Automation and Sector Impacts Research 2016

Construction Sector Outlook

Scottish Enterprise

optimat
strategies for success

Report

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Executive Summary

This report considers current and future adoption of automation by the construction sector in Scotland to 2025 and beyond. It has been developed with contributions from construction sector companies, industry representatives, automation suppliers and leading academics in this area. The key findings of this report are:

- The pace of technological change in automation and reducing costs of practical solutions are increasing the rate of adoption by the construction sector
- Adoption of automation technologies is an opportunity to increase productivity, improve health and safety performance and resource efficiency performance
- Although there are some examples of automation have been successfully adopted in the Scottish construction sector and its product/material supply chain, feedback suggests that these rates of adoption are lower than leading countries in this area including Japan, Germany, France, Denmark and Sweden (although industry structure and market characteristics of these other countries are a factor in the different rates of adoption)
- Automation in the construction sector covers a broad range of solutions from physical automated process lines and robotics to digital systems and tools, with an increasing trend to convergence of physical and digital technology to produce solutions that combine automated physical tasks with automated analysis and decision making
- The structure of the construction sector in Scotland is characterised by large numbers of micro-businesses (<10 employees) with limited time and financial capacity to carry out pilots with new automated technology
- Different types of automation require different levels of capital investment. For some technologies the capital cost is at a level (and the equipment modular in nature) where it is feasible to run a pilot project and evaluate the benefits. Other automated technologies can require millions of pounds of investment (such as large scale automation of offsite building manufacture)
- The size of the market in Scotland, and the lack of certainty about future market demand, places constraints on the degree of large scale investment that is perceived to be financially viable
- There are opportunities to develop a Scottish based automation supply chain with innovative solutions aimed at the construction (and other) sectors. Stakeholders identified automated inspection of buildings and infrastructure and automated onsite material tracking solutions as two examples of this
- There are examples of new initiatives already in development to support the construction sector identify, assess and adopt automation technologies, such as the Construction Scotland Innovation Centre's soon to be launched demonstration facility
- Adoption of automation technology has potential to improve the attractiveness of the sector to new labour market entrants through a reduction in repetitive tasks,

transfer of activities from site to factory and improved health and safety performance

- Increased levels of automation will result in different skills required from the construction sector labour force, such as operation, maintenance and repair of physical automation equipment and programming and operation of digital solutions. The sector needs to work with skills development intermediaries and delivery agents to ensure the future workforce is equipped for the requirements of a sector with higher levels of automation.

This report provides examples of current and emerging automation technology relevant to the construction sector in Scotland and uses stakeholder feedback to develop a vision for 2025. A summary of the key trends leading to this vision is shown in the illustration below.

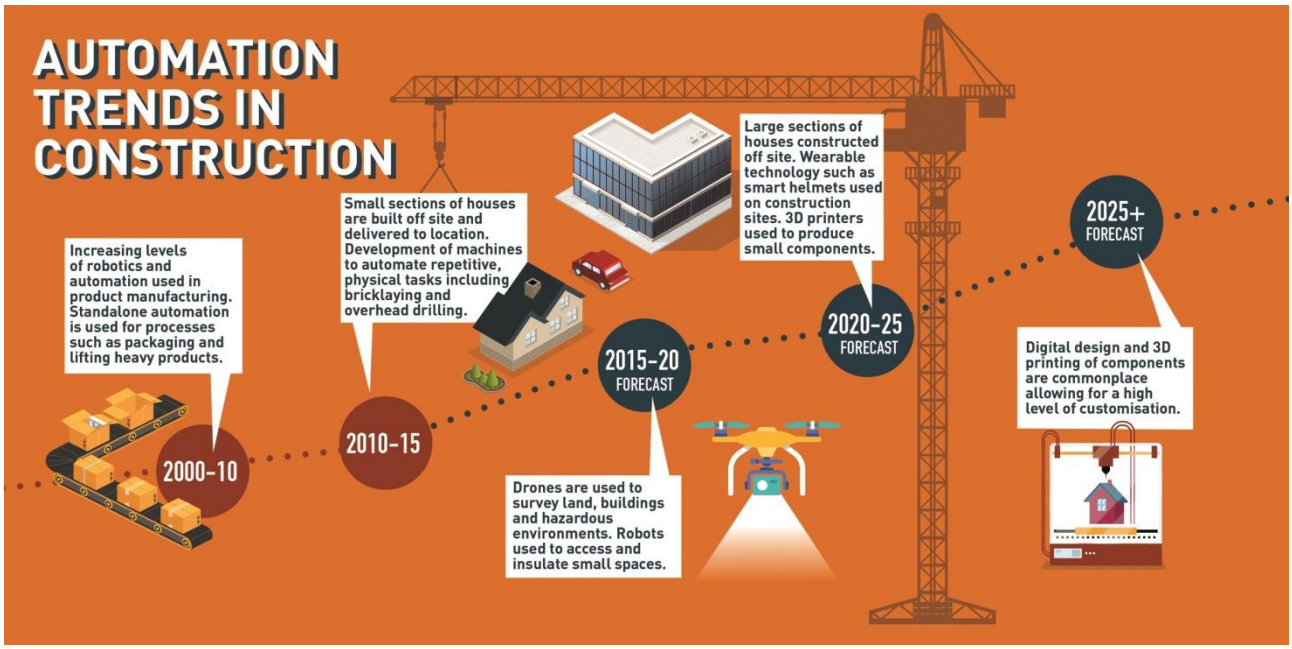

Figure 1: Automation Trends in Construction

The report examines these trends in more detail and comments on keys issues that need to be addressed to achieve the vision for 2025. The report concludes with recommendations for companies operating in the sector, industry representative bodies and the public sector.

