the Australian context. It is an interesting topic.

Clarity & Structure

- Figures 1, 4, 5 and 6 are actually tables and so should be included as Tables.
- Figures 2 and 3 should be combined and instead be A and B panels for the same figure. This will reduce the repetitiveness of the legends between the figures.
- It is unclear what part of Methods would result in "3.4 QUALITATIVE DATA – CASE STUDY". It was not mentioned in the Methods that a case study would be conducted.
- More discussion of the similarities and differences between what was found from the different data collection methods (qualitative and quantitative) is warranted to demonstrate whether results are consistent across both methods. Triangulating data from different sources is a strength of studies, even if they find differing perspectives, this is still an interesting finding and should be discussed.

Use of Evidence & Research Methods

- It is unclear what these references pertain to: "National Equipment Register n.d.", "AssetRun, n.d.", "Comparesoft, n.d.". What is the n d?
- I am unsure whether this statement is substantiated: "The effect of this age distribution is an evident resistance to deviating from established and dated workflows". Is there evidence that age is related to dated workflows? If so, that needs to be referenced.
- "Six interviews were conducted with the age range being 23-52 years, aiming to discern whether differing levels of experience impacted perceived problem severity." This should say "with the age range *of interviewees* being 23-52 years". Also, does age necessarily correspond to level of experience? Did authors measure level of experience? If not, literature to state the relationship between age and experience in this industry should be included.
- The Methods describing the interviews should include details such as whether an interview guide was used (it was, and Fig 5 should be mentioned here)? Were interviews recorded on Teams? What happened to the transcripts? Were they deidentified? How was consent recorded?
- Authors do not mention how they calculated sentiment and rating scores and using visual scales in the Methods. This needs to be described.

- The sentiment statements are quite vague and do not describe what was said. More descriptive terms should be used.

Engagement with Literature

- The majority of the references used are websites with very minimal journal papers. This does limit the validity of the review of current literature in this field. Authors should use more papers in the study.
- In the Conclusion, more use of literature to describe how this study adds to what is known in this area would strengthen the paper. Emphasis should be on similarities or differences between this study's findings and what is already known.

Grammar & Language

- The paper is well-written and easy to read.
- Authors should be cautious about the abbreviations used throughout and ensure they are defined in their first use eg CAGR, AI, ML, ConTech

Final Recommendation:

- Accept with major revisions (acceptance conditional on satisfactory **major** revisions)

Addressing Tool Loss for Construction SMEs: Investigating the Implementation of Bluetooth Low Energy (BLE) for Tool Tracking in the Australian Construction Industry.

ABSTRACT

If a tool goes missing, it is often written off as an overhead cost for large, established construction firms. However, for small-to-medium-sized construction enterprises (SMEs), the cumulative impact of these losses can be~~written off as overhead costs for large, established construction firms, but for small-to-medium-sized construction enterprises (SMEs), the culmination of these losses is~~ severe. Tool loss and theft constitute one of the largest concerns for SMEs, as it leads to avertable financial strain and wasted time. Technologies such as Global Positioning System (GPS) and Radio Frequency Identification (RFID) currently serve as solutions; however, these current models are inapt for SMEs as they rely on complex networks and specialised hardware. Hence, these services are exclusively employed by large construction firms that have ample capital. This paper accentuates the capabilities of Bluetooth Low Energy (BLE) technology as a more feasible alternative for tool and asset tracking due to its accessibility and scalability, tailored to the needs of SMEs. Through a structured literature review, complemented by insights from independent contractors gathered through online interviews, current systems' shortcomings are identified and compared with BLE technology across key areas such as affordability, live-tracking accuracy, read range, and ease of use and deployment. It is concluded that the BLE-centric model has the potential to ~~offers~~offer an optimal value proposition for SMEs with the balance between affordability and tracking capacity, with its future potential augmented with opportunities such as geofencing and personnel tracking/logging. Therefore, this research spotlights the untapped market opportunity for a low-friction, cost-efficient tool tracking solution that is intentionally geared toward small-scale construction operations.

KEYWORDS: Construction SMEs, real-time tracking, tool loss, cost efficiency, RFID/BLE technology

INTRODUCTION

1.1 Overview of Industry Landscape

In Australia, at least AUD 650M worth of high-cost equipment is lost through theft annually from construction sites, a significant figure that rises further when cases of misplacement and undocumented losses are considered (National Equipment Register n.d.). Despite the accelerated development of digital systems and processes across other sectors, the construction industry is notorious for its resistance to adopting emerging technologies, with a 2017 McKinsey report placing agriculture as the only other industry below construction that lacks digitisation and innovation (Dewhurst 2017).

A potential root for this stagnancy lies within the traditional mental framework and outdated workflows that construction workers operate under, highlighted when examining the demographic profile of construction workers across major construction hubs and the average ages, indicating high levels of experience. The average age of a construction worker in North America is 42 (Klocek 2024); in Australia, it is 38 (Department of Employment and Workplace Relations 2024); in the UK, it is over 50 (CITB 2023); and in China, the median age is now 47, with recent trends suggesting that China's figure is projected to increase in the future.

~~The effect of this age distribution is an evident resistance to deviating from established and dated workflows. This is ~~D~~d~~ue to the minimal margin for error and the sensitivity of the industry, experimentation is not encouraged and likely justifies the 2017 McKinsey report mentioned above. ~~that discourages experimentation, due to the economic and time sensitivity of this industry.~~ Moreover, as small-to-medium-sized construction enterprises (SMEs) continue to solidify their presence as the backbone of the construction industry due to the increasing demand for residential and commercial infrastructure—such as the surging demand for housing in Australia—businesses require seamless and intuitive solutions that will aid in overcoming problems and enhance coordination when completing tasks by trimming idle or wasted time.

1.2 Context

According to Australia's enterprise classification model, small-to-medium-sized construction enterprises, or construction SMEs, are defined as having fewer than 200 FTEs (full-time equivalent employees) (NSW 2021), a unit of measurement to evaluate a company's full-time employees, while considering part-time employees, to standardise the number of working hours into full-time positions (Valier 2025). Moreover, another metric that is acknowledged when calculating a business's size in Australia is the turnover-based ladder, where businesses that have annual aggregated turnover of up to 10M (million) AUD are deemed 'small', between 10M AUD and 250M AUD are classified as 'medium', and above 250M AUD are labeled 'large' (Australian Taxation Office 2024). This paper's business proposition will have a scope of SMEs that make less than 10M AUD per year, with the following example business types listed below in Figure 1.

Employee Number	**Turnover Category (AUD)**	**Example Business Types**
Micro Enterprise (0–4)	Small Business (≤ $10 M)	sole-trader plumber; solo electrician
Small Enterprise (5–19)	Small Business (≤ $10 M)	12-person concrete finisher; electrical subcontractor
Medium Enterprise (20–199)	Small Business (≤ $10 M)	30-person carpentry subcontractor; 60-person commercial painter

~~Figure~~ Table 1: Table of the types of businesses that are classified as SMEs in Australia.

