HEXAGON

Research by:

FMI

Autonomous Construction Tech Outlook

Achieving better project outcomes through autonomy

Autonomous technology is now used by 84% of commercial construction firms — discover how you can take advantage.

Leadership perspective

The technology that will define the next era of construction

Construction is on the precipice of its next great era of innovation, fueled by the demands of a rapidly growing population and the need to care for our planet. Add to this the troubling market conditions caused by widespread inflation, supply chain disruptions and a tense and unstable geopolitical climate, and construction leaders are increasingly challenged to meet owners' expectations to deliver on time and on budget.

With so much at stake, leaders within the construction space are turning to autonomous solutions to assess risks and improve the effectiveness of operations — keys to overcoming business challenges in the areas of productivity, sustainability and profitability.

Every day, millions of assets are produced on each jobsite. Often, these assets are disconnected, inaccurate or incomplete. The vast volume of data created far exceeds people's ability to collect it and make sense of it. The pace of change on a job means the data we do have is often outdated by the time we need it. The limits of time, space and our own cognitive ability are where we fall short. Luckily for us, autonomy can transcend these barriers that have held us back.

Autonomy is not about taking jobs. It's about making the data we have, and are yet to generate, the greatest tools in our toolbox. The insights unlocked from autonomy will make our jobsites safer, more efficient and less wasteful than ever before, making it possible to build a world where both people and industry sustainably thrive.

Just like the reverberating effects from the industry's transition from manual to power tools, or paper to digitisation, the widespread adoption of autonomous technology is a transformation that will define the next era of construction.

But change is not easy. To get our finger on the pulse of the industry, we surveyed over 1,000 technology leaders from general contracting firms of all sizes to learn where the industry is in its adoption, perception of and benefits realised from autonomous and automated technology. And although we found that the industry is becoming more comfortable with autonomy — and the majority of firms have adopted autonomous technology at some level — the construction industry needs to champion and accelerate wide-spread adoption and optimisation throughout our businesses for lasting and scalable impact.

Hexagon is proud to be a champion of autonomy in construction as a driver for a more sustainable and profitable future. And we're even prouder to partner with so many construction firms that are embracing autonomy to build a higher quality of life for their communities.

To the continued innovation of our industry,

Thomas Harring
President
Hexagon's Geosystems division

The insights unlocked from autonomy will make our jobsites safer, more efficient, and less wasteful than ever before, making it possible to build a world where both people and industry sustainably thrive.

Thomas Harring

contents

About

Hexagon

Hexagon is a global leader in digital reality solutions, combining sensor, software and autonomous technologies. We are putting data to work to boost efficiency, productivity, quality and safety across industrial, manufacturing, infrastructure, public sector and mobility applications.

Our technologies are shaping production and people related ecosystems to become increasingly connected and autonomous – ensuring a scalable, sustainable future.

Hexagon's Geosystems division provides a comprehensive portfolio of digital solutions that capture, measure and visualise the physical world and enable data-driven transformation across industry ecosystems.

Learn more about Hexagon (Nasdaq Stockholm: HEXA B) at hexagon.com and follow us @HexagonAB.

FMI

FMI is a leading provider of consulting and investment banking services to the built environment, offering deep industry research, rich market insights and tangible solutions that drive real results for our clients. We provide strategy, leadership and organisational development, operations improvements, mergers and acquisitions and financial advisory services to our clients. For more information, please visit fmicorp.com.

Please get in touch with Hexagon's construction technology experts to learn more.

Executive summary

A data leverage gap is emerging between the vast amount of data generated throughout the lifespan of a building project and the data actually used to generate valuable insights that improve project performance. One promising solution to close this gap is to leverage autonomous technology to capture, organise and analyse project data more effectively.

Together with FMI, we surveyed 1,004 technology leaders from commercial GC firms in the US, UK and Australia to better understand where autonomous technology is used in construction and its role in solving the construction industry's most pressing problems.

84% **of firms are using autonomous technology in their operations**

Project management workflows are the most automated area. Robotics are the least.

32.1%
use autonomous project management tools (billing, scheduling, etc)

16.5%
use fully autonomous robotics

Nearly 40% of tech leaders mainly associate autonomy with equipment. Only 10% consider AI, indicating there is a disconnect between how people think of autonomy and how they are actually using it.

38.9%
equipment

10.2%
AI

Firms that have integrated 4 or more autonomous workflows throughout their business report greater improvements than those using fewer, including:

58% enhanced sustainability and waste reduction

55% better cross-functional collaboration

52% increased safety compliance

60% **of leaders in construction believe autonomy will have a significant impact in the following areas:**

Market competitiveness

Profitability

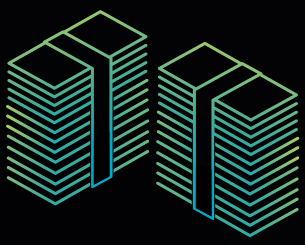
Owner satisfaction

Sustainability

In the next 3 years, the construction industry is planning to make significant investments in autonomous technology.

$7.1 million

Amount the average firm plans to invest



$162 billion

Amount the industry as a whole will invest

Demographics

We surveyed over 1,000 technology decision-makers from commercial General Contracting (GC) firms in North America, Europe and Australia to understand how, where and why they use autonomous technology in their operations.

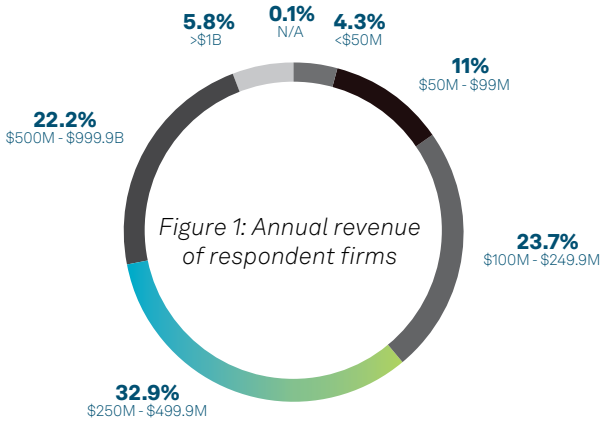


Figure 1: Annual revenue of respondent firms

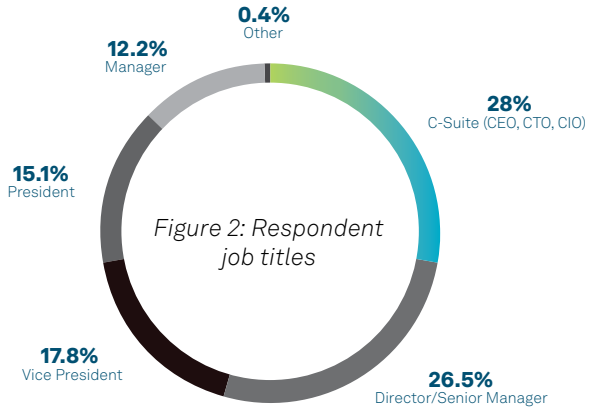


Figure 2: Respondent job titles

All respondents are leaders within their companies responsible for making decisions about technology.

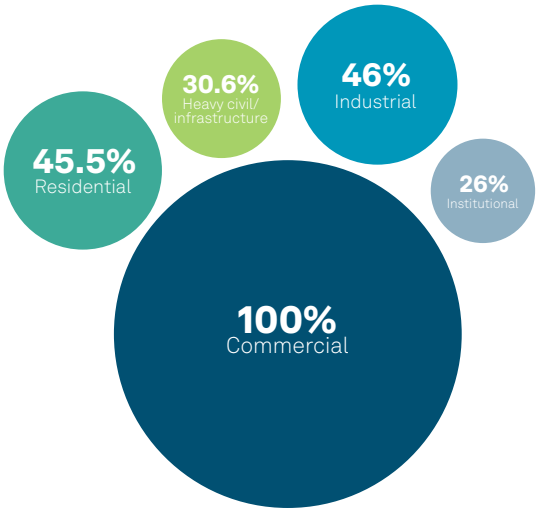


Figure 3: Types of construction performed

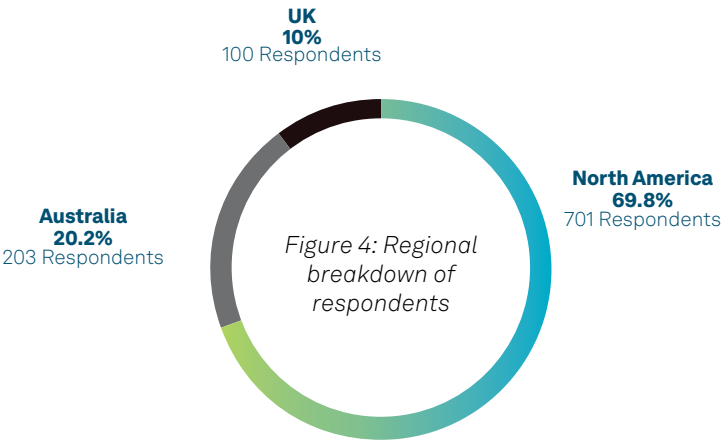


Figure 4: Regional breakdown of respondents

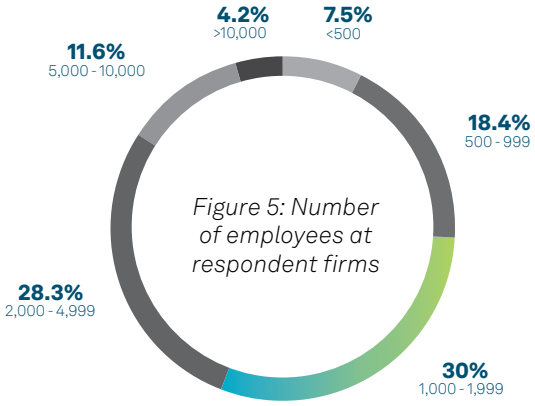


Figure 5: Number of employees at respondent firms

Data-driven decisions: How autonomous construction technology is closing the data leverage gap

On average, 197 million assets are produced over the course of a construction project[1]. These assets, including images, videos, change orders, punch lists, building information model (BIM) files, emails and memos, produce many terabytes of data that, if properly collected, stored, organised and analysed, can reveal powerful insights about a project throughout its entire lifecycle, from design conception to commissioning and handover.