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1. Purpose and overview of the research

1.1 Objective of the research

This report is one of three similar reports, with the other two focusing on automation in food manufacture (including agriculture) and in financial and business services. The key findings of all three reports are summarised in a separate Strategic Overview report. The objective of this report is to provide an overview of the current level of adoption of automation in the Scottish construction sector and identify how this might change over the period to 2025. The report identifies examples of automation that have been adopted by the construction sector in other countries and potential future applications that are currently at research and demonstration stage.

1.2 The research process

Research for this report was carried out during August and September 2016. This involved a combination of secondary research and primary research. The sources of secondary research are listed in appendix A with detailed references provided as footnotes throughout the report. The primary research obtained feedback from eight industry and academic stakeholders. Industry stakeholders provided insight from the perspective of construction product manufacture, offsite manufacture, onsite construction and robotics supply chain.

1.3 Definition of automation in construction

Automation in construction covers[1]:

- *physical tasks* – providing strength and energy (e.g. collaborative robotic bricklaying equipment, automated offsite manufacture of timber frame systems)
- *cognitive tasks* – receiving and issuing information (e.g. digital construction software systems which can automatically update building cost models and energy performance in response to changes in design)
- *organising tasks* – making decisions (e.g. autonomous aerial vehicles scanning ground layouts and controlling the operation of unmanned earthmoving equipment)

Automation can involve the use of existing equipment already established in other sectors (e.g. pipeline inspection and repair equipment from the oil and gas sector) or the development of new equipment (e.g. exoskeletal devices). New technology in this area can either automate an existing construction process (e.g. automated overhead drilling) or enable new construction processes to be introduced (e.g. fabric cast concrete using 6-axis robots enabling designs not previously possible through the use of formwork).

[1] Based on construction systems types and automation/robotic tasks outlined in: Frans van Gassel and Ger Maas (2008), 'Mechanising, Robotising and Automating construction processes', Robotics and Automation in Construction, Carlos Balauer and Mohamed Abderrahim (Ed), ISBN: 978-953-7619-13-8, InTech

1.4 Definition of the scope of the construction sector

Scotland's Construction sector accounts for 10% of total Scottish jobs (170,000). The sector is made up of 31,000 businesses which generate 21.4bn annually.

Figure 1, below, illustrates the broad scope of the sub-sectors involved in the overall construction sector.