On average, a construction worker will lose 38 hours annually in search of absent tools (Berntsen 2025), averaging to approximately 10 minutes per day. Due to the fast-paced nature of construction and the multiple job sites that tools are often shared across, this pain point is common across mobile construction businesses such as local plumbing, electrician, and paving services. Construction SMEs operate in complex environments that demand competence and productivity, resulting in documentation and ordered tracking systems commonly being neglected. The compounding of these seemingly insignificant gaps frequently leads to 'ghost assets', which are tools that are documented but don't exist physically; repeated delays, hurting budgets as schedules are not time-efficient, leading to project extensions and overtime pay; reputation damage due to tardiness; heightened tensions and widespread frustration.

Larger construction businesses leverage enterprise tool-management software that provides intricate information about assets through the utilisation of Radio Frequency Identification

Additionally, larger companies employ “kit rooms”, a designated space in high-value areas that store and manage tools and equipment, where dedicated staff members manage audit trails, maintenance cycles, and check-in/out timings to optimise tool effectiveness. These sophisticated systems typically require major upfront investment, both time and capital, creating a high barrier to use for construction SMEs, who account for a large proportion of all construction companies registered globally, such as in the United Kingdom, where 97% of all construction companies registered are SMEs (Ali 2025).

1.3 Scoping Tool Loss within the Construction Industry

Although technologies such as passive RFID are affordable at a per-unit cost, ~<$1 per tag, the infrastructure that is required to exploit its benefits, such as obtaining specialised readers, dedicated IT support, and building a broad network, does not make it a viable solution for SMEs’ limited budget. The restraint that hinders construction SMEs from replicating the current solutions utilised by dominant construction firms is tight cash flow, due to competitive thin margins and their unique placement within the industry: too small for enterprise strategies, but too large for manual methods. Each model available in the market mandates a compromise from SMEs. In the case of conserving costs, SMEs would be trading their time and labour for manually tracking equipment and tools with the use of cumbersome spreadsheets and barcode systems. Alternatively, SMEs could use enterprise solutions; however, a system costing typically tens of thousands of dollars exceeds their allocated budget for tool replacement.

Newer construction SMEs that have limited capital often resort to labour-intensive and monotonous methods for tool logging, such as paper-based checking systems, online spreadsheets, visual boards, verbal communication, and/or basic scanning technologies such as barcodes. The paper-and-pen method is appealing to cash-tight and early-stage SMEs, given the cultural inertia and cost-effectiveness of a universally understood method; however, its fundamental drawbacks lie in its vulnerability to damage and inaccuracy due to the rugged environment of construction, as well as its inability to be shared across digital platforms.

A substitute many SMEs employ includes utilising spreadsheet platforms such as Excel, addressing the latter issue raised with the clipboard method. This solution can be shared across many teams through inexpensive, cloud-based software, as well as offering a simple interface where it can be customised to suit individual and specific workflows. Nevertheless, its flaws share overlap with the clipboard approach, where it lacks entry automation, real-time tracking, and is prone to inconsistencies and errors. Another distinct issue includes the possibility of data loss in the case of file corruption. Furthermore, the oral, trust-based communication system is ubiquitous in the industry, attributed to its speed and informality; however, similar issues, such as the opportunity for discrepancies and loss of information, persist.

1.4 Competitor Technology Analysis and Comparison with BLE

Technologies such as barcode scanning are increasingly entering the market, oriented toward construction firms that emphasise cost-efficient solutions. This product is being marketed as an SME-friendly alternative to enterprise-grade asset management solutions, offering benefits such as instant digitalisation across online applications/websites through its low upfront costs and ease of integration. This approach functions with site employees manually scanning the tool’s unique barcode in combination with their ID badge, creating instant digital logs that incorporate user identity, time/date stamps, and location of pickup/drop-off, promoting personnel accountability.

Yet, this approach shares a similar pain point that is present in manual tracking systems: it is reliant on high user input from workers who must document each stage of the tools' usage, creating an opportunity for gaps in tracking as well as friction in workflows. Furthermore, businesses such as GigaTrak offer this barcode-based service starting from just USD 75 per month. However, this exhibits the second issue that lies with companies that offer barcode-based tool tracking services; this cost is strictly limited to software license, access to cloud hosting, support, and automatic tool upgrades, excluding barcode printers, specialised scanners, and other essential hardware components, which would collectively inflate the cost of implementation (AssetRun, n.d.).

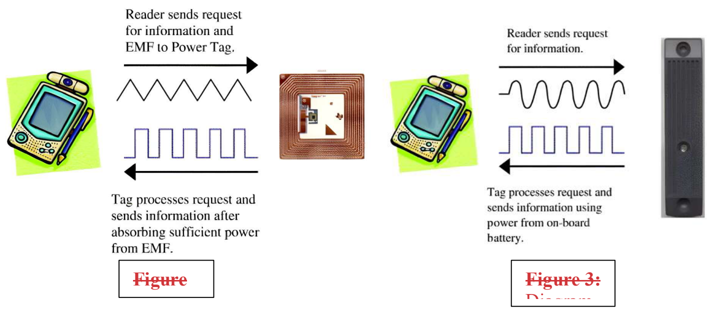
Other issues include durability concerns, where the tag is invalid if scratched or dirtied, and read range, as barcode scanning requires a direct line of sight to be read. Moreover, workers face a steep learning curve, as manually documenting an abundance of tools leads to low field adoption and a high abandonment rate in the industry~~ for human-dependent, tool-tracking services~~. Therefore, these limitations accentuate the growing demand for automated, straightforward asset management systems that are tailored for the pace and structure of SME operations. This paper acknowledges the unmet need~~, which serves as the underlying rationale proposing the~~ and thus investigates the possible incorporation of alternative technology infrastructure, such as Bluetooth Low Energy (BLE), to replace present-day market solutions.

Radio Frequency Identification (RFID) technology is disruptive within the construction industry, with larger firms beginning to utilise it to modernise asset management. Dating back to its first use case to track aircraft in WWII, RFID's purpose has evolved to be an integral component within the industry of asset tracking, with retailers such as Walmart investing USD 500 million into an RFID system in 2024 and River Island improving their stock accuracy from 78% to 98% through the deployment of RFID tags (Comparesoft, n.d.).

RFID functions through two main components: the tag, which is attached to the tracked item; and the reader, which transmits radio waves that directly communicate and receive data from the tags through the assistance of antennas (Goodrum, McLaren, and Durfee 2005, 2). RFID tags are available in two forms, passive or active, with prices for each tag ranging from 0.10–5 USD and 15-50 USD, respectively. The underlying reason for the considerable price difference for passive RFID tags is the absence of a power source, as depicted in Figure 2, extending their operational life as they draw their power from the electromagnetic force emitted from the RFID scanner. Its lightweight and inexpensive nature deems it ideal for businesses that must track large inventories.

That said, this structure results in a significantly shorter read range—as great as 4 metres—and is diminished when scanned through industrial materials such as metal, requiring the proximity of the reader to be within a few centimetres to successfully read the tag. Its counterpart, active RFID tags, do not suffer from this issue as their internal battery allows them to autonomously transmit information to the reader without the presence electromagnetic field, as depicted in Figure 3. The effect of this point of difference is improved speed and accuracy in scanning assets when compared to passive RFID tags. Active RFID tags' read ranges are consistently observed to be between 15-25 metres; albeit, this technology suffers from the same issue of a degradation in read range when interfered with by dense industrial infrastructure (Andoh 2012, 12).