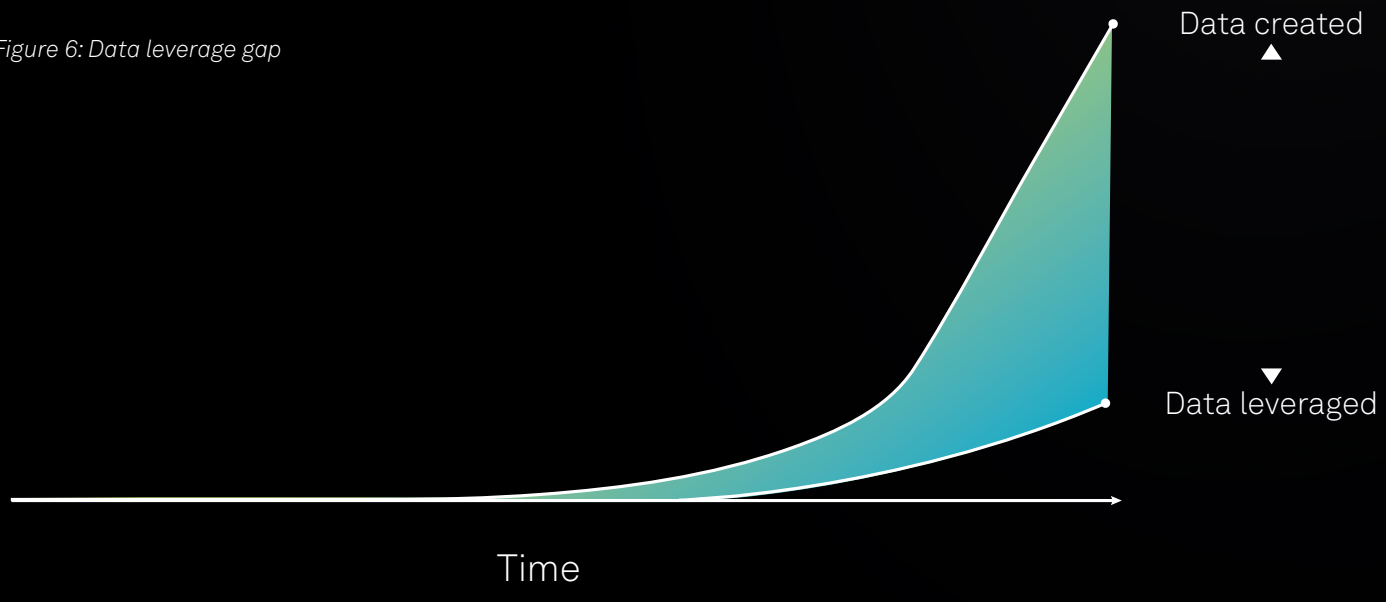
However, it's impossible for humans alone to process the vast mountains of data generated on a construction project in a comprehensive and useful way. The result is underleveraged data that sits unused — or is lost completely — in disconnected, siloed systems. This is what we call the data leverage gap — the ever-widening chasm that exists between the data created during the lifecycle of a building project and the data actually used to produce meaningful insights that drive outcomes *(Figure 6).*

Autonomising the production, collection, analysis and distribution of this data is the answer to solving the data leverage gap. Simply put, autonomy is an advanced form of automation. The more intelligent the automation, the more human intervention can be reduced and the more autonomous something becomes *(Figure 7).* Within these autonomous technologies are varying levels of autonomy, ranging from human-assisted (i.e., certain functions can be automated to simplify control) to full autonomy (all expected tasks can be completed without human intervention).

Take, for example, the process of jobsite productivity monitoring. Reality capture technology, like cameras, sensors and scanners, are used to collect real-time information about the surrounding environment. With traditional monitoring methods, workers have to physically walk the site to capture footage and then manually upload the footage to a computer for analysis. New advances in autonomous reality capture have led to the invention of robotic scanners that can roam the site without requiring human operation, using artificial intelligence (AI) functionality to learn the environment so they can dynamically navigate obstacles and capture the world around them. The robotic scanners can then automatically upload images, video and other assets to progress-monitoring software to detect deviations, issues or conditions the system has been programmed to identify.

Learn more about how autonomous progress monitoring benefitted a large-scale construction project in "Improving construction progress tracking through autonomy".

Figure 6: Data leverage gap



But how does this close the data leverage gap? In addition to improvements in data quality, autonomous systems organise the real-time, highly accurate data they capture in a common data environment that becomes a single source of truth for all stakeholders. AI can then analyse and interpret the data to help systems and stakeholders extract meaningful insights that turn into action — for example, identifying a leak in a utility room that could cause significant damage if not quickly fixed.

Reality capture is only one example of the areas of construction that have significantly benefitted from autonomy. In this autonomous construction tech outlook, you'll discover how autonomous technologies are used across construction operations to overcome challenges and meet business goals, and where the industry is in its autonomous journey.

Simply put, autonomy is an advanced form of automation. The more intelligent the automation, the more human intervention can be reduced and the more autonomous something becomes.

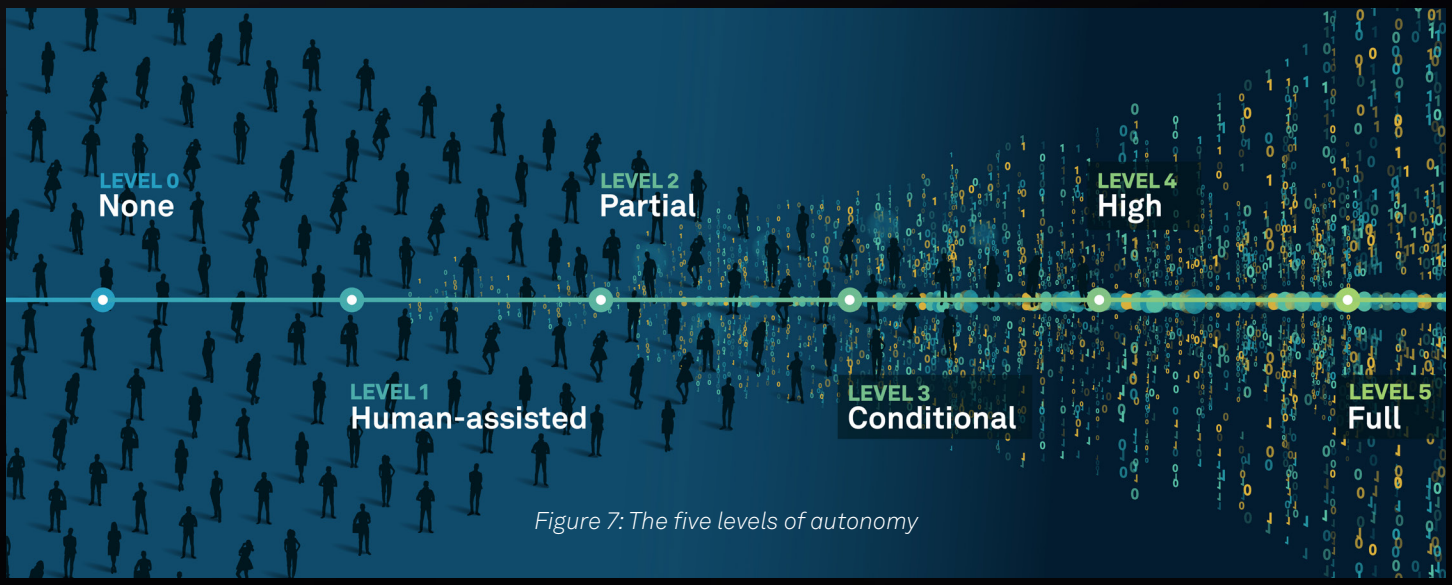


Figure 7: The five levels of autonomy

Level 0 – **None:** A human operator performs all tasks
Level 1 – **Human-assisted:** A human operator is in charge of performing tasks, but certain functions are automated to simplify control
Level 2 – **Partial:** Some tasks are automated so operation can be autonomous for short periods or within specific circumstances
Level 3 – **Conditional:** Autonomous operation is possible within certain bounds, but human intervention may be necessary at short notice
Level 4 – **High:** Tasks are designed to be completed autonomously but may require human intervention if circumstances change beyond specific bounds
Level 5 – **Full:** All expected tasks can be completed without human intervention

CASE STUDY

Improving construction progress tracking through autonomy

With over 600 million square feet built in the U.S., AECOM Tishman — a subsidiary of AECOM — has a strong track record in managing large and complex projects.

For AECOM Tishman, managing a large-scale project involves tackling three main challenges: monitoring progress, identifying deviations and handling ongoing design changes during construction. Clashes on the construction site can lead to costly rework, so their goal is to proactively address issues before they occur by first capturing discrepancies between field installations and BIM.

“Managing reality capture data sets can be daunting, and we needed a solution to do the heavy lifting of processing and visualising data in objective ways”, said Christian Peña, Project Manager – Virtual Design and Construction (VDC).

Implementing autonomous solutions for deviation analysis and tracking

AECOM Tishman’s team implemented Avvir Inspect® deviation analysis and Avvir Progress® tracking as well as several custom reports uniquely tailored to their needs. Reality capture was conducted weekly through photo capture and terrestrial scans.

The elements of the pilot solution were threefold:

1. Chart progress by comparing 360º photos to the BIM weekly and manipulating the data to produce a spectrum of custom reports.
2. Automate comparison between the BIM and laser scans of existing conditions to identify discrepancies between design intent and reality.
3. Identify discrepancies between the BIM location and as-built reality, and automatically push updates to the model based on existing conditions.

The outcome was a blend of meaningful data autonomously curated in a way that was easy to communicate, including:

- Weekly progress dashboards: Portal data visualised in graphs in Power BI
- Labour productivity projection analysis: Forecasting progress per trade labour data
- Impact analysis: Future-looking critical clash detection
- Room-specific progress: Tracking on related BIM elements

Benefits

Through autonomous technology, the AECOM team effectively identified 112 critical forward-looking clashes within a two-month period, and weekly progress reporting led to an improved ability to flag issues and adjust work in the field.

Automating their progress tracking also led to the following benefits:

- The ability to track progress and performance data at the project and trade level
- Improved communication of large datasets through visual representation
- Enhanced collaboration and decision-making through the creation of a digital twin

Through autonomous technology, the AECOM team effectively identified 112 critical forward-looking clashes within a two-month period, and weekly progress reporting led to an improved ability to flag issues and adjust work in the field.

State of adoption of autonomous technology in construction

Autonomous technology has moved out of the emerging technology space in commercial construction into widespread adoption; in fact, 84% of firms are using autonomy in some part of their operations *(Figure 8).*

Figure 8: Do you have autonomy in any tasks, processes, equipment or systems?

To understand where the industry is in its adoption of autonomy, we classified firms into three categories: progressive, moderate and laggard *(Figure 9).*

The majority of construction firms (63%) are moderates, meaning they have begun to adopt autonomy in specific areas of their business but are still largely using autonomous technologies to supplement human activity (instead of using fully autonomous robotics).