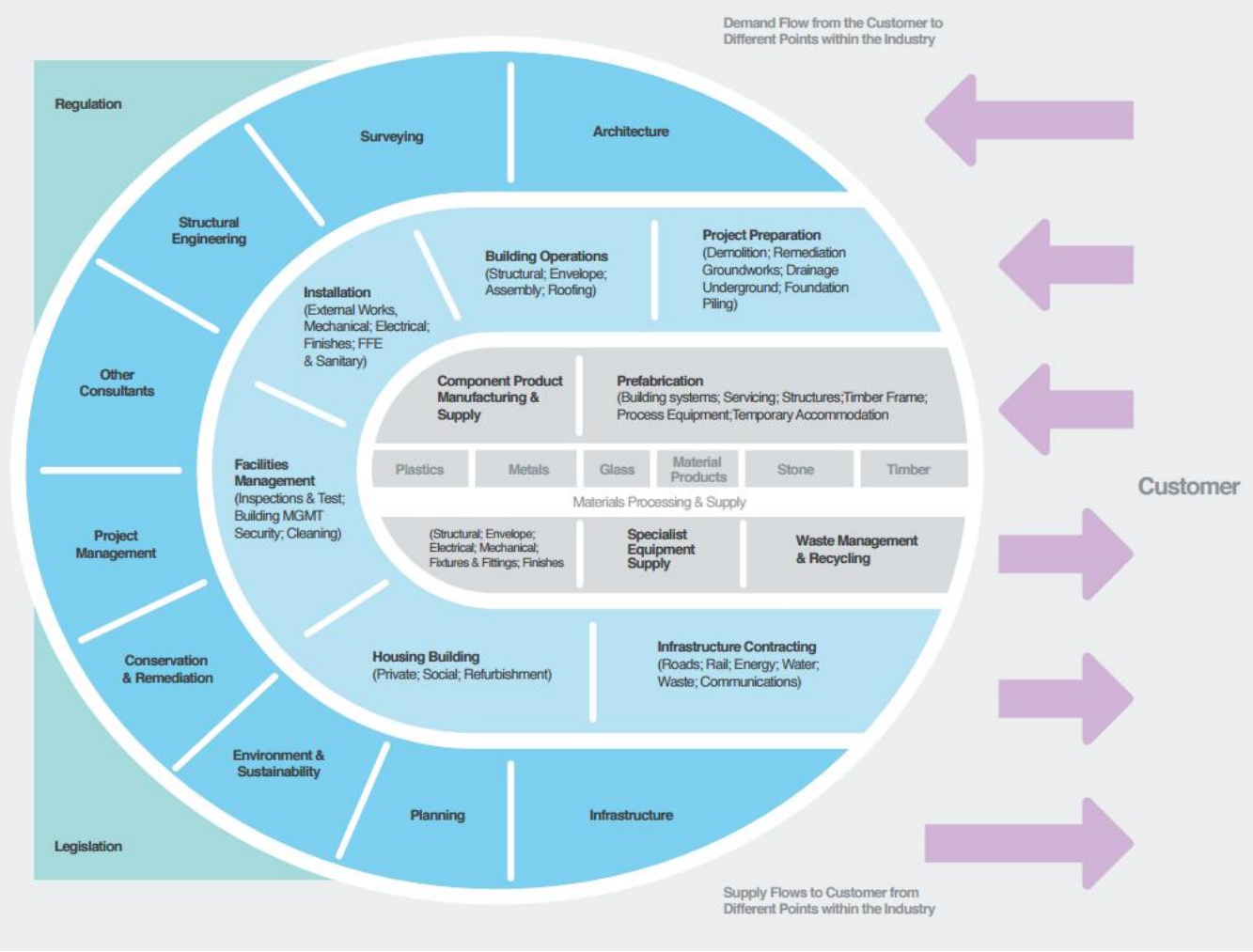

Figure 2 - Map of the Construction sector[2]

This map covers material and product supply chains, onsite and offsite operations and supporting professional service providers. The different parts of the sector work together to deliver housing, commercial & industrial buildings and infrastructure solutions.

[2] Building for The Future – The Scottish Construction Industry's Strategy, 2013 – 2016, Construction Scotland http://www.cs-ic.org/media/1050/construction_strategy_2013_2016.pdf

1.5 Sector overview

The sector has developed to serve mainly a local market in Scotland (although there are examples of international engineering service companies and product/component manufacturers that export to the rest of the UK and overseas markets).

A historical breakdown of the Scottish construction market is shown below.

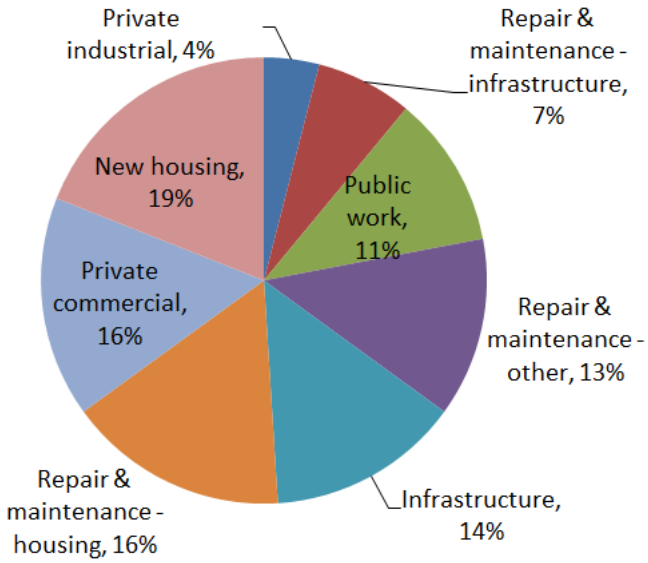

Figure 3 - Construction output, by type, in Scotland[3]

New housing is predominantly private sector led in Scotland. The repair and maintenance sector accounts for 36% of all activity (across housing, infrastructure and other sub-markets).

1.6 Characteristics of the Scottish construction sector

1.6.1 Characteristics

The sector is characterised by a large number of small operators across all sub-sectors. There are also a number of large engineering companies and main contractors present in Scotland that are international (for example, Laing O'Rourke, Amec Foster Wheeler and Carrillion).

Figure 3, below, shows the predominance of micro firms in the Scottish construction sector across all subsectors. Civil engineering companies tend to be relatively larger (although 90% of companies have less than 20 employees).