Figure 1~~2~~: Diagrammatic representation of passive (Panel A) and active (Panel B) RFID technology. Goodrum, Paul M., Matt A. McLaren, and Adam Durfee. "The Application of Active Radio Frequency Identification Technology for Tool Tracking on Construction Job Sites." *Automation in Construction* 15, no. 3 (2006): 292–302. https://doi.org/10.1016/j.autcon.2005.06.004.



Yet, its comprehensiveness is also its setback, as advanced infrastructure installation demands extensive capital investment, segmenting the market of potential consumers to only large construction enterprises. With readers costing thousands of dollars, coupled with strategic placement of antennas and cable infrastructure, the accumulation of these expenses deters construction SMEs that lack sufficient capital to execute such a large-scale system.

A competing technology experimented with in the construction industry that aims to provide the live tracking ability of RFID is the Global Positioning System (GPS) technology. GPS technology leverages the constellation of satellites that orbit Earth, providing real-time location data through a process of triangulation. It requires a minimum of four satellites for 3D positioning, with the process determining the exact longitude, latitude, and altitude coordinates (Crato, 2010). While GPS excels in outdoor environments, due to the nature of the technology, accuracy and reliability deteriorate indoors, around bridges, and under tree canopies, all of which are conditions common on worksites. Hence, GPS has been restricted in most cases to outdoor, high-value assets, such as forklifts and excavators, where its placement aligns with the strengths of the technology.

This raises the overarching question: how can the live-tracking abilities and automation of RFID and GPS be intuitively incorporated in an SME-focused system, whilst eliminating the prerequisite of intensive infrastructure?

Bluetooth Low Energy, abbreviated to BLE, operates through the interaction of beacons and Bluetooth-enabled devices, such as smartphones, making it ideal for indoor environments where its location can be shared with surrounding technology. It is a wireless communication protocol that operates in the 2.4 GHz ISM band, purposely designed for low-energy, short-range data transmission. In a typical setup, beacons will periodically broadcast a unique identifier signal that will be interpreted by receivers, which are smartphones or other Bluetooth-enabled devices/gateways, establishing logs that provide real-time tracking of assets, which can be accessed seamlessly through interfaces such as mobile applications. This signal transmission process, as well as low latency, ~~justifies~~ elevates BLE's competence within indoor settings, areas where systems such as GPS may be unreliable.

BLE beacons contain a battery that remains idle unless a connection is initiated, ~~thus~~ making it impressively power-efficient and extending each beacon's lifespan to up to 5-10 years. Moreover, BLE beacons have a read range of up to 100 metres in open conditions, ~~speeding~~ simplifying the~~up the~~ implementation process and opening up future scaling opportunities. Additionally, its interaction with existing IT infrastructure is attractive to SMEs with budget restraints, as there is no need for extra network installations, dedicated scanners, antennas, and other system-specific equipment.

Nonetheless, BLE is inferior in location precision when compared with GPS, as it does not offer exact coordinates, but rather an approximate area, with an average accuracy distance of up to 5m in optimal conditions (inpixon, n.d.). To add on, a beacon may display 'nearby' or 'last seen at' in certain situations rather than live location, as it relies on the presence of receivers.

A summary of the competing technologies' application uses, advantages, and disadvantages is displayed in Figure 4.

Technology	Application Uses	Advantages	Disadvantages
Barcodes	- Inventory tracking - Tool check-in/check-out - Simple asset logging	- Relatively low cost - Straightforward implementation process - Intuitive for most users	- Requires manual scanning and line of sight - No live tracking or location data - Prone to human error
BLE (Bluetooth Low Energy)	- Live tracking of tools on job sites, indoors and outdoors - Geofencing capabilities and push notifications controls when items leave their zone	- Real-time tracking - Long battery life (5–10 years) - Smartphone-compatible - Cost-effective and scalable - Minimal infrastructure required	- Fluctuating range (10–100m) - Susceptible to signal interference (e.g., metal) - Slightly lower precision than GPS - May require additional installation of beacons for increased accuracy
Passive RFID	- High-volume, enterprise inventory control - Fixed checkpoint scanning	- Inexpensive tags (USD 0.10–5) - No battery required - Durable and compact	- Limited range (~1–4m) - Requires dedicated readers and antennas

	- Bulk tool authentication and processing - Entry/exit scanning	- High reliability - Fast and efficient scanning	- High infrastructure setup and costs - Signal blocked by metal/liquid - Limited to checkpoint-based tracking
Active RFID	- Real-time tracking of high-value assets - Site-wide, long-range applications - Automated inventory systems	- Longer read range (30-150m) - Continuous and automatic transmission - Works without reader proximity - High accuracy and reliability	- Expensive tags (USD 15–50+) - Requires battery replacements - Requires dedicated IT support - Infrastructure is complex and capital-intensive
GPS	- Outdoor tracking of large vehicles and heavy equipment - Mobile asset monitoring - Theft prevention/recovery	- High location accuracy - True real-time tracking - Suitable for remote locations - Established and reputable technology	- Poor indoor performance - High power consumption - Costly hardware and subscriptions - Not suitable for smaller tools

~~Figure 4~~Table 2: Table highlighting the major points of difference in each competing technology.

Therefore, this paper will examine how BLE technology ~~can~~ could address construction SMEs' two valued resources, cost and time efficiency, by automating the management of tools and assets, and as a result, possibly decrease the unnecessary expenditure on restoring lost equipment. The proposed business model's unique value proposition will be its ~~objective~~ aim to incorporate the advantages of high-infrastructure and complex technologies, such as the reliability of active RFID, without its tie to heavy, up-front ~~capital~~ investment, instead offering a more flexible structure that is accessible for ~~all~~smaller-sized businesses. ~~Potential customers for this hypothesised business model will be gauged through primary and secondary methods of data collection, detailed below.~~

METHODOLOGY

2.1 PRIMARY DATA COLLECTION - INTERVIEWS

During the interview process, judgmental and convenience sampling methods were implemented, as this approach would allow for authentic insight within the demographic in the construction industry that experiences the repercussions of persistent tool loss on a micro and macro scale. Judgmental sampling was utilised when restricting the scope of interviewees to the type of people who would consistently experience tool and equipment loss during their workflow, which included tradespeople and subcontractors.

In a similar vein, convenience sampling effectively complemented the selection process by electing to contact local and available people out of the candidate pool. This approach is conducive to receiving more detailed responses and ideas, as interviewees who entered the discussion with an innate eagerness to express their concerns rather than feeling pressured would be more inclined to respond openly and genuinely. With this paper's focus on Australia's construction industry, emphasis was placed on interviewing Australian-based

c[redacted]struction [redacted]rkers, specifically in
(Philip, 2024).