Only 16.5% of construction firms have yet to adopt any type of autonomy at all, indicating that laggards risk getting left behind their competition.

- Laggard firms (16.5%) – Do not use any autonomous or automated systems
- Moderate firms (63%) – Use one to three autonomous or automated systems / More likely to use systems with limited or some autonomy
- Progressive firms (20.5%) – Use four or more autonomous or automated systems / More likely to use technologies with full autonomy

The most common types of autonomous technology used in construction

Among the autonomous technologies used by construction firms, almost 47% are partially or conditionally autonomous. An example of this level of autonomy is a quality assurance program that uses AI to analyse millions of construction images to identify potential problems and assign corrective work proactively. The program must be told what to look for and what is considered "correct" based on the model, and can then automate the analysis of the images to flag deviations. Although the software automates the tedious and time-consuming parts of the task, a human is still required to validate the findings and take action. *(See the AECOM case study on the previous page for an example of this workflow in practice).*

The remaining 23% and 30% of autonomous technologies in use today are split between limited autonomy and full autonomy, respectively. The types of autonomous technology used varies from workflow automation to fully autonomous robotics that can safely navigate remote or hazardous locations without endangering human operators.

Today, the most popular form of automation is in project management, including billing, change management, reporting, budgeting, logistics management and materials requisition and allocation *(Figure 10).*

Figure 9: Progressive, moderate and laggard firms

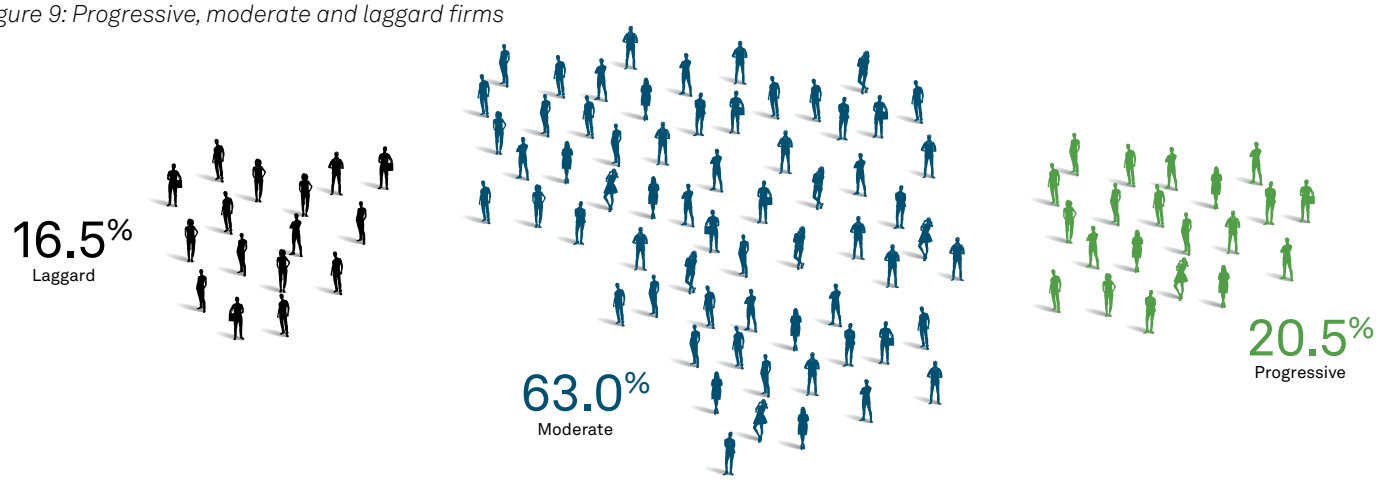


Figure 10: Which autonomous (or automated) technologies does your company currently utilise? Respondents were allowed multiple responses.

Project management tools:
Billing, change management, reporting, budgeting, logistics management, materials requisition and allocation, etc.

Workplace safety tools:
AI image analysis, compliance tracking, incident reporting, job hazard analysis, machine control, etc.

Quality checks:
Impact assessments, punch lists, etc.

Surveying tools:
Robotic total stations, ground-penetrating radar, preparing, compiling and analysing survey data, etc.

Verification tools:
As-built verification tools, project inspection, etc.

Document management tools:
Change orders, defect management, O&Ms, punch lists, RFIs, etc.

Construction vehicles:
Machine control systems, environmental awareness, safety awareness, etc.

Monitoring tools:
Productivity and progress monitoring, site surveillance and insights, etc.

Pre-construction tools:
Bid management, capital planning, estimating, schedule creation, etc.

Modelling and simulation tools:
4D/5D BIM modelling and simulations, BIM visualisation software, digital layout, clash detection, etc.

Measurement tools:
Laser measuring, laser scanning, mobile mapping, point cloud processing and modelling, etc.

Collaboration tools:
Office-to-field communication, report creation, report distribution, etc.

Data capture:
As-built capturing, reality capture, etc.

Fully autonomous robotics:
Robots that perform specific tasks, such as laying bricks, excavating, grading, etc.

Benefits of autonomous (or automated) technology

By putting the data generated in a construction project to work through autonomous systems and tools, construction leaders can drastically improve business outcomes.

Although it may seem obvious that implementing more autonomous processes in a construction project will lead to better outcomes, what's surprising is *how significant* the increase in benefits is *(Figure 11)*.

Progressive firms are 58% more likely to experience sustainability improvements and waste reduction, 55% more likely to experience better collaboration and 52% more likely to experience improved safety compliance than moderate firms.

Moreover, certain types of autonomous technology demonstrate strong correlations with specific benefits. For instance, 40% of companies using autonomous surveying tools reported an advantage in competing for new business, and 38% using fully autonomous robotics saw improvements in sustainability and waste reduction *(Figure 12)*.

Sensor-software systems

To maximise the benefits, sensors and software must be integrated together *(called "sensor-software systems")*. Sensor-software systems are the foundation of any autonomous workflow. Each technology serves a specific function, but when combined, they unlock the full potential of autonomy. Sensors "see", while software with AI "analyses and decides". Together, they direct the actions of autonomous workflows and robotics. Similar to the human body, each function is critical to the success of the whole.

Figure 11: Benefits gained from using autonomous (or automated) technologies

	Moderate	Progressive	% difference
Improved sustainability / less waste	24%	38%	58%
Improved safety compliance	23%	35%	52%
Better supply chain mapping	24%	34%	42%
Increased process efficiency	22%	33%	50%
Advantage when competing for new business	23%	32%	39%
Faster, more accurate communication between the office and the field	23%	32%	39%
Faster decision-making	24%	29%	21%
More accurate progress monitoring	22%	29%	32%
Easier cross-functional collaboration	20%	31%	55%
Greater resiliency	23%	24%	4%
Heightened transparency	20%	26%	30%
Fewer errors / greater visibility of potential errors	18%	26%	44%
Lower overhead costs	21%	21%	0%
Reduced organisational risk	19%	23%	21%
Less rework	17%	20%	18%

When applied to construction technology, the number of autonomous solutions employed is positively correlated to both the number of benefits and degree of benefit experienced *(Figure 13).* Take, for example, the process of improving transparency between the office and the field. First, jobsite cameras must be installed to capture real-time footage of the jobsite, and then these cameras must have the ability to autonomously upload footage to a software system that can understand what the data means through AI and machine learning.

Finally, that software will store, organise and analyse the data, distilling important insights and distributing those insights to key stakeholders. This example represents three distinct autonomous workflows that need to be integrated: capturing the footage *(sensors "seeing"),* analysing the data *(AI "analysing")* and distributing the insights *(autonomous workflow "doing").* Take any one of these out of the workflow and the effect would be diminished — less efficiency, less visibility and more prone to error.

However, it's important to note that fully autonomous systems are not the only way to realise benefits, and objectives like reducing overhead costs can be achieved with fewer integrations, particularly if the scope is limited to a single department or location. *See the case study, "Implementing autonomous processes in the payroll department to reduce overhead"* to learn how a mid-sized electrical contractor did just that.

The bottom line is breaking down barriers of data siloes is key to closing the data leverage gap — with autonomous technology acting as a catalyst to do so.

Figure 12: Autonomous technology used and benefits most frequently achieved

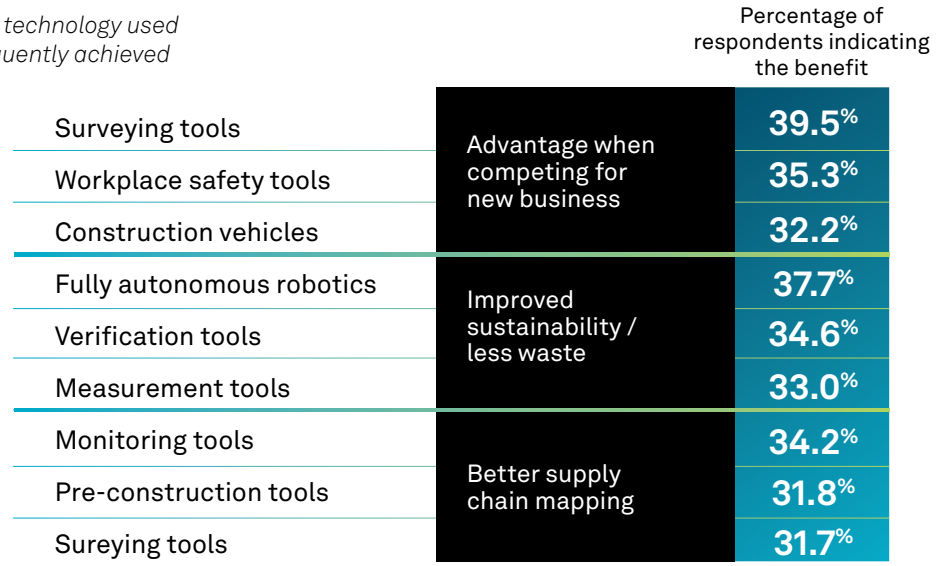
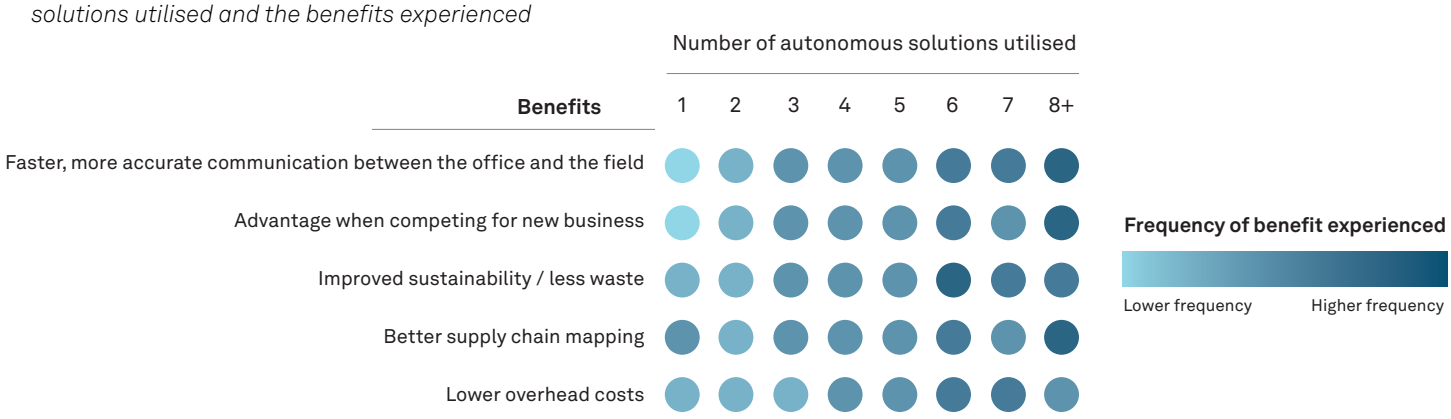


Figure 13: Correlation between the number of autonomous solutions utilised and the benefits experienced



CASE STUDY

Implementing autonomous processes in the payroll department to reduce overhead

A mid-sized electrical contracting firm was looking for ways to streamline its business processes — starting with payroll.