[3] Baselining and research into the construction sector in Scotland, SQW, 2012 - http://www.cs-ic.org/media/1051/full_report.pdf (Data refers to 2010)

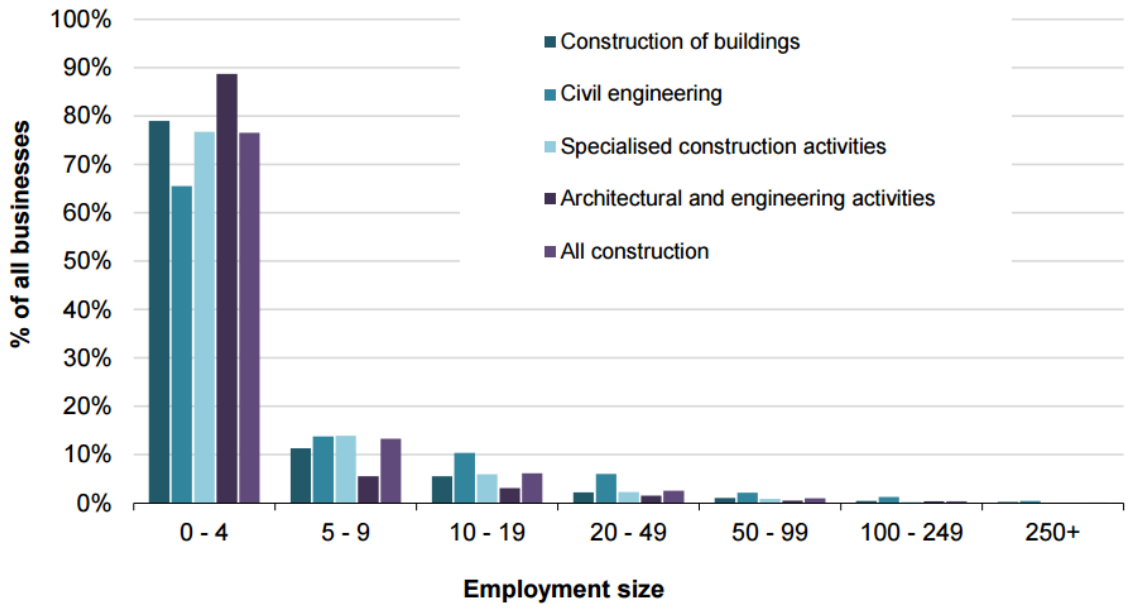

Figure 4 - Size of businesses (employment) in the Construction Sector[4]

Private sector demand for housing is more than double the public sector demand and future housing sales can be difficult to predict. Current onsite construction practices are flexible in response to underlying economic conditions and the related market demand. Typically, house-builders are not vertically integrated with offsite manufacture (although there are exceptions such as Stewart Milne Timber Systems/Stewart Milne Construction and CCG Offsite Manufacture and CCG Construction). According to feedback from consultees one of the main issues with this structure is the lack of predictability in market demand acting as a constraint on investment in automation by companies involved in offsite factories.

[4] Baselining and research into the construction sector in Scotland, SQW, 2012 - http://www.cs-ic.org/media/1051/full_report.pdf

2. Vision for 2025

This vision for automation in the Scottish construction sector by 2025 has been developed through consultation with a number of Scottish construction sector companies, support bodies and expert academics in this area.