Six interviews were conducted with the age range of interviewees being 23-52 years, aiming to discern whether differing levels of experience impacted perceived problem severity. When asked, all interviewees stated they began their career in their late teens or early twenties, a common trend in the Australian labour and trades market. Each interview had a duration of 20-35 minutes, with most participants sharing anecdotes and detailing related issues of concern. All interviews followed a common interview guide, displayed below in Table 3. A few participants curbed their responses to the specifics of the questions, shortening the length of the discussion to 1-2 sentence responses. To compensate for the lack of ~~initial~~ detail, further follow-up questions were asked and recorded, encouraging the interviewee to elaborate on key themes that were brought up. All interviews were facilitated through Microsoft Teams, a video conferencing platform. Prior to any information being shared, consent was granted by the interviewee to include their responses within this paper. A persisting obstacle that arose was due to a misunderstanding of the questions~~,~~ , participants commonly deviated from the ~~key ideas that were in the~~essence of the question, and hence, follow-up clarifications ~~brought their responses back to the essence of the question.~~were required.

~~Listed below in Figure 5 are the questions each interviewee was asked.~~

#	Topic	Interview Question
1	*Nature of Work*	Tell me more about the nature of your work and the key differences it has when compared to other professions.
2	*Problem Areas*	What areas or aspects within your work do you believe the most problems arise from?
3	*Recurring Frustrations*	Across multiple projects, are there any common and persistent nuisances that cause consistent frustration among managers and colleagues? If so, what are some specific examples you would be comfortable sharing?
4	*Current Solutions & Improvements*	Regarding [*problem raised*], what are the current workarounds or solutions your company has been using? If relevant, what improvements would you like to see in these solutions?
5	*Decision-Making Factors*	In your line of work, what factor do you consider to be the most important when determining whether there is a need to address a problem, or when comparing competitors' solutions to an issue?
6	*Tool Tracking for SMEs*	Research shows that due to the fast-paced nature of construction, managing tools’ locations to prevent misplacement is a tedious and often manual task that is a large and growing pain point within the industry. Current solutions are often not a proper fit for small- to medium-sized construction businesses. To what extent do you believe this is true? Have you had personal experience with this problem, and if so, how are you overcoming it?

Figure 5Table 3: Table categorising each question asked to interviewees into distinct topics.

2.2 SECONDARY DATA COLLECTION

During this paper's literature review, quantitative metrics that were sought were exact figures that depicted the average annual cost of tool loss/theft within the construction industry, whether it be national estimates or whole industry statistics. However, reports, such as construction crime indexes, were more available than specific measures of tool loss, as cases are typically not reported sufficiently for accurate tracking. Moreover, the exact costs of the integration of competing systems, such as RFID, were challenging to obtain, as each technology system is case-specific, and no company would have a 1:1 cost to another; therefore, cost ranges were presented instead. More quantitative data that were researched were the differences in read range, cost, and lifespan in the major tracking technologies in this paper: GPS, Passive RFID, Active RFID, and BLE.

Qualitative data, such as a case studyies of existing competitorsMilwaukee One-Key, a leading competitor in offering solutions for tool and asset tracking, was collected were analysed to outline the limitations of current technologies and to observe if any SME-focused solutions were available on the market. Peer-reviewed academic papers were key sources that were used to compare and contrast the leading technologies for asset tracking: GPS, BLE, RFID, and Barcode systems. Trade publications and news sites, covering the implementation of RFID and other technologies, were used to strengthen the reputation and legitimacy of tool tracking solutions by highlighting the effectiveness seen within other industries. White papers from established organisations were utilised to understand the current models that are on offer for construction businesses. Government websites, such as the Australian Taxation Office, were referred to when delineating the scope of the issue and to clarify the definitions that were stated earlier in the paper.

One of the major challenges when researching BLE was the scarcity of scholarly research detailing BLE's specific usages within small-scale construction contexts. Repeatedly, most resources would explore its benefits in healthcare and logistics, leaving its value for construction SMEs to be underexplored, ergo increasing reliance on vendor case studies, which lack objectivity. Another barrier when evaluating current technologies was the fluctuation in price and performance. This is because most companies offer modular solutions that differ in value proposition, depending on the use case, and hence make it difficult to form standardised comparisons.

RESULTS

3.1 QUALITATIVE ANALYSIS – DATA VISUALISATION

Sentiment ratings and the corresponding visual scale were derived through an intuitive and subjective analysis of the tone and language used collectively by the interviewees. The rating system spans from 1, indicating minimal alignment/overlap between the sentiment statement and the interviewee's response, to 5, which represents the highest degree of alignment.

Question	Sentiment Statement	Avg. Rating (1-5)	Visual Scale

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Tell me more about the nature of your work and the key differences it has when compared to other professions.	**Pride** in work ~~identity~~ and unique aspects in the industry	4	★★★★☆
What areas or aspects within your work do you believe the most problems arise from?	**Perceived** problem severity and its ubiquity/frequency	3	★★★☆☆
Across multiple projects, are there any common and persistent nuisances that cause consistent frustration among managers and colleagues? If so, what are some specific examples you would be comfortable sharing?	**Frustration** with recurring issues	4	★★★★☆
Regarding [*problem raised*], what are the current workarounds or solutions your company has been using? If relevant, what improvements would you like to see in these solutions?	**Satisfaction** with existing solutions/methods	3	★★★☆☆
In your line of work, what factor do you consider to be the most important when determining whether there is a need to address a problem, or when comparing competitors' solutions to an issue?	~~**Priorities during the decision-making process**~~**Importance** of decision factors when evaluating solutions	2	★★☆☆☆
Research shows that due to the fast-paced nature of construction, managing tools' locations to prevent misplacement is a tedious and often manual task that is a large and growing pain point within the industry. Current solutions are often not a proper fit for small- to medium-sized construction businesses. To what extent do you believe this is true? Have you had personal experience with this problem, and if so, how are you overcoming it?	**Concern** and awareness about tool loss within small scale construction contexts. General **interest** in this niche	5	★★★★★

~~Figure~~ Table 46: Table presenting the responses received and sentiment average calculations.

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3.2 PRIMARY DATA ANALYSIS – PROFESSIONAL TRADE TRENDS

Across all interviews conducted, there was a prominent convergence in mindsets, specifically the emphasis on quality over speed. Whilst efficiency is aimed for in all construction operations, most respondents stressed that quality shouldn't be sacrificed, as a rushed job would set off a cascade of subsequent delays. A consistent theme in responses regarding decision-making was the prioritisation of overall customer satisfaction and long-term cost benefits, which aid in delivering the finished project punctually and thoroughly. A recurring cause for tight deadlines and loss of time is miscommunication between trades (horizontal) and management-to-tradespeople (vertical), with challenges such as critical measurement and planning errors. Although the age range of the interviewees was 29, no apparent connections were evident between their experience level and perceived problem severity.

Participants stated that the compounding of minor disruptions and lapses across different departments increases workload and pressure during the final stages of development. Candidates further elaborated by stating that sub-targets can be delayed, but the final deadline is fixed, and there are significant repercussions for overruns, with a participant giving the example of penalties starting from thousands of dollars being applied per day the project is extended. These anecdotes correspond with previously observed patterns within the construction industry, where evident worksite inefficiencies disrupt workflows and thus compromise productivity and overall project coherence.