Background

The company's payroll process was causing a 10-day lag in project hours and cost visibility. Employee payments were often incorrect, and hours were charged to the wrong phase code or project, leading to a lack of confidence and trust in the data. Overall, the payroll process required three employees to interpret and manually enter timecard data into the enterprise resource planning system, resulting in 24 hours of entry time and up to 96 hours of rework per week. To maintain this time-intensive and error-prone process, the team would soon have to grow by 4x.

Additionally, there was no single standard for foremen to record and submit time, which meant tribal knowledge was necessary to complete the process. This signified a single-point failure risk. The process was neither scalable nor repeatable, representing a risk to the company's growth plans.

Process improvements

Through implementing digital, automated workflows and eliminating non-value-added steps, the firm was able to implement improved processes that were scalable, standardised and repeatable. Ultimately, this increased accountability for field personnel and resulted in a process that eliminated wasted time and extra steps.

Benefits

Through the implementation of an autonomous digital payroll process, the firm avoided spending $333k in additional accounting personnel as they grew from 250 to 800+ employees. They were also able to save $100k by reducing the number of payroll employees from three to one.

And, because payroll functions could be managed through mobile devices ($600) instead of laptops ($1600), the firm experienced $50k in savings across 50 devices.

Other benefits included:

- Increased trust and confidence in the data
- Having up-to-date information on labour costs throughout project phases
- Keeping detailed records of labour costs for jobs
- Ensuring payments arrive on time, in the right amount
- Enabling the organisation to drive business decisions with data

Through the implementation of an autonomous digital payroll process, this mid-sized electrical contracting firm avoided spending $333k in additional accounting personnel as they grew from 250 to 800+ employees.

Understanding how autonomous technologies can address challenges and priorities in commercial construction

Business challenges faced by construction firms

Autonomous technology is quickly advancing, offering new opportunities for increased efficiency and productivity. However, for technology investments to be successful, leaders must align them with specific business challenges and priorities. By taking a strategic approach to implementing autonomous technology in specific priority areas, firms can improve their bottom line and stay competitive in the rapidly changing landscape of commercial construction.

Technology decision-makers in commercial construction firms have identified procurement and supply chain issues as the top challenge they face, followed by communication and collaboration and inefficiencies and waste *(Figure 14).* Moderate and progressive firms cited investing in new technologies as the number one area of focus to address these challenges — even laggard firms are prioritising investments in technology and data capture and analysis even higher than more traditional solutions such as training programs and improving security *(Figure 15).*

Short-term priorities

Like all sectors, the next 18 months will require construction firms to prioritise operational issues that will help them become more resilient through the current economic situation, including better materials management across the supply chain and increasing efficiency and productivity *(Figure 16).* Efforts tied to business performance, like driving new business, addressing the ongoing labour shortage and improving collaboration and communication are also high priorities. In summary, firms are focused on getting through the short-term headwinds related to inflation and the supply chain shortages while still maintaining current projects and driving new opportunities.

Figure 14: What areas of your operations are most challenging?

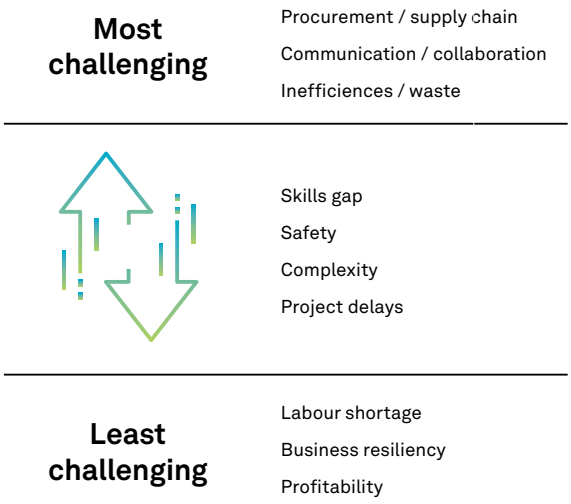
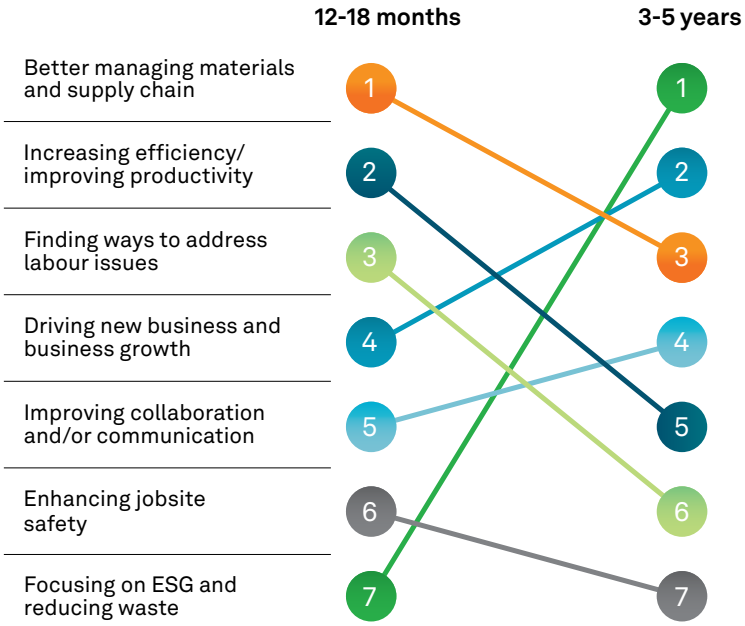


Figure 15: What solutions does your company currently have in place to address your business challenges?

	Laggard	Moderate	Progressive
We're investing in new technologies	34.3%	39.5%	47.6%
We're collecting more data / investing in better data analysis	35.5%	32.1%	42.2%
We're invested in new security software / systems	30.1%	36.0%	34.0%
We've created training programs / partnered to provide training to shore up the skills gap	32.5%	32.5%	41.3%
We've hired outside consultants	27.1%	32.9%	37.4%
We've added external security to our jobsites	36.8%	30.3%	35.9%
We've hired new team members with specific expertise to address key challenges	31.9%	29.5%	34.5%
We're providing incentives to help with recruitment	31.9%	30.2%	31.6%
We currently don't have any solutions in place to address these main business challenges	2.4	0.0%	0.0%

Figure 16: Comparison of short-term (12-18 months) and long-term (3-5 years) priorities



Remarkably, sustainability initiatives make major moves in the order of priorities between the short and long term – ascending from the lowest priority to the highest priority in just 3-5 years.

Autonomous construction technology can help firms address these short-term priorities.

For example:

- Autonomous materials management workflows can be used to better handle the supply chain by automating the ordering and tracking of materials, optimising delivery schedules, streamlining the process of receiving and verifying materials and enabling predictive maintenance to reduce downtime.
- Autonomous collaboration workflows can be used to improve communication among team members, allowing for real-time data-sharing and decision-making.
- Autonomous reality capture systems (robotic drones, scanners, UAVs) can be used for site surveying, mapping and monitoring, reducing the need for manual labour and increasing the speed and accuracy of data collection.

Long-term priorities

Priorities are more evenly distributed over a longer-term horizon of three to five years, with sustainability and waste reduction notably moving from the lowest priority in the short-term to the top priority in the long-term *(Figure 16)*. This is likely due to increasing market pressure for the construction industry to reduce its carbon footprint and introduce greener building and operating practices. *See "Building an industry that sustainably thrives".*

Autonomous technologies that can contribute to greener business practices and reducing waste include:

- Fully autonomous robotics that increase the efficiency and accuracy of builds
- Measurement tools that improve the accuracy of the construction process and optimise resource usage
- Verification tools that ensure all aspects of the project are in compliance with plans and aid in identifying and addressing issues quickly to avoid rework

Building an industry that sustainably thrives

Sustainability is a critical concern for the construction industry, which generates 37% of global human-caused carbon dioxide[2] and consumes 40% of raw materials[3]. With countries and organisations worldwide aiming for net-zero emissions, construction firms understand the significance of enhancing their commitment to eco-friendly practices and waste reduction. In fact, 34% of leaders surveyed for this report consider sustainability to be their top business priority within the next three to five years — even more than driving new business, better managing materials and supply chain and increasing collaboration.

The trifecta of delivering a job on time, within budget and to the required quality is now evolving to include a fourth realm: sustainability. In an industry known for single-digit margins, profitability is a constant concern, and for a long time sustainability was seen as the enemy of profitability. However, the paradox of sustainability and profitability is that by embracing greener practices, firms can reduce operating expenses by reducing material, labour and rental equipment costs. Additionally, building owners are demanding it — 42% of GCs reported client requirements as the top reason they are adopting more sustainable practices.[4]

Despite good intentions, firms may struggle to deliver on their sustainability promises when costs or schedule are at risk. The transition to sustainable building practices will only take root when the changes made also improve cost, quality and efficiency of a job.

The solution is to capture site data as early and as often as possible, and to continuously use and improve upon that data with real-time information from the jobsite.

By doing that, increasingly intelligent autonomous sensor-software solutions can make sense of the data in order to dynamically organise, analyse, interpret and distribute key operational insights using AI. These insights help firms identify where they experience waste in their processes and make corrections to drive more sustainable practices in the future.