2.1 The 2025 vision for automation in Scottish construction

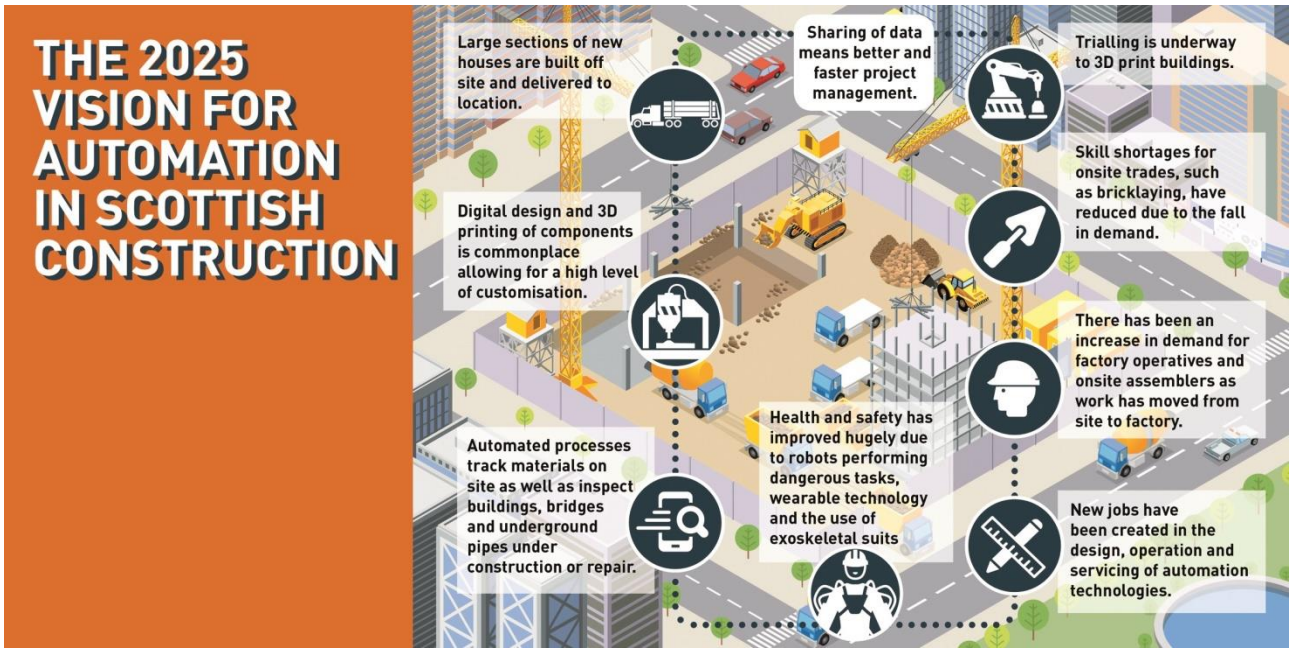

Figure 5: 2025 Vision for automation in Scottish construction

The key elements of the 2025 vision are:

- An increasing share of the new-build housing market is taken by large highly automated offsite manufacturing. Upstream supply chain integration of construction product and component suppliers, collocated with offsite manufacturers, is increasingly common. Following the success of Legal and General Homes, other financial service companies have entered the market to establish 'mega-factories' similar to automotive plants. Consumers have reacted well to the high degree of customisation possible offered by this type of solution and the high quality of the build. Many traditional onsite trades companies are increasingly reliant on the repair and maintenance sector
- Interoperability concerns about efficient sharing of data through the supply chain have been addressed and the use of Building Information Modelling BIM is widespread. This has enabled cost and productivity savings to be achieved and the quality of the construction output has increased

- Health and safety performance onsite has been improved significantly through a combination of use of robotics to reduce workforce exposure (e.g. inspection and monitoring in hazardous environments), the use of onsite wearable technology to monitor health risks and tracking via GPS. The use of exoskeletal suits reduces fatigue, important to the aging workforce
- 3D printing of components onsite has enabled a degree of customisation not previously possible and architects are pushing the boundaries of design using new automated construction techniques to produce structures
- A local supply chain focused on automated inspection of assets has developed in Scotland servicing the construction sector and also the oil & gas, energy transmission network operators and wind turbine operators
- 3D concrete and steel printing has been trialled on a small scale on a number projects but it is still a niche area of construction

The high level benefits and implications of this increased adoption of automation by the construction sector are:

- Significant increase in productivity for offsite manufacturers resulting from more efficient production processes and a reduction in post completion repair and remediation work
- The sustainability performance of the sector has improved with higher levels of energy efficient housing in operation and less waste being produced at the manufacturing stage
- Health and safety has improved across the sector with automation of infrastructure inspection, onsite worker tracking, use of exoskeletal devices and the move towards more activity being carried out in a controlled factory environment
- Skill shortages for onsite trades, such has bricklaying, have reduced due to the fall in demand corresponding to higher levels of offsite manufacture
- There has been an increase in demand for factory operatives and onsite assemblers as a greater proportion of the work has moved from site to factory
- House builders offering high levels of customisation to consumers have been able use this differentiation to gain market share and obtain a premium over mass produced traditional build housing

3. Market drivers and barriers

This section describes the key drivers and barriers to adoption of automation in the Scottish construction sector. This was identified through consultation with academic, industry and other stakeholders. This feedback complemented the findings of the desk-based review.

3.1 Drivers

Drivers influencing adoption of automation in construction include:

- Reduction of health & safety risks faced by employees through reducing exposure during various tasks, such as carrying out inspections at height, demolition and overhead drilling
- Improvement of productivity given that construction sector productivity growth is lagging other sectors, such as manufacturing
- Improving the attractiveness of construction as a career choice to compete in the market for new talent
- Ongoing move to more digital construction in the form of Building Information Modelling (with public sector procurement of construction requiring BIM Level 2, where appropriate, by April 2017[5])
- The labour force available to carry out onsite 'wet-trades' (e.g. brick laying, plastering) is ageing and skill shortages in this area are expected to increase. This is part of a wider trend of an ageing workforce across the construction sector[6]
- Desire for cost savings which could be achieved, for example, through improved quality of build (and therefore fewer remedial activities post construction). Cost savings are also possible through use of digital construction and onsite robotics, where very precise instructions for the build process can reduce variability of approach by onsite operators. This could lead to a reduction in the historic practice of over-specifying of structures to compensate for onsite variability (e.g. the accurate placement of reinforcement bar in concrete flooring could save up to 20% in the amount of rebar used[7])
- Increasing desire for more sustainable housing with high energy efficiency performance

3.2 Barriers

Barriers influencing adoption of automation in construction include:

- Several stakeholders described how the uncertainty of future demand in the housing sector constrained investment in off-site manufacture. The size of the sector in Scotland is relatively small in comparison to other areas of the UK (such as

[5] http://www.scottishfuturestrust.org.uk/our-work/sft-build/construction-procurement-review/building-information-modelling-bim/

[6] 'The impact of the ageing population on the construction industry', CIOB

[7] Based on feedback from stakeholder consultation

the South East of England) leading to barriers to investment arising from uncertainty of future demand