When focusing the discussion on tool loss, there appeared to be a subtle divergence in the data. Whilst all participants acknowledged the prevalence of tool theft across colleagues and similar projects across the region, only a few respondents felt it was a primary concern for themselves, as others reported minimal experience with site break-ins, downplaying the severity of the issue. This is credited to the variation of projects that the tradespeople have been involved in, as those who claimed to have little to no first-hand experiences of theft noted that the smaller and secure sites they have been accustomed to often have 'site boxes', which are locked overnight and store all equipment needed by site-workers. Those familiar with tool theft mentioned that larger, multi-site projects present multiple opportunities for tools and equipment to be left behind or misplaced and never to be seen again, due to the more frequent travelling between work locations. Surprisingly, all participants shared a common, persisting nuisance that they felt was common within the industry: high-value batteries going 'missing', often being taken and used by workers who do not own them.

The root of this problem lies within the structure of how power tools are organised within construction sites. Most tradespeople possess personal 'kits' and 'tool bags'; however, the charging station for their equipment lies in a shared space where surveillance is absent. Thus, the high volume of batteries entering/exiting charging 'zones' often leads to the availability of batteries declining over time. Moreover, whilst experience with tool theft is closely tied to worksite scale and the frequency of moving tools, nearly all respondents claimed to have instances of misplacing equipment, small or large, due to their own fault. An outlier that emerged during this topic was Interviewee 4, who stated they had never lost equipment due to personal mistakes. This participant attributed this to mitigation strategies that were implemented, such as returning all personal equipment to their vehicle and not relying on shared storage spaces, effectively eliminating the risk for tool loss. This stance aligns with previous research, as larger and time-consuming projects entail frequent travelling for construction SME workers, thereby allowing more cases for tools to be forgotten, misplaced, or go 'missing'.

Overall, the qualitative data from the interviews presented parallels with the research outlined above, how the accumulation of disruptions in productivity contributed to disorder in the workplace, complemented by the pressure inflicted by rigid deadlines. Furthermore, participants revealed a varying sense of urgency to address tool loss/theft, suggesting that widespread adoption of BLE technology within construction SMEs will require messaging tailored to the differing profiles of tradespeople.

3.3 QUANTITATIVE DATA ANALYSIS – MARKET DATA

This research is contextualised within the Information and Communication Technology (ICT) sector, located within the Internet of Things (IoT) branch. The proposed solution is placed in the Construction Technology (ConTech) industry, with the target market encompassing construction SMEs. Submarkets comprise independent contractors, residential builders, tool rental companies, and subcontractors that rely on portable equipment, such as plumbers, cabinetry installers, electricians, and carpenters.

In 2024, the global asset tracking market was valued at an estimated USD 23.42 billion, with a projected growth of 12.6% CAGR (Compound Annual Growth Rate), as illustrated in Figure 7. This market is expected to reach USD 59.64 billion by 2032 (Fortune Business Reports, 2025). Factors that are driving the proliferation of asset-tracking solutions include the increasing demand for IoT-based asset tracking solutions, as they support manufacturers in monitoring real-time data that prolongs the lifespan of machinery. Moreover, the transition from retail to e-commerce, with projections that 53% of all purchases will be facilitated online in 2029, imposes pressure on businesses to deliver a seamless consumer experience and thus, digitalise their production pipeline through the usage of asset tracking systems. Another market growth factor is the appealing nature of Software-as-a-Service (SaaS) subscription models, as it diminishes the need for significant, up-front capital investment and proposes a more predictable expenditure layout. This paper's target of utilising technologies such as BLE is supported through the rising ubiquity of smartphones and IoT-enabled devices, which strengthens the reliability of the infrastructure that BLE beacons depend on.

Figure 27: A chart displaying the expected trajectory of the Global Asset Tracking Market. "Asset Tracking Market Size & Trends | Research Report [2032]." August 11, 2025. https://www.fortunebusinessinsights.com/asset-tracking-market-109490.

The global [redacted] [redacted] [redacted]
rate of 17.5% CAGR up to 2034, with a value of approximately USD 30,086.9 million (Dimension Market Research, 2025), depicted below in Figure 8. Several growth factors for the ConTech market include skilled labour shortages, incentivising companies to automate tasks and systems to reduce required labour; the emergence of ~~AI/ML~~Artificial Intelligence/Machine Learning, which analyses datasets to predict and prevent overruns and budgeting errors; and the inefficiencies of traditional methods, such as miscommunication and wasted time/materials. In 2024, the largest categories for investment in ConTech, in respective order, were productivity tools (e.g., management software and AI), green construction technology (e.g., solutions/materials to reduce carbon emissions), and future tech (e.g., robotics and 3D printing) (Proptech Jobs, n.d.).

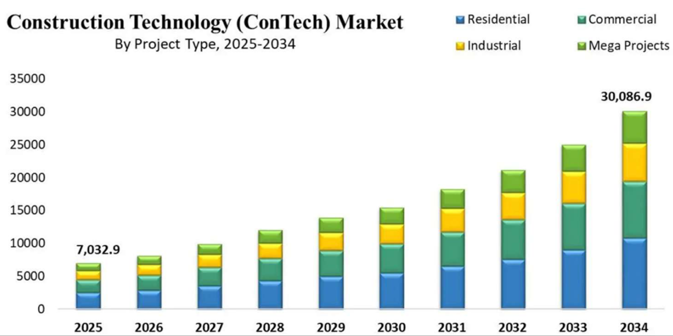

Figure 38: Projected global ConTech market growth up to 2034. Dimension Market Research. "Construction Technology (ConTech) Market to Reach USD 30,086.9 Mn By 2034." Accessed August 23, 2025. https://dimensionmarketresearch.com/report/construction-technology-market/.

3.4 QUALITATIVE DATA – CASE STUDY

In the construction landscape in Australia, Milwaukee One-Key is currently the most reputable tool tracking solution, with the technology first introduced in 2015. It leverages the established Milwaukee name and ecosystem and is available free of cost on applicable Milwaukee-branded products. The mobile application offers a polished user interface, with features such as geofencing alerts, cloud-based tracing, and theft-detection notifications. The large-scale promotional campaigns, accompanied by its prominent distribution network in tool retailers such as Bunnings Warehouse, strengthen awareness within the construction community, with multiple interview participants praising its practicality.

However, One-Key's attempt to create an *ecosystem lock-in* through its restriction to Milwaukee equipment is its core limitation, as it neglects the reality of many SMEs who utilise a variety of brands for their tools as a strategy to optimise cost-efficiency. In contrast, the proposed leaner business model that incorporates BLE-architecture for tool tracking will be designed to work ~~on~~ with any tool/asset, regardless of manufacturer, in a more affordable and streamlined manner. By emphasising the integral aspects of well-known tracking solutions, such as live-accuracy, and excluding irrelevant feature sets for SMEs, such as barcode scanning capabilities, the proposed solution will permit deeper collaboration with construction SMEs and a more straightforward onboarding process. This balance will allow for personalised support and quicker product iteration through feedback received by early clients, a clear advantage over One-Key, where feedback loops are longer and product roadmaps are more extensive, which hinders Milwaukee's ability to pivot swiftly.

DISCUSSION

4.1 ~~BIAS ASSESSMENT AND~~ PRIMARY RESEARCH ANALYSIS

The primary data from the interviews yielded valuable insights within the construction industry, with the interviewees detailing the most forefront pain points in their respective workflows and how it is currently being addressed. This open-ended format allowed more candid discussion and deeper exploration into the nuanced day-to-day realities faced by the construction workforce, which would not have been expressed through other mediums, such as surveys or phone calls, as non-verbal cues, such as body language and pauses in their speech, proved substantial when responding.