By putting data to work more efficiently, firms can also achieve more precise estimates and takeoffs. This allows them to only order the materials they need, thereby minimising the amount of raw materials wasted. Additionally, by ensuring work is done the right way, in the right place, at the right time, firms can mitigate the need for rework, reducing the amount of raw materials used and lowering emissions caused in the process.

Overall, autonomy drives sustainability in the construction industry by providing the insights necessary to prevent, identify and correct wasteful practices. By using autonomous technologies, construction firms can improve their sustainability efforts while also increasing profitability — ultimately creating a win-win solution for both the industry and the environment.

Traditionally, schedule, quality and cost were the main performance indicators that owners cared about. Now, owners are increasingly demanding a fourth requirement: sustainability. By better leveraging jobsite data, construction firms will see improvements in all four areas.

Schedule

Quality

Cost

Sustainability

34% of leaders surveyed for this report consider sustainability to be their top business priority within the next three to five years.

Aligning autonomous technology investments with business priorities and outcomes

There is a disconnect between the areas of operations in which firms are utilising autonomous technologies and their most pressing priorities. To understand this more, we compared the top priorities *(Figure 16 on page 19)* and the tools that deliver benefits that are best aligned with these priorities *(Figure 13 on page 15)*. Then, we assessed how many respondents are investing in these tools to understand if their technology investments are aligned with their priorities.

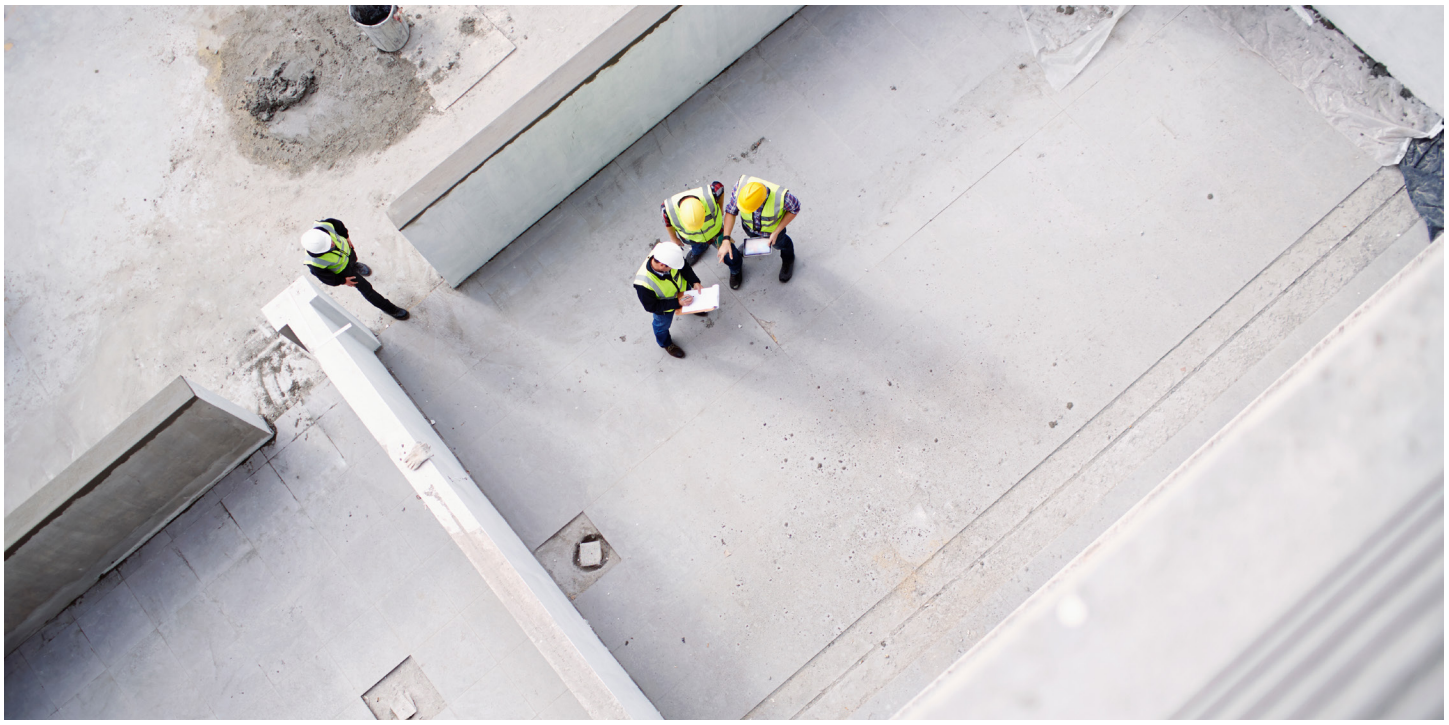
Through this analysis, we determined that autonomous monitoring tools, including site surveillance, are the most beneficial for supply chain mapping. Despite the fact that better managing supply chain is the most frequently reported short-term priority, only 28% of respondents have invested in autonomous monitoring technology. This disconnect occurs across all top priorities over the immediate 12-18 month horizon.

Additionally, 37% of respondents found fully autonomous robotics drove sustainability benefits, the leading priority over three to five years. However, only 17% of firms are investing in this type of technology.

There could be many explanations for why this disconnect exists, and there is no single answer for the whole industry. For one, AI and autonomy are still emerging in some areas of construction operations. 5D BIM, for example, is still working towards fully autonomous construction cost tracking and management.

Autonomising effective data aggregation and sharing among the trades, and between the trades and the GC on a project, is another area ripe for innovation. This is the ultimate use case for breaking data out of ineffective siloes and will drive enormous benefits and results across the project when it becomes a reality. While some parts of these processes are automated today, there is still much untapped potential that is yet to be unearthed.

However, the improvements in data capture and AI-driven analysis that exist today bear fruit for those who implement them and will position firms to take full advantage of the advancements in emerging technologies as they come.



Technology snapshot: Analysis of the most common benefits associated with specific types of autonomous technology

Based on an analysis of the key challenges and priorities faced by commercial construction firms, and the advantages offered by autonomous technology, the following technologies have shown to contribute to industry objectives.

Technology leaders who use modelling and simulation tools report increased efficiency

Research found that 35% of technology leaders who reported using autonomous modelling and simulation tools stated that they experienced an increase in process efficiency. These tools can replace tedious and difficult manual tasks and identify issues in the design that could cause delays and inefficiencies throughout the build phase.

Capabilities include:

- Automating 3D model creation to reduce time and resources required for manual modelling
- Automating construction schedules to identify potential bottlenecks and optimise the construction process
- Simulating different scenarios, like changes in design or weather conditions, to identify potential issues and mitigate risks

Overall, the use of autonomous construction modelling and simulation tools can improve planning, coordination and execution of construction projects for increased process efficiency through the design, planning and building phases.

Technology leaders who use fully autonomous robotics report improved sustainability and reduced waste

Almost 38% of construction firms using fully autonomous robotics report that the most common benefit is improved sustainability *(Figure 12)*. In the case of autonomous reality capture, robots can scan the construction site every day and upload data to identify any areas of concern, proactively address issues and reduce — or even eliminate — the potential for future rework. Assigning robots to tasks that are repetitive can also improve efficiency, helping your firm to complete projects faster, freeing up skilled labour for other value-additive tasks and reducing the need to have heavy equipment onsite longer.

See the case study, "Increasing efficiency and augmenting labour through autonomous reality capture" to learn how autonomous reality capture is helping a commercial construction firm eliminate waste and increase efficiency.

Technology leaders who implement autonomous surveying tools experience an advantage when competing for new business

Automated surveying tools, such as UAVs and terrestrial scanning, can give a competitive edge in acquiring new business through:

- More detailed and accurate estimates
- Faster data capture
- Improved volumetric calculations
- Reduced risk

Autonomous surveying can also aid in cost control and project visibility for the owner, which are favourable factors in bid proposals. Additionally, these tools can increase the reliability and precision of survey data — a crucial factor in important project decisions.

Technology leaders who utilise document management workflows infused with autonomy note improved safety compliance

While there are several autonomous technologies associated with improving safety compliance, 36% of technology leaders who are using autonomous document management systems reported an improvement in this area.

One way in which these tools can improve safety compliance is by automating the process of collecting, organising and analysing safety-related documents. For example, automated document management tools can scan and organise training records to ensure that all workers on a construction site have received the necessary safety training and certifications. The tool can also flag any workers who are overdue for training or have expired certifications, helping managers to stay on top of compliance and address any issues in a timely manner.

CASE STUDY

Streamlining project management with AI-enabled jobsite monitoring

Background

AutoZone is a leading retailer and distributor of automotive replacement parts and accessories with more than 7,000 stores across the U.S., South America, Puerto Rico and the Virgin Islands. As the company continues to build more stores, the ability to effectively manage construction projects is crucial.

Better project management through visual data

AutoZone decided to implement construction camera services from OxBlue to provide real-time project visibility. With more than 625 users and 700+ completed projects, AutoZone uses data captured from on-site cameras to identify trends and improve communication across their builds.

The cameras play an important role in project management for the Store Development team, which needs to oversee jobsites across the hemisphere. Side-by-side views give AutoZone the ability to understand project progress in a matter of seconds. The team routinely uses a side-by-side comparison of 7 to 14 days' worth of activity. They then have the ability to drill down into hour-by-hour or 10-minute increments to identify what changes have occurred and proactively work with contractors to manage their schedule.

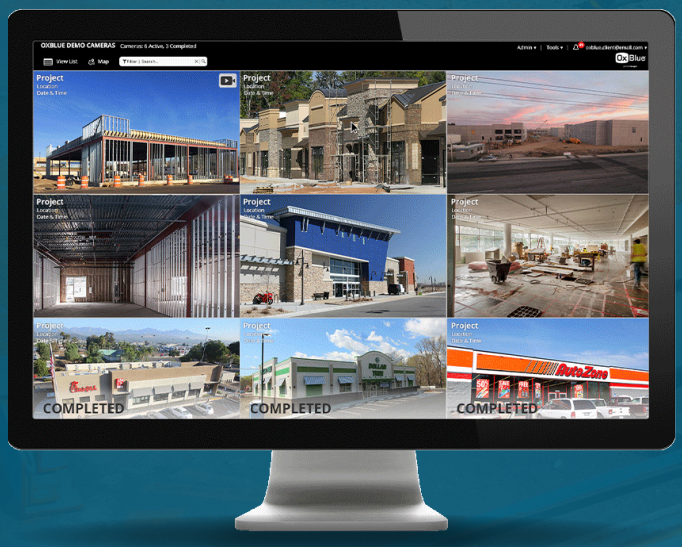
Adding autonomous technology, informed by AI, streamlines the process of recognising patterns and issues during the lifecycle of a project. OxBlue's cameras detect activity levels throughout the day, autonomously identifying productivity, equipment and safety compliance trends. The AutoZone team uses the activity analysis feature to document when work begins and ends, and when it's interrupted by bad weather — and the system sends automatic alerts for low activity, prolonged inactivity or abnormal temperatures. This enables the team to address issues early and minimise change orders, ensuring smooth project execution.