- One stakeholder highlighted that the demand for offsite manufactured housing has a positive relationship with the level of energy efficiency performance required (set mainly by government regulation but also, to a lesser extent, by market demand). Feedback suggested that a barrier to increased investment in automation was related to the current levels of energy efficiency requirements being insufficiently high (as higher levels of energy efficiency favour offsite construction over onsite construction)
- Interoperability issues between different commercial and proprietary Building Information Modelling software systems is a barrier to achieving greater benefits from digital construction
- Some stakeholder feedback suggests that the limited number of examples of automation being used in construction in Scotland means that awareness of opportunities could be more widespread
- The availability of skilled labour (in automation processes) is also regarded as relatively low in Scotland, by one stakeholder, compared to the situation in other parts of the UK where transferable automation skills are developed in other sectors, such as automotive manufacture
- Regulations regarding autonomous drones are clearly necessary for public safety but also place constraints on the scope of operation of this technology for construction related applications

4. Current patterns of adoption of automation technologies

Feedback from both industry and academic stakeholders is that current use of automation in the Scottish construction sector is limited. The view expressed by some stakeholders is that Scotland has a lower rate of adoption than the rest of the UK and many western European countries including Germany, France, Sweden and Denmark. The construction sector in Japan was also highlighted as a leading user of automation in offsite housing production. According to several stakeholders there are structural differences in the supply and demand for housing in Japan in comparison to Scotland. The key companies involved in offsite manufacturing are large conglomerates with relatively easier access to capital markets for investment in automation and there is a culture in the demand side to replace entire houses every 40/50 years. This behaviour of consumers leads to a more predictable demand for housing.

In the construction sector in Scotland (as defined in figure one) the adoption of automation has mostly occurred in the construction product manufacturing environment. For example *[with each allocated a reference: Construction 1, 2, 3 etc. used in later figure 4],*

- Automation present in the production processes of basic components such as board and sawn timber (e.g. Norbord[8]) *[C1]*
- Insulation manufacturer, Superglass (based in Stirling) operates a highly automated production process and use robotics in its packaging operations *[C2]*

Superglass – automating the production of construction products

Superglass is the UK's only independent manufacturer of glass mineral wool insulation. Based in Stirling, the company produces insulation for roof, floor, wall and blown applications from over 30,000 tons of recycled glass. Production consists of several highly automated processes including glass melting, spinning of fibre, curing, trimming, cutting, compression and application of primary packaging.

Two static robots are then used to palletise and apply secondary packaging to the product. The pallets of product are then ready for warehousing and shipping. The high levels of automation and use of robotics ensure the company is competitive in the marketplace with consistently high levels of quality.

[8] http://www.forestryscotland.com/media/308758/ttj%20norbord.pdf

- CCG Off Site Manufacture use various robotic cutting, lifting and manoeuvring equipment to support movement of panels and components (e.g. windows) through the production process[9] *[C3]*
- Stewart Milne Timber Systems uses automation in some parts of the production process at its offsite timber kit production facility in Aberdeen. This includes nail bridging and framing stations *[C4]*

Stewart Milne Timber Systems – building on automation success

The Stewart Milne Timber Systems factory in Oxford is one of the most advanced automated timber frame operations in Europe. The £10m purpose-built manufacturing facility is capable of producing over 8,000 houses per year with a single kit being produced every 30 mins. In addition to houses the factory also produces apartments, hotels, student accommodation, care homes and medical facilities. Opened in 2003, the purpose built factory is part of the solution to deliver consistently high quality products that are assembled onsite. The company continues to identify new areas to use automation and robotics in the production process to improve safety, quality and productivity.

The original Stewart Milne Timber Systems factory in Aberdeen is currently a more labour intensive process with some automation being used, such as nailing bridges and framing stations. Future plans for Scottish timber frame production include the introduction of much higher levels of automation and robotics, building on the experience from the Oxford site. The use of integrated systems to enable consumers to customise homes at the point of sale is also being investigated. This type of 'mass customisation' has been proven in other sectors, such as automotive production. Mass customisation is also currently used in Japan, where consumers can specify a home in a retail environment and move into that house in about six weeks.

[9] http://c-c-g.co.uk/divisions/off-site-manufacturing/

- Several Scottish based companies offering drone inspection of buildings[10] and this is now being taught to building surveying students at Dundee and Angus College[11], for example *[C5]*
- In infrastructure maintenance there are examples of using robots for underground pipe inspection and maintenance. For example a 'Cast Iron Sealing Robot' has been used to identify and repair faults in gas pipes in Edinburgh. This was carried out by ULC Robotics (headquartered in New York) for SGN[12] *[C6]*
- Laing O'Rourke's Scottish office has been active in developing digital construction over a number of years. This is supportive of the overall company drive to increase the offsite component of construction. For example, they used digital construction in the design and construction of the Dumfries and Galloway Royal Infirmary hospital[13]. This allowed them to virtually build the hospital to optimise the design process (e.g. clash detection, check future maintenance access) use the data as an input to their offsite construction and monitor the as built performance against plan *[C7]*
- Corecut, based in Broxburn, recently used its remote controlled robotic demolition capability on the Queen Street tunnel renewal project to break up 10,000 tonnes of concrete to manageable sections for removal by train[14] *[C8]*

In Scotland there is some academic research expertise carrying out activities that could contribute to the development of the automation supply chain. For example, the Edinburgh Centre for Robotics and other expertise in Heriot Watt, Strathclyde, Glasgow, Aberdeen and Dundee Universities. According to one stakeholder, better linkages between these centres would support the development of commercial automation solutions. Examples of areas to focus on were given as automated inspection and automated monitoring of materials and components onsite.