4.2 LIMITATIONS AND BIAS ASSESSMENT

~~However, the small sample size and confined geographical focus on Brisbane limited the scope of results that were possible.~~ With the study's focus being confined geographically to Brisbane, the possible sample size was restricted, and thus, results may not be representative of other regions and contexts.

If reconducted, the results' ~~would~~ accuracy would be strengthened~~benefit from~~by having input from a ~~larger~~ broader participant pool that encompasses a wider spread of construction disciplines and locations, domestic and international. Moreover, crucial feedback from other members of the construction process, such as SME owners, site supervisors, managers, and board members, was absent and would have further contextualised the status quo and what influences shape purchasing decisions. For a more complete insight, future studies with managers and business owners should be conducted to complement the feedback given by the tradespeople.

The underrepresentation of authoritative roles and key decision makers, and the overemphasis on tradespeople, skewed the data that was collected, as concerns such as long-term maintenance and return on investment (ROI) calculations were not adequately represented. Furthermore, by omitting a diversity of subcontractors, sufficient data was not provided to conclude whether tool tracking remains a significant issue across all trades. This issue of focusing on depth instead of breadth risks potentially amplifying trade-specific problems that may not be common in other lines of work~~, further skewing the dataset.~~.

A notable obstacle that arose when facilitating the interviews was the differing levels of engagement that respondents exhibited, with some demonstrating a willingness to elaborate and others requiring additional probing. ~~This fundamental difference~~The cause for this lies within the range of communication styles that were evident within the interviewees, such as the usage of hand gestures and varying personality types (e.g., introverted vs extroverted). Thus, the answers ranged from concise and purposeful to those who openly digressed into other topics. The effect of these inconsistencies led to lost ~~moments~~ points of conversation that could have elevated the richness of their replies. If repeated, the uneven depth of responses could be mitigated if questions were supplied beforehand, thereby encouraging deeper thought and preventing valuable insight from emerging after the discussion has concluded.

4.3~~2~~ RESEARCH GAPS AND IMPLICATIONS FOR THE BUSINESS PLAN

With additional time and resources, exact figures delineating the true costs—financial and temporal—of tool loss for construction businesses could be incorporated~~ into future research~~. By segmenting this data by company size, explicit comparisons can be made to truly measure the extent of tool loss for SMEs, empirically validating the testimonials from the interviews. Furthermore, to reality test other ~~statements~~ claims and predictions made in this paper~~in secondary research~~, such as the perceived ease of deployment and hypothesised reductions in lost equipment, future studies should ~~prototyping~~ prototype a BLE-based solution with~~ in~~ real~~ life scenarios, by partnering with~~ construction SMEs over a prolonged period~~, would~~ to confirm findings and outline vital metrics, such as the frequency and type of tools that get lost. Furthermore, to recognise whether the identified pain points are region-specific or universal, it would have been advantageous to collect data outside of Brisbane, as varying construction legislation could have raised further pain points that would equally require recognition. Overall, with these amendments, not only will the results' validity be strengthened, but accurate and efficient product design could be achieved through the Minimal Viable Product (MVP) concept. This methodology focuses on delivering an early version of a product and developing it iteratively through consumer feedback; in this instance, it would be delivering core features for early adopters, construction SMEs.

It is highlighted in this paper that there are three attributes that construction SMEs place weightage on: seamlessness in its initial deployment, return on investment ratio, and friction in long-term usage. In more specificity, investment-heavy models that include specialised hardware and infrastructure create a high barrier for usage and thus deter SMEs from many high-end solutions currently on the market. Therefore, for this paper's proposed solution, a leaner business model would be implemented ~~through the~~by leveraging ~~of~~ a widely available ~~devices (e.g., smartphones and BLE-enabled devices~~network of BLE-enabled devices), which will form the backbone of the technology and ~~ultimately~~ likely trim costs.

Moreover, to combat the unmet need of a competent and affordable solution, a subscription-based model or ~~alternate~~ price tiers can be offered to accommodate SMEs' ~~constrained~~ budgets and logistical requirements. From a marketing standpoint, it is imperative to also address the tangible time savings when adopting a tool tracking solution, in conjunction with the ROI benefits. These efficiencies are achieved with the technology's automated architecture, eliminating manual logging processes that are present within other forms of documentation, such as barcode scanning and spreadsheet entry. Without restricting this technology's application to specific equipment or tool size/type, this system's modularity empowers SMEs to adapt features to however it suits them, thereby circumventing the rigidity and ecosystem lock-ins that are ~~prevalent~~ present in current solutions such as Milwaukee One-Key.

4.4 TRIANGULATION OF FINDINGS

Overall, a high level of consistency was achieved when comparing the quantitative and qualitative data. The strongest point of convergence between the findings was the validation of BLE's affordability, with the quantitative results highlighting its low upfront and long-term maintenance costs. This corroborates the insights presented in the qualitative data, where the costs of systems such as GPS and active RFID are the primary reasons for their low adoption in the SME submarket, indicating that a prerequisite for this market segment is price efficiency. Whilst the literature reviewed demonstrated other technologies' dominance in tracking precision over BLE in given circumstances, this diverges from the opinions of SME subcontractors, who elaborated on the low level of exactitude that is realistically required, meaning that the trade-off of price to tracking precision is acceptable when considering the long-term application of this technology.

CONCLUSION

Reflecting on the primary data, in the form of video interviews with tradespeople within the industry, and the secondary data, through a comprehensive literature review, this business proposal has been refined towards the development of BLE-based architecture for small-scale construction operations. Central features include smart alerts when items exit pre-defined geofences, automated audit logging, and real-time tracking.

This study significantly contributes to broader literature by accentuating the capabilities of BLE technology by focusing on its potential application in the Australian construction setting, a possibility not sufficiently explored in the market or in prior studies. A critical point of difference between this study and others is the emphasis on the lived experiences and insights of Australian independent contractors, detailing what constitutes an 'acceptable' level of tracking accuracy, which contrasts with the industry's natural focus on ultra-precise technologies, which are impractical and an infeasible reality for most SMEs. Furthermore, this study confirms the technical capabilities of competing technologies—such as the low power consumption of BLE and the pinpoint accuracy of RFID—and compares their nuanced differences; however, it extends further to provide a hypothesised model tailored for the constraints of construction SMEs, a market segment that doesn't prioritise technical superiority, but rather the balance between functionality and affordability.

The competitive differentiator when ~~compared~~ comparing the proposed solution to existing market solutions is the leveraging of smartphones and other universal devices as receivers for data transfer, diminishing infrastructure costs, whilst elevating convenience and simplicity. Beyond the construction ~~sector~~industry, the significance of safeguarding high-value equipment and assets persists, such as in healthcare and logistics disciplines, forming endless opportunities for BLE systems to be utilised ~~in endless contexts~~. This unique value proposition will fulfil the standing unmet needs of SMEs and ultimately address the disparity between larger and smaller enterprises regarding efficiency and security, not just in construction.

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Response to Referee One's Comments

Referee Comment 1:

"The study is based on a small sample from Brisbane, Australia, so its findings may not apply to other regions or contexts."