Benefits

Implementing jobsite cameras infused with AI and autonomy has allowed AutoZone's team to proactively monitor projects and adjust for trends.

Additional benefits include:

- Increased project transparency
- Reduced number of change orders
- Improved communication



Autonomous technology, informed by AI, streamlines the process of recognising patterns and issues and allows AutoZone to increase project transparency.

Perceptions of autonomy throughout the construction process

When asked which words, ideas or technologies come to mind when considering autonomy, technology leaders mentioned equipment such as robots, self-driving vehicles or autonomous tools almost four times more than the second and third leading topics: autonomous decision-making and AI, respectively *(Figure 17)*. This indicates that technology leaders are still mainly thinking of autonomous technology in terms of hardware.

Certainly, there has been a lot of excitement around the advancements made in autonomous heavy equipment, robotic drones and surveying tools. These types of technologies are making strides with worker safety and efficiency, two major contributors to sustainable jobsite practices.

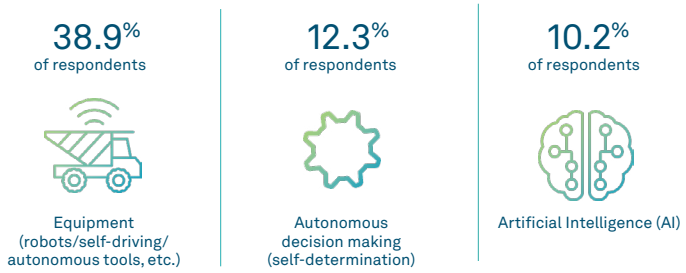
- Autonomous heavy equipment accurately and effectively performs construction tasks according to the design model, using AI-empowered object recognition to avoid collisions and alert operators to hazards in their path.

- Robotics improve worker safety and reduce the risk of injury on the jobsite by performing unsafe tasks, working in hazardous environments and detecting and alerting personnel about potential dangers to minimise injuries and accidents on construction sites.

- Autonomous surveying tools — both flying and terrestrial — capture highly-accurate, real-time footage of all areas of the jobsite that provides insight and visibility of jobsite status and conditions.

Increasingly advanced intelligence is what differentiates automation from true autonomy. Yet, only 12% of respondents identify autonomous decision-making and only 10% identify AI as the first association they make when thinking of autonomy *(Figure 17)*. This indicates that many technology leaders in construction still have a "hardware first" mindset and need to start thinking about the full potential of autonomous sensor-software systems with AI capabilities.

Figure 17: Words, ideas or technologies most associated with autonomy



Autonomous workflows in software applications throughout all phases of construction

For data to do its best work, it must be captured as early as possible, starting at the very beginning of the design process. Many firms are utilising autonomous technologies like reality capture of the existing jobsite even before winning a bid to prepare more accurate and detailed proposals. This leads to an increase in bids won. *(Learn more about how autonomous surveying is driving new business for 40% of firms).*

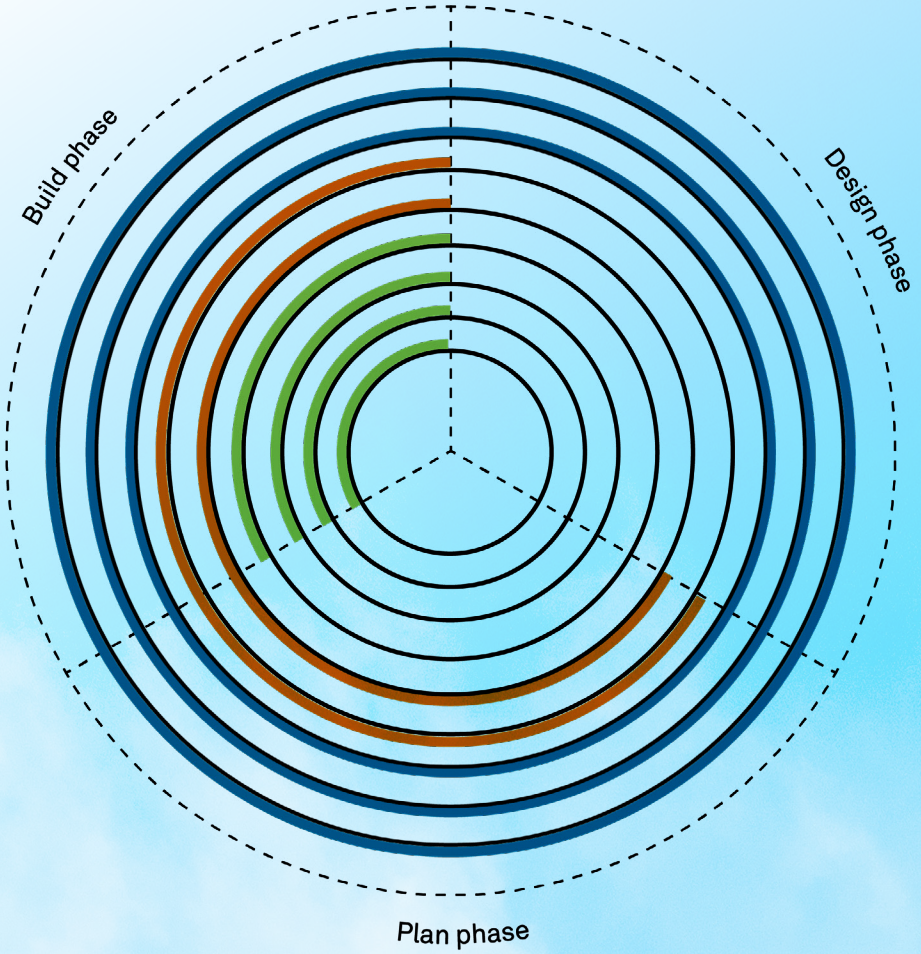
The digital thread of data throughout the entire building lifecycle is driving results in key business metrics including sustainability, productivity and efficiency by ensuring that the right things are built at the right time, in the right place, in the right way. For example, by capturing data about the existing conditions of a site where a future building or renovation will be, GCs are able to provide their architects with highly accurate and detailed data about variables like existing utilities, terrain or structural considerations of neighbouring buildings or structures. These variables can be factored into the design model from the very beginning, meaning fewer unknowns during the planning phase or — even worse — during construction

when unpleasant surprises mean the potential for wasted raw materials and labour hours, both of which are already scarce resources on the jobsite.

Utilising autonomous technologies during the design and planning stages of construction empowers stakeholders and processes during the building phase with a significant advantage –highly accurate and comprehensive data from the very beginning of the project is available and can be leveraged for meaningful insights that lead to better outcomes, like staying on schedule, on budget and as-designed. This is also very important for the building owner as they will have more confidence that projects will run smoothly with less risk. A huge advantage will be awarded to GCs who can offer this during the bidding process.

Autonomous capabilities across the design-plan-build phases

Where in the construction process is autonomous technology most effective? The answer is throughout the entire process, from designing the model to developing the plan to constructing the building. Capturing data as early as possible in the process by surveying the site, neighbouring structures and existing conditions ensures a digital thread of data that will inform the entire process, leading to better project outcomes.



- **Documentation and verification**
  Autonomous visual construction documentation solutions use cameras, reality capture scanners and AI-empowered software to autonomously identify trends and detect jobsite status, providing a photographic record of jobs for better collaboration and cost savings during and after construction.
- **Quality assurance and control**
  QA/QC software with autonomous comparison and detection capabilities can automatically compare the design model to a point cloud generated from real-time reality capture scans to detect deviations, autonomously flagging high-priority items that will clash with future unbuilt elements.
- **Site safety and monitoring**
  AI-enabled workflows that monitor worker behaviour and jobsite conditions, autonomously flagging potential hazards or noncompliance of safety protocols.
- **Office and field workflow optimisation**
  Integrations with jobsite monitoring software allows for autonomous field-to-office communication in a common data environment, empowering all stakeholders with real-time information from the field to manage the project schedule.
- **5D BIM cost management**
  Software that integrates data from the project schedule, model, and budget, along with real-time site monitoring, informs all stakeholders of jobsite health in a single, shared data environment for 360⁰ transparency.
- **Machine control and automation**
  Partially or fully automate specific heavy machinery functions to execute construction tasks according to the design model and to provide automatic progress updates to the office.

- **Design and engineering modelling**
  Automate complex and time-consuming workflows using AI for pattern recognition and classification of building elements, allowing models to scale from 2D to 3D to BIM much more rapidly.

- **Document workflow management**
  Set rules and parameters to automate the management and progression of document workflows, reducing manual efforts.

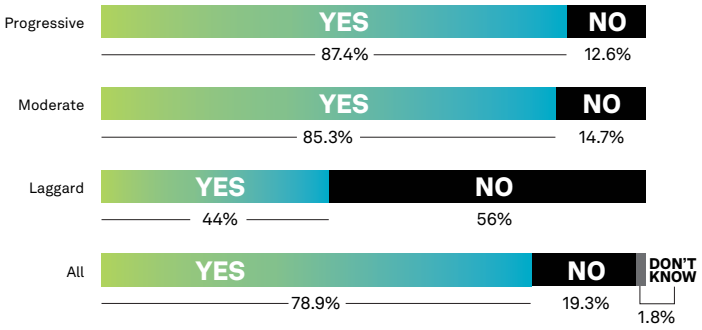
- **Reality capture**
  Using autonomous reality capture technology, like robotic UAVs and scanners, throughout the lifecycle of the project provides architects, engineers and contractors with highly accurate, real-time documentation of the site, making budgets and schedules more accurate, reducing the opportunity for mistakes and waste, and replacing human workers in hazardous environments.

For more information about these autonomous solutions, contact Hexagon's autonomous construction technology experts.

R&D investments in autonomous technology

The construction industry is known to have modest IT budgets, and even slimmer R&D budgets. According to JBKnowledge's 2021 ConTech report, R&D budgets at construction firms actually decreased by 3% in 2020, with 56% of respondents saying they had no R&D budget at all.[5] Despite low or non-existent budgets, 79% of tech leaders plan to invest in autonomous (or automated) technology within the next three years *(Figure 18).*

Figure 18: Does your company plan on investing in autonomous (or automated) technology within the next three years?