The Scottish Funding Council supported Construction Scotland Innovation Centre (CSIC) is in the process of establishing a physical facility to allow companies to trial automation solutions offline with advisory support. This will support company executives to develop a business case for adoption in their own operations.

[10] For example: http://www.scottishconstructionnow.com/2734/finally-edinburghs-buildings-inspected-drone/
[11] https://dundeeandangus.ac.uk/news/students-take-to-the-air/
[12] http://ulcrobotics.com/cisbot-travels-under-iconic-george-street-in-scotland-repairing-gas-infrastructure/
[13] http://www.scottishfuturestrust.org.uk/files/publications/LOR_Dumfries_BIM_Case_Study.pdf
[14] http://www.corecut.co.uk/services/diamond-drilling-services/queen-street-tunnel-case-study.aspx

5. Leading-edge developments

The potential for automation in construction, within the next ten years in Scotland, will be influenced by the types of solutions being adopted by the construction sector in other geographic areas and innovative developments currently taking place in research laboratories. This section provides some examples of these developments.

5.1 Digital construction

The use of digital construction can produce direct benefits and also provide a platform of data that can drive the development of other products and services.

5.1.1 Direct benefits of digital construction

Digital construction (often referred to as Building Information Modelling) has the objective of developing data regarding a construction project in a common format that can be shared amongst the supply chain. A key objective is to reduce the variability and human interpretation of how to construct an element of a building or structure. Suppliers of components and materials provide standardised data about their products to be specified by architects and engineers in projects. Subsequent changes to projects will be recorded in a single BIM model for the project and data on attributes such as cost and performance will automatically be updated. Virtually constructing using BIM enables optimised designs to be produced given certain constrains (e.g. achieving a minimum energy efficiency performance) and allows virtual clash detection to avoid these problems in the actual physical build *[C9].*

5.1.2 Products and services exploiting digital construction data

Examples of products and services enabled by gathering and processing digital construction data include:

- Use of automated drones to scan terrain and compare to desired post-groundworks requirements. The drones then automatically control unmanned earthmoving equipment on the ground, in real time. Development by Komatsu in Japan in collaboration with Skycatch of the USA. The project has, in part, been developed in response to labour shortages in Japan[15] *[C10]*
- Use of drones to scan buildings during the construction phase (externally and internally) and automatically compare against BIM design data to give real-time progress reporting and identification of variations. Technology developed by Remote Aerial Surveys in the UK[16] *[C11]*
- Mass customisation of housing by the consumer at point of sale. Sekisu in Japan offer mass customisation where the buyer can choose from a large menu of layout and finish options and the information is then digitally transferred to the factory and supply chain, with the home ready for occupation within around six weeks[17] *[C12]*

[15] http://www.theverge.com/2015/10/13/9521453/skycatch-komatsu-drones-construction-autonomous-vehicles
[16] http://www.remoteaerialsurveys.co.uk/blog/from-uav-to-bim-how-uav-data-fits-into-the-scan-to-bim-work-flow/22
[17] http://www.building.co.uk/modern-construction-bring-on-the-robots/5079918.article

- Automated tracking of materials on a construction site. Developed by Atkins Global and demonstrated in the US[18] *[C13]*
- Laing O'Rourke Engineering Excellence Group has trialled the use of construction helmets fitted with monitoring technologies which automatically track the physical location and temperature of users. This was carried out at a site in Australia[19] *[C14]*

5.2 Physical automation

This section contains examples of automation as it has been applied in the construction sector; where it is still at research stage and; examples of automation from other sectors.