My Response:

Thank you for your comment. I have implemented your suggestion of adding a 'Limitations' section (integrated with the bias assessment) by splitting the subsections (4.1 and 4.2) in the Discussion part of the paper. I have also inserted your observation above by explicitly stating that the 'results may not be representative of other regions and contexts.'

Referee Comment 2:

"The writing could be simpler and easier to read."

My Response:

I am grateful that you have brought this up, as upon reading my paper again, I have realised that at times, I have been superfluous with my language. To rectify this, I have gone through the paper again to make my language more succinct and smoother to read.

Referee Comment 3:

"All participants were tradespeople; no managers, owners, or decision-makers were included."

My Response:

Thank you for this suggestion. Under the new 'limitations' section, I have clarified my wording to the following:

"Moreover, crucial feedback from other members of the construction process, such as SME owners, site supervisors, managers, and board members, was absent and would have further contextualised the status quo and what influences shape purchasing decisions. For a more complete insight, future studies with managers and business owners should be conducted to complement the feedback given by the tradespeople.

The underrepresentation of authoritative roles and key decision makers, and the overemphasis on tradespeople, skewed the data that was collected, as concerns such as long-term maintenance and return on investment (ROI) calculations were not adequately represented."

Referee Comment 4:

"The paper states that BLE can reduce tool loss and improve productivity but does not provide data, costs, or test results."

My Response:

Thank you, and I agree with your sentiment. Regarding your suggestion of clarifying that these claims are predictions, I have changed my terminology to use 'potentially', 'may', and 'could' whenever describing BLE's capabilities in tool tracking. In addition to that, I have stated the following in the discussion section:

"Furthermore, to reality test other claims and predictions made in this paper, such as the perceived ease of deployment and hypothesised reductions in lost equipment, future studies should prototype a BLE-based solution with real construction SMEs over a prolonged period to confirm findings and outline vital metrics, such as the frequency and type of tools that get lost."

Response to Referee Two's Comments

Referee Comment 1:

"Figures 1, 4, 5 and 6 are actually tables and so should be included as Tables."

My Response:

Thank you for your comment. I understand the confusion that has come with the visual elements in my paper. I have accepted your recommendation of renaming the tables as 'Table __' instead of 'Figure __'.

Referee Comment 2:

"Figures 2 and 3 should be combined and instead be A and B panels for the same figure. This will reduce the repetitiveness of the legends between the figures."

My Response:

I agree and have rectified the structure as suggested.

Referee Comment 3:

"It is unclear what part of Methods would result in "3.4 QUALITATIVE DATA – CASE STUDY". It was not mentioned in the Methods that a case study would be conducted."

My Response:

Thank you for your comment. I understand the importance of being clear and detailed in the Methodology section by linking it to the Results section in a structured manner. However, I am unsure specifically where the inconsistency lies, as I have already stated the below in the Methodology section:

*"*Qualitative data, such as a case study of Milwaukee One-Key, a leading competitor in offering solutions for tool and asset tracking, was collected to outline the limitations of current technologies*."*

Please inform me if the comment that you have made has been misinterpreted.

Referee Comment 4:

“More discussion of the similarities and differences between what was found from the different data collection methods (qualitative and quantitative) is warranted to demonstrate whether results are consistent across both methods. Triangulating data from different sources is a strength of studies, even if they find differing perspectives, this is still an interesting finding and should be discussed.”

My Response:

Understood. I have created a section in the discussion section that discusses the similarities and differences in the findings.

“Overall, a high level of consistency was achieved when comparing the quantitative and qualitative data. The strongest point of convergence between the findings was the validation of BLE’s affordability, with the quantitative results highlighting its low upfront and long-term maintenance costs. This corroborates the insights presented in the qualitative data, where the costs of systems such as GPS and active RFID are the primary reasons for their low adoption in the SME submarket, indicating that a prerequisite for this market segment is price efficiency. Whilst the literature reviewed demonstrated other technologies’ dominance in tracking precision over BLE in given circumstances, this diverges from the opinions of SME subcontractors, who elaborated on the low level of exactitude that is realistically required, meaning that the trade-off of price to tracking precision is acceptable when considering the long-term application of this technology.”

Referee Comment 5:

“It is unclear what these references pertain to: “National Equipment Register n.d.”, “AssetRun, n.d.”, “Comparesoft, n.d.”. What is the n d?”

My Response:

As I was a part of the IRIS Indigo Summer Intensive Program, I was advised by my mentor, Mona Rahmani, that due to the lack of scholarly material in regard to my topic in particular, I would have to utilise white papers and other reliable and correctly cited sources, and if no date was mentioned, I would have to write 'n.d.' to indicate the lack of a published/modified date. This is also standard for APA formatting.

Referee Comment 6:

“I am unsure whether this statement is substantiated: “The effect of this age distribution is an evident resistance to deviating from established and dated workflows”. Is there evidence that age is related to dated workflows? If so, that needs to be referenced.”

My Response:

I agree with your sentiment, and it overlaps with another comment I received from the other Referee. I have concluded that I am rephrasing an earlier statement (see the following).

“A potential root for this stagnancy lies within the traditional mental framework and outdated workflows that construction workers operate under, highlighted when examining the demographic profile of construction workers across major construction hubs and the average ages, indicating high levels of experience.”

As this particular extract is not definitive in its tone and utilises ‘potential, I believe it would be beneficial to keep this and delete the sentence(s) that you have mentioned in your comment. As there is no clear information available that correlates age and dated workflows in the construction industry, I have altered my wording to ‘likely’ and similar terminology to avoid making unjustified claims.

Referee Comment 7:

“Six interviews were conducted with the age range being 23-52 years, aiming to discern whether differing levels of experience impacted perceived problem severity.” This should say “with the age range *of interviewees* being 23-52 years”. Also, does age necessarily correspond to level of experience? Did authors measure level of experience? If not, literature to state the relationship between age and experience in this industry should be included.

My Response:

I apologise for not clarifying earlier, but before the interview began, I asked all participants when they began working within the industry in an effort to try to understand the background of the interviewee before the questions began. Below, I have pasted what I have written in the paper:

“When asked, all interviewees stated they began their career in their late teens or early twenties, a common trend in the Australian labour and trades market.”

As the starting age of all participants is fairly similar, the age range is quite beneficial, as some are interns, whilst others have around 30 years of experience.

Referee Comment 8:

"The Methods describing the interviews should include details such as whether an interview guide was used (it was, and Fig 5 should be mentioned here)? Were interviews recorded on Teams? What happened to the transcripts? Were they deidentified? How was consent recorded?"

My Response:

Thank you for your feedback. I have adjusted the methods section to indicate that a 'common interview guide' was utilised. Yes, the meetings were recorded on Teams and helped determine the sentiment rating as close attention was required not only on their responses, but **how** they delivered their response (body language, non-verbal cues, etc). Names were not recorded for anonymity reasons, and prior to the first question being asked, participants were informed of the purpose of this interview so that consent could be requested, which was granted by every participant.

Referee Comment 9:

"Authors do not mention how they calculated sentiment and rating scores and using visual scales in the Methods. This needs to be described."