On average, firms plan on investing $7.1 million in autonomy within the next three years – with 30% planning to invest over $10 million *(Figure 19).* These investment plans are aligned with the importance of autonomy across key business metrics. Three quarters of progressives, who are utilising fully autonomous processes in more areas of their operations than moderates or laggards, agree that autonomous technologies will be very impactful in sustainability efforts in the future, and almost as many (71%) agree that autonomous technologies give them a competitive advantage in the market.

Additionally, over 60% of moderates and half of laggard groups agree that autonomy will be very impactful to sustainability, market competitiveness, owner satisfaction and profitability *(Figure 20)*. **The question then remains — what is holding some firms back from making these investments?**

$7.1 million

The average amount individual firms plan to invest in autonomous (or automated) technology in the next three years

$10 million

30% of respondents plan to invest over $10 million in autonomous (or automated) technology in the next three years

$162 billion

The amount the industry as a whole plans to invest in autonomous (or automated) technology in the next three years

Figure 20: How impactful will autonomy be in AEC in the following areas?

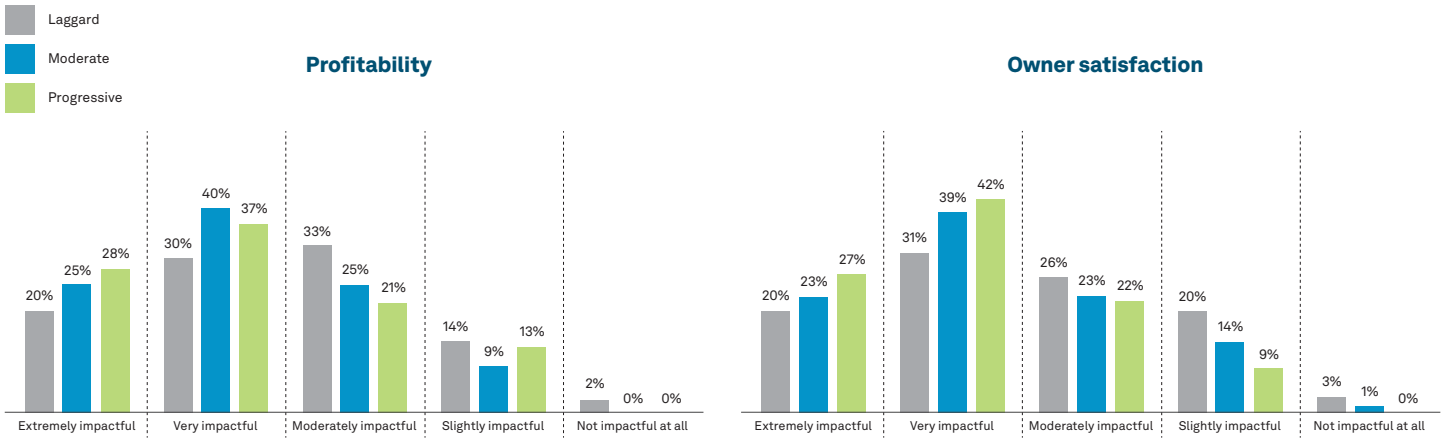
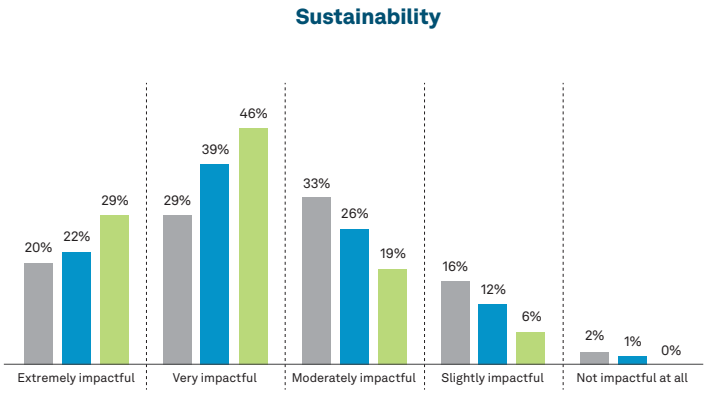
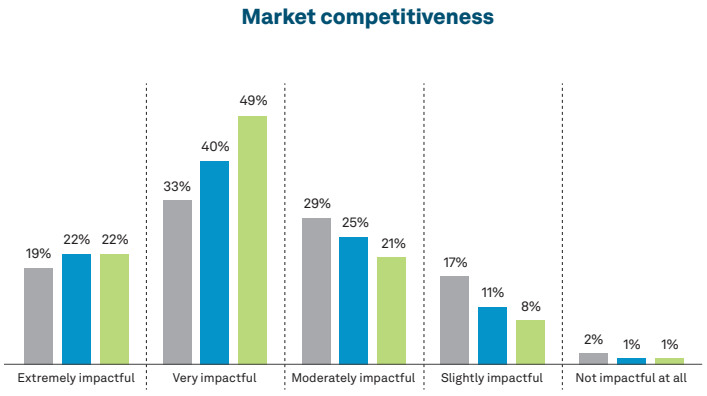


Figure 19: Average amount (in millions) firms are considering investing by company size.





Overcoming hesitations: why some firms have yet to implement autonomous construction solutions

Concerns remain about the use of autonomy in commercial construction. The most common hesitation regarding autonomous technology is a fear of unsupervised automation (24%), followed by uncertainty of outcomes (20%) and security concerns around data breaches, hacking and privacy (19%) *(Figure 21).*

Figure 21: Fears, hesitations and uncertainties regarding autonomous technology

Technology leaders from laggard firms are fairly split on the reasons why they haven't yet adopted autonomous (or automated) technologies *(Figure 22).* These fears are not unfounded. Between low budgets for technology investments, the fear of costly disruptions to operations and technology burnout among stakeholders, introducing new technology comes with challenges.

However, the maturation of autonomous technology in the industry offers insight into the benefits that were not previously available. Many progressive and moderate firms report benefits in the exact areas of concern laggard firms mentioned. This indicates that the perception of autonomy among laggards may not accurately represent the reality experienced by firms that have adopted it. Those who need reassurance and guidance can look to use cases from their colleagues to understand how autonomy can produce better project outcomes.

Reason 1: The value is unclear.
Leaders in laggard firms state that autonomy must enable faster decision-making, enhanced internal data circulation and heightened transparency in order to prove its value *(Figure 23).*

Faster decision-making is a benefit that both moderate and progressive firms have attributed to their autonomous operations. Transparency and data circulation will also be improved indirectly through increased process efficiency and better cross-functional collaboration, with the rate of improvement increasing as more autonomy is introduced.

For a deeper look into how autonomy has aided enterprise general contractor Turner Construction with faster decision-making, data circulation and transparency, *see the case study "Increasing efficiency and augmenting labour through autonomous reality capture".*

Reason 2: Not sure which technology to select.
The market for autonomous construction technology is rapidly growing and can be overwhelming with the number of solutions available. For this reason, technology leaders will benefit from taking a strategic approach to deciding which technology to invest in. This is where

Figure 22: Reasons why laggard firms have not yet adopted autonomous (or automated) technologies

Lack of understanding of the value provided with deploying an autonomous solution	35.4%
Not sure which autonomous technology to select	32.3%
Cost prohibitive	32.3%
Too disruptive for operations	31.7%
Lack of buy-in from end-users	31.0%
Lack of familiarity with autonomous technologies	28.5%
Worried about how to incorporate it into the current tech stack	26.6%
Lack of buy-in from key decision makers	24.7%
Lack of infrastructure to support (e.g., no Wi-Fi in field)	20.3%

Figure 23: Which outcomes would need to be more easily achieved through autonomous (or automated) technology for you to consider adoption?

Faster decision-making	32.9%
Enhanced internal data circulation	29.8%
Heightened transparency	28.0%
Better supply chain mapping	27.3%
Lower overhead costs	26.1%
Increased process efficiency	26.1%
More efficient waste management	25.5%
Easier cross-functional collaboration	24.8%
More accurate progress monitoring	24.8%
Improved project planning	24.8%
Reduced organisational risk	19.9%

external consultants are valuable, as they can help you build a roadmap and integration plan that aligns to your business objectives. Surprisingly, only 33% of firms have plans to work with consultants, indicating this is an underleveraged resource that should be considered *(see Figure 14 on page 18).*

Reason 3: It's cost-prohibitive.
The majority of tech leaders who have adopted autonomous technology have reported positive financial benefits.

On a scale of 1-10, 85% of respondents who work for progressive construction firms — that is, firms that utilise four or more autonomous systems — indicate that the impact of autonomy on their bottom line is significant *(rated 7 or higher) (Figure 24).*

Furthermore, as indicated on the previous page, technology decision-makers in commercial construction firms largely agree that autonomous technology will be very important in owner satisfaction and profitability in the future, suggesting that investing in autonomous technology may soon become an imperative for business performance and necessary for firms to be strategically positioned for success in the future.

Reason 4: It's too disruptive for operations.
The positive outcomes of adding autonomous processes to operations are widespread. Benefits are realised even when autonomy is applied in specific areas, like in moderate firms, and are improved as autonomous processes are adopted more broadly. However, as with any digital transformation initiative, there must be a well-developed rollout plan with training and integration support in order to avoid disruptions to operations.

Progressive firms (who have the most successful outcomes with autonomous adoption) are investing in more than just technology; they're also investing in training programs, external consultants and employees with specific expertise to deliver better business results, more than their moderate or laggard counterparts *(Figure 25).*

This underscores the importance of a roll-out plan with internal and external support for the highest chance of success. One popular approach is to pilot a new autonomous process in a single department, site or workflow — allowing the organisation to test, optimise and scale with minimal risk to operations.