My Response:

Thank you for making me aware of this. I have corrected this by prefacing the table with the following:

"Sentiment ratings and the corresponding visual scale were derived through an intuitive and subjective analysis of the tone and language used collectively by the interviewees. The rating system spans from 1, indicating minimal alignment/overlap between the sentiment statement and the interviewee's response, to 5, which represents the highest degree of alignment."

Referee Comment 10:

"The sentiment statements are quite vague and do not describe what was said. More descriptive terms should be used."

My Response:

Thank you for bringing this up. I completely understand why the sentiment statements could be seen as vague, and I have gone through and edited each one, adding more descriptive terms and bolding key words to hopefully make it clearer to the reader. Please let me know if this requires further amendment.

Referee Comment 11:

"The majority of the references used are websites with very minimal journal papers. This does limit the validity of the review of current literature in this field. Authors should use more papers in the study."

My Response:

I agree strongly with your statement. However, as I mentioned above in your comment regarding my use of 'n d', regarding my topic, a large portion of the available scholarly material is behind paywalls/institution access or is not relevant to the link I am attempting to establish between the construction industry's demand for efficient asset tracking and BLE's capacity to do so. I have discussed this point with my mentor previously, and she assured me that, as I am proposing a BLE-focused model, utilising public information of competitors or existing solutions is acceptable.

Referee Comment 12:

"In the Conclusion, more use of literature to describe how this study adds to what is known in this area would strengthen the paper. Emphasis should be on similarities or differences between this study's findings and what is already known."

My Response:

Thank you for your insight. I have added a paragraph to the Conclusion section of my paper, which is also pasted below.

"This study significantly contributes to broader literature by accentuating the capabilities of BLE technology by focusing on its potential application in the Australian construction setting, a possibility not sufficiently explored in the market or in prior studies. A critical point of difference between this study and others is the emphasis on the lived experiences and insights of Australian independent contractors, detailing what constitutes an 'acceptable' level of tracking accuracy, which contrasts with the industry's natural focus on ultra-precise technologies, which are impractical and an infeasible reality for most SMEs. Furthermore, this study confirms the technical capabilities of competing technologies—such as the low power consumption of BLE and the pinpoint accuracy of RFID—and compares their nuanced differences; however, it extends further to provide a hypothesised model

tailored for the constraints of construction SMEs, a market segment that doesn't prioritise technical superiority, but rather the balance between functionality and affordability."

Addressing Tool Loss for Construction SMEs: Investigating the Implementation of Bluetooth Low Energy (BLE) for Tool Tracking in the Australian Construction Industry

I have taken the time to carefully review the changes made to Submission 100066. Based on the significant effort the author has put into addressing the concerns raised during the review process, I am happy to provide a positive decision to accept this paper for publication. The student was very responsive and has materially improved the quality of the work.

Post-Revision Feedback and Comments:

The important improvement in this draft is the author's willingness to transparently address the study's limitations. The creation of the distinct "Limitations and Bias Assessment" section directly resolves earlier concerns regarding the generalizability of the findings.

I was also pleased to see the new "Triangulation of Findings" section. The author successfully connected the dots between the quantitative market data (showing BLE is affordable) and the qualitative interviews (showing that workers don't need perfect tracking accuracy). This synthesis answers the previous critique about whether the different data methods were telling a consistent story.

On the presentation side, the paper looks much more professional. The author followed the advice to convert the previous "figures" into proper Tables (Table 1, Table 2, etc.). Also, combining the separate RFID diagrams into a single Figure with Panels A and B was a smart move that reduces clutter.

Finally, regarding the citations: I accept the author's explanation for using "n.d." (no date) since they are relying on industry white papers where dates are often missing. However, I would advise them that even in niche fields like Construction Tech, it is better to look for "accessed on" dates to strengthen validity.

I also noted that they wisely softened the language regarding age and technology; describing it as a "potential root" of the problem is much safer and more accurate than stating it as a definite fact.

In conclusion, the author has met the revision requirements satisfactorily.

Best regards,

Abdullah

Addressing Tool Loss for Construction SMEs: Investigating the Implementation of Bluetooth Low Energy (BLE) for Tool Tracking in the Australian Construction Industry

Authors have done a good job in addressing the majority of comments raised by reviewers. Additional/persisting suggestions I have include:

Introduction

- The title for Table 1 does not need to include the word "Table" i.e. it should read "Table 1: Types of businesses that are classified as SMEs in Australia". Please check all table titles and figure legends regarding this.
- The section "1.4 Competitor Technology Analysis and Comparison with BLE" should actually start with defining BLE, as the purpose of this section is to compare other technologies to it. How it presently reads means BLEs only come up much later so does not flow that well. This section may also benefit from the use of headings for each competing technology eg headings named "Barcode scanning", "RFID" etc.
- Figure 2 needs the panels A and B labelled.
- "A competing technology experimented with in the construction" should read "within".
- As the comparator is BLE, for Table 2, BLE should be the first row.
- "A summary of the competing technologies' application uses, advantages, and disadvantages is displayed in Figure 4." Figure 4 should be "Table 2". Please check all in-text references to tables/figures to ensure they have been updated correctly. I have identified several additional instances where inconsistencies are present e.g. Fig 7, Fig 8.

Methods

- "Judgmental sampling" should be defined. Including a reference to the methodology would be great.
- All of the following should go in the Discussion, or perhaps even at a stretch Results. It does not belong in Methods: "One of the major challenges when researching BLE was the scarcity of scholarly research detailing BLE's specific usages within small-scale construction contexts. Repeatedly, most resources would explore its benefits in healthcare and logistics, leaving its value for construction SMEs to be underexplored, ergo increasing reliance on vendor case studies, which lack objectivity. Another barrier when evaluating current technologies was the fluctuation in price and performance. This is because most companies offer modular solutions that differ in value proposition, depending on the use case, and hence make it difficult to form standardised comparisons."

Results

- 2.1 methodology requires more information regarding who conducted the interviews (their experience in qualitative research), whether audio and/or video was recorded by Teams, were the interviews transcribed? Importantly, how were interviews analysed? Thematically? By how many people?
- As this is a qualitative study, authors should be including a response to the "Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups".

- The following belongs in Methods: “Sentiment ratings and the corresponding visual scale were derived through an intuitive and subjective analysis of the tone and language used collectively by the interviewees. The rating system spans from 1, indicating minimal alignment/overlap between the sentiment statement and the interviewee’s response, to 5, which represents the highest degree of alignment.”
- Further, more information about what a sentiment statement is, including a reference to a paper that shows how it was calculated – and by whom i.e.. Was the Teams recording reviewed, and reviewed by how many people? Currently it does not seem to have been conducted rigorously in a way in which another independent reviewer would analyse and get the same sentiment rating. However, this could just be because of the way it has been written.
- Authors did not provide any representative quotes from interview participants. Was there a reason for this? Most qualitative papers do this to show that their findings were derived from the participant responses.

Overall

- The abbreviation of SMEs can be used after the first time it is defined, for consistency.
- I am still unsure about the use of “n.d” for references, as not all of these n.d. references appear in the References list, so there is no way to identify where the information came from for those note included in the References. I would suggest authors either remove these n.d references or add them all to the References list, to show where this information is coming from. On that note, “Bibliography” should be “References”.