Figure 24: Bottom line impact from benefits of autonomous technology

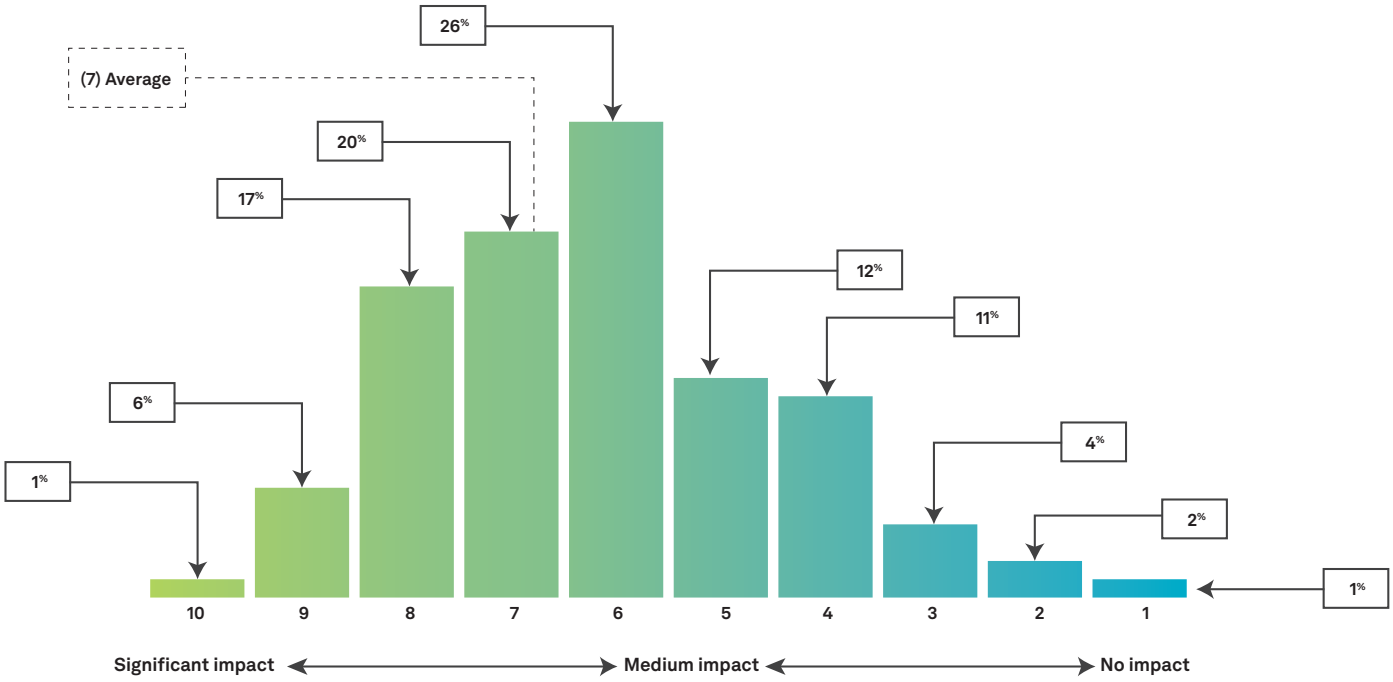


Figure 25: What solutions does your company currently have in place to address your business challenges?

	Laggard	Moderate	Progressive
We're investing in new technologies	34.3%	39.5%	47.6%
We're collecting more data / investing in better data analysis	35.5%	32.1%	42.2%
We're invested in new security software / systems	30.1%	36.0%	34.0%
We've created training programs / partnered to provide training to shore up the skills gap	32.5%	32.5%	41.3%
We've hired outside consultants	27.1%	32.9%	37.4%
We've added external security to our jobsites	36.8%	30.3%	35.9%
We've hired new team members with specific expertise to address key challenges	31.9%	29.5%	34.5%
We're providing incentives to help with recruitment	31.9%	30.2%	31.6%
We currently don't have any solutions in place to address these main business challenges	2.4	0.0%	0.0%

Respondents were allowed multiple responses

Reason 5: Lack of buy-in from end users.
For the successful adoption of autonomous technology, addressing the various challenges and concerns that may hinder end user buy-in is essential. According to Hexagon's construction technology experts, some of the most common reasons end users may resist autonomous technology include:

- Fear of autonomy: A common industry perception is that autonomous technologies pose a threat to job security. To overcome this, firms should educate workers on how these tools can improve and augment their jobs, while still requiring human oversight in many cases. In other cases, autonomy can take over the unsafe or tedious tasks that human workers can't — or don't want — to do.
- No dedicated budget for innovation: Unless autonomous technology is specifically funded for — or required by — a client, teams may be hesitant to deploy new technologies if the cost comes from their own project budget. To overcome this barrier, progressive firms often provide an "overhead" innovation budget to test new tools.
- Competing priorities: End users are often asked to solve everything all at once, which can result in no progress being made. To overcome this, firms should take a phased approach. One common starting point is the deployment of autonomous workflows for simple, repetitive tasks, while retaining human oversight for critical decision-making processes.
- Starting too late in the process: When it comes to data accuracy, the model must be the driver. Data inputs must be accurate from the beginning of the project for autonomous technologies to be useful. Firms should prioritise the creation of an accurate BIM as the foundation for all projects, starting with autonomous surveying of the site before breaking ground to guide site design and planning.

Firms must address concerns like fear of autonomy, cost, competing priorities and fear of operational disruption to overcome reluctance towards autonomous technology adoption.

CASE STUDY

Increasing efficiency and augmenting labour through autonomous reality capture

Turner Construction Company is known for its commitment to eliminating waste and improving efficiencies in its work processes for optimal productivity and QA/QC. One of the ways they accomplish this is by developing detailed 3D models of their projects before and during construction, which they augment with real-time scanning.

The company recently adopted the use of the Leica BLK ARC autonomous laser scanning module, mounted on Boston Dynamics' popular mobile robot, Spot, to roam their jobsites capturing real-time footage of site conditions and progress.

"It gives us flexibility that we didn't have before," explained Kris Wahl, Innovation Project Manager with Turner. "We can reduce the time and effort associated with scanning and get that critical data into the hands of our field teams quicker for informed decision-making."

As the demand for faster scanning grows, companies like Turner are demonstrating the effectiveness of autonomous reality capture. Turner has successfully integrated autonomous scanning into its workflows, resulting in significant time savings of hundreds of hours.

"Autonomy is really important in construction because when we automate processes, we ensure that they're happening consistently and routinely no matter what else is happening on the jobsite," said Wahl. "The data we capture from scanning is really important, but the actual act of walking a site and scanning isn't the best use of our people's time and abilities. With [autonomous laser scanning] handling scanning duties, our folks are freed up for higher-value tasks associated with driving schedule, quality and safety on a project."

Building on its success with the autonomous scanner, Turner is now making the Leica BLK ARC a permanent part of its scanning arsenal to continue reducing labour-intensive tasks.

"It really streamlines our ability to capture as-built conditions and continually monitor the progress and quality of work," Wahl said. "[The BLK ARC] is routinely and autonomously capturing scan data, and then our VDC teams are checking it against the coordinated BIM model to ensure things are being installed as planned."

They're also using the BLK ARC on Spot to perform crucial checks against their model, catching errors big and small, which makes for a smoother project overall, with fewer surprises. The effort is already paying off. Regular missions with the BLK ARC have revealed misplaced fireboxes, electrical units off-plan and even misalignments within a fire suppression system that would have hampered effective coverage in the event of a fire.

Protecting employees and removing tedium

In its mission statement, Turner says that its "primary asset is people", and Leica's autonomous robotic solution helps put its mission into practice by protecting workers from potentially dangerous environments.

"We can send [autonomous scanners] into tight or hazardous spaces where we don't want to send people," Wahl said. "One of the more common uses of scanning is to capture as-built conditions before we begin a renovation or demolition project."

The use of autonomous technology also allows Turner's people to focus on doing what they are good at — thinking through complex problems using intuition and creativity.

"When we talk about what we want innovation to do for us at Turner and for the construction industry, we always go back to this goal of removing tedium and inefficiency so people can reach their greatest potential to do meaningful and fulfilling work," Wahl said. "Robotics and automation are just one way to accomplish that. By eliminating repetitive and time-consuming manual tasks, people can use their skills and ingenuity for the important stuff."

With [autonomous laser scanning], our folks are freed up for higher-value tasks associated with driving schedule, quality and safety on a project.

Kris Wahl, Innovation Project Manager
at Turner Construction

Future of industry: The Smart Digital Reality™

Construction has been a vital ecosystem since the dawn of time. From the evolution of building approaches, to the invention of power tools, to the digitalisation of assets, the ecosystem has undergone massive transitions over the course of history. Like all industries, the buildings ecosystem is in the midst of yet another seismic shift: the adoption and widespread usage of autonomous technology.

As a result of the IoT data deluge, the construction industry has access to more data than ever before. But instead of delivering on its promised value, all of the data we now possess has created new problems. Construction teams build against plans that are out of date, causing costly rework that wastes resources. General contractors and trade contractors use disconnected systems and processes, causing miscommunications and frustration. The reality is, data is only as good as the systems we use to leverage and mine it for insights, and the industry is creating a wealth of data that goes unused or underleveraged. The result is a data leverage gap that is exponentially increasing.

That's where autonomous technology comes in. Autonomy is simply the next evolution of the ecosystem, allowing companies within the buildings space to extract the full value of data that is available to them.

Hexagon is empowering autonomy within commercial construction by delivering sensor-software systems to create a Smart Digital Reality, that is, a 3D space that is a one-to-one replica of the real world. Rooted in the real world, the Smart Digital Reality provides a complete line of sight to the ever-changing conditions on a jobsite to boost efficiency, productivity and quality for construction firms.

The Smart Digital Reality is the evolution of the digital twin. Perhaps the most critical difference between a traditional digital twin and the Smart Digital Reality is what makes it truly intelligent: it's infused with real-time data inputs so as the world changes, those changes are reflected in its digital counterpart. This feedback loop is constant. When physical site changes are made, sensors capture and reflect this information in the digital world, where insights are updated to inform stakeholders. Through the implementation of autonomous technology, the Smart Digital Reality becomes independently intelligent — capable of empowering action and decision-making free from human interaction.

Commercial construction firms can begin harnessing the power of autonomy today. By evaluating current processes and business priorities, organisations can determine where autonomous technologies can be used to better leverage data to solve challenges and address immediate and strategic goals — allowing them to weather turbulence and emerge successful.

Reach out to Hexagon's construction solutions experts to learn more about how the Smart Digital Reality and our suite of autonomous solutions can deliver successful outcomes for your firm.

hexagon.com/contechreport

References

1. *Famous, Gabriele. "Three Technology Trends Shaping the Future of Design and Construction in 2018." Aconex Group. 2018.*

2. *United Nations Environment Programme (2021). 2021 Global Status Report for Buildings and Construction: Towards a Zero-emissions, Efficient and Resilient Buildings and Construction Sector. Nairobi.*

3. *WBCSD. (2020). Transforming the built environment. World Business Council for Sustainable Development (WBCSD). Retrieved February 7, 2023, from https://www.wbcsd.org/Programs/Cities-and-Mobility/Sustainable-Cities/Transforming-the-Built-Environment.*

4. *Dodge Data & Analytics. (2021). World Green Building Trends. Construction.com. Retrieved February 7, 2023, from https://proddrupalcontent.construction.com/s3fs-public/WorldGreen-2021-SMR-29Oct.pdf.*

5. *JBKnowledge. (2021, December). JBKnowledge's 2021 ConTech report.*


HEXAGON