5.2.1 Construction sector examples

The following examples of automation applied in the construction sector were identified:

- High level of automation in offsite timber construction factory. Claims to produce a new panel every 17 minutes for use in modular construction up to six stories high. Lindbacks, Sweden[20] *[C15]*
- Planned development of a highly automated offsite housing factory near Leeds by Legal and General Homes. Using Cross Laminated Timber the new company (owned by the insurance and pension specialist, Legal and General) will build modularised floors of houses in a factory environment then deliver to a site and assemble a house in one working day. The housing options include terraced, semi-detached, detached, and up to 20 storey towers. This move into housebuilding is likely to be disruptive to existing housebuilders[21] *[C16]*
- The use of robotic production of formwork for precast concrete manufacture to achieve novel shapes not possible through using current methods. Demonstrated by the LafargeHolcim Foundation[22] *[C17]*
- Fully automated bricklaying robot developed by Australian Fastbrick Robot Limited. Claimed to lay 1,000 bricks per hour[23] *[C18]*
- Collaborative onsite bricklaying robot capable of cutting and placing bricks to be fixed in position by a human bricklayer. Developed in conjunction with ETH Zurich (Swiss Federal Institute of Technology in Zurich[24]) *[C19]*
- Mobile drilling robot designed to drill overhead holes in concrete. Developed by Norwegian company nLink and being trialled by Skanska at the Battersea Power Station development[25] *[C20]*

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18 http://www.atkinsglobal.co.uk/~/media/Files/A/Atkins-Corporate/north-america/services-documents/applied-technologies/Atkins-materials-tracking-logistics-technologies.pdf

19 http://www.infoworks.laingorourke.com/innovation/2015/smart-hats-monitor-health.aspx

20 http://digitalconstructionnews.com/2016/04/01/scandinavia-leads-the-way-with-offsite-wood-construction/

21 http://www.legalandgeneral.com/homes/

22 https://www.lafargeholcim-foundation.org/projects/high-efficiency-concrete-formwork-technology-zurich-switzerlan

23 http://digitalconstructionnews.com/2016/08/11/revolutionary-robot-lays-1000-bricks-an-hour/

24 http://www.reuters.com/article/us-switzerland-robotbuilder-idUSKCN0SF1BU20151021

25 http://www.offsitehub.co.uk/industry-news/news/skanska-to-introduce-robots-for-battersea-development/

- Development of an onsite concrete 3D printer that is mobile on caterpillar tracks and can utilise recycled concrete as an input material. Research carried out by BAM and trialled at a housing construction site in Amsterdam[26] *[C21]*
- Automated paving block laying machine. Developed by Vanku BV of The Netherlands[27] *[C22]*
- Automated underfloor insulating robot – designed to access hard to reach voids under the floor. Developed by Q-Bot based in London and trialled by the London Borough of Islington as part of an energy efficiency in social housing project[28] *[C23]*
- Exoskeletal devices for onsite use, to reduce fatigue and occurrence of injury through repetitive task. Developed by Ekso Bionics in the USA[29] *[C24]*
- Exoskeletal devices to assist in lifting heavy items, developed by Panasonic in Japan[30] *[C25]*
- Remote controlled demolition robots developed by Husqvarna of the USA[31] *[C26]*

5.2.2 Examples from other sectors

- Automation is already used in many production line processes in different sectors (e.g. food and drink). New, cheaper and easier to programme, robots have become available, such as Sawyer robot by Rethink Robots[32]. One stakeholder suggested that the price of some second hand robots could be purchased for less than £30,000, meaning that payback periods (compared to costs of an employee) could be attractive *[C27]*
- The automotive and aerospace sectors offer examples of high levels of automation that could provide insights and stimulate applications in construction sector operations. For example, in Scotland, Spirit AeroSystems Europe uses robotic riveting on aircraft wings[33] *[C28]*

5.3 Research

A number of opportunities were identified that are still at research stage, including:

- Fabric cast concrete produced by 6-axis robots to achieve structures not possible through the use of traditional formwork. Research carried out by the University of California[34] *[C29]*
- 3D steel printing of a bridge structure by MX3D based in The Netherlands[35] *[C30]*

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[26] http://www.constructionenquirer.com/2016/06/13/bam-launches-3d-printing-site-robot/
[27] https://europaving.com/brick-laying-machine-vs-human-brick-paver
[28] http://www.q-bot.co/index.php
[29] http://eksobionics.com/industrial/
[30] https://www.engadget.com/2016/03/21/panasonic-robotic-suits/
[31] http://www.husqvarna.com/us/construction/products/demolition-robots-product-range/dxr-250/
[32] http://www.rethinkrobotics.com/sawyer-intera-3/
[33] http://www.kansas.com/news/business/aviation/article1078842.html
[34] http://www.dezeen.com/2016/05/19/ron-culver-joseph-sarafian-fabric-forms-cast-concrete-robotic-arms-construction-method-of-the-future/
[35] http://mx3d.com/projects/bridge/

- In the deconstruction phase there is work being carried out at the research phase into robots that can recover waste from hazardous or hard to reach locations (it is being developed for the nuclear industry by Forth Engineering, based in Cumbria, and the University of Manchester)[36] *[C31]*
- Research into the potential for using drones to detect and repair potholes in roads. An ESPRC funded project being carried out by Leeds University[37] *[C32]*
- Development of wearable robotic limbs to aid humans when lifting, holding objects and carrying our repetitive tasks. Developed at Massachusetts Institute of Technology[38] *[C33]*
- Large scale robotic 3D concrete printing – developed in concept by researchers at the University of Dresden in Germany[39] *[C34]*

5.4 Summary of current and leading-edge developments

The above developments in automation are summarised in the figure below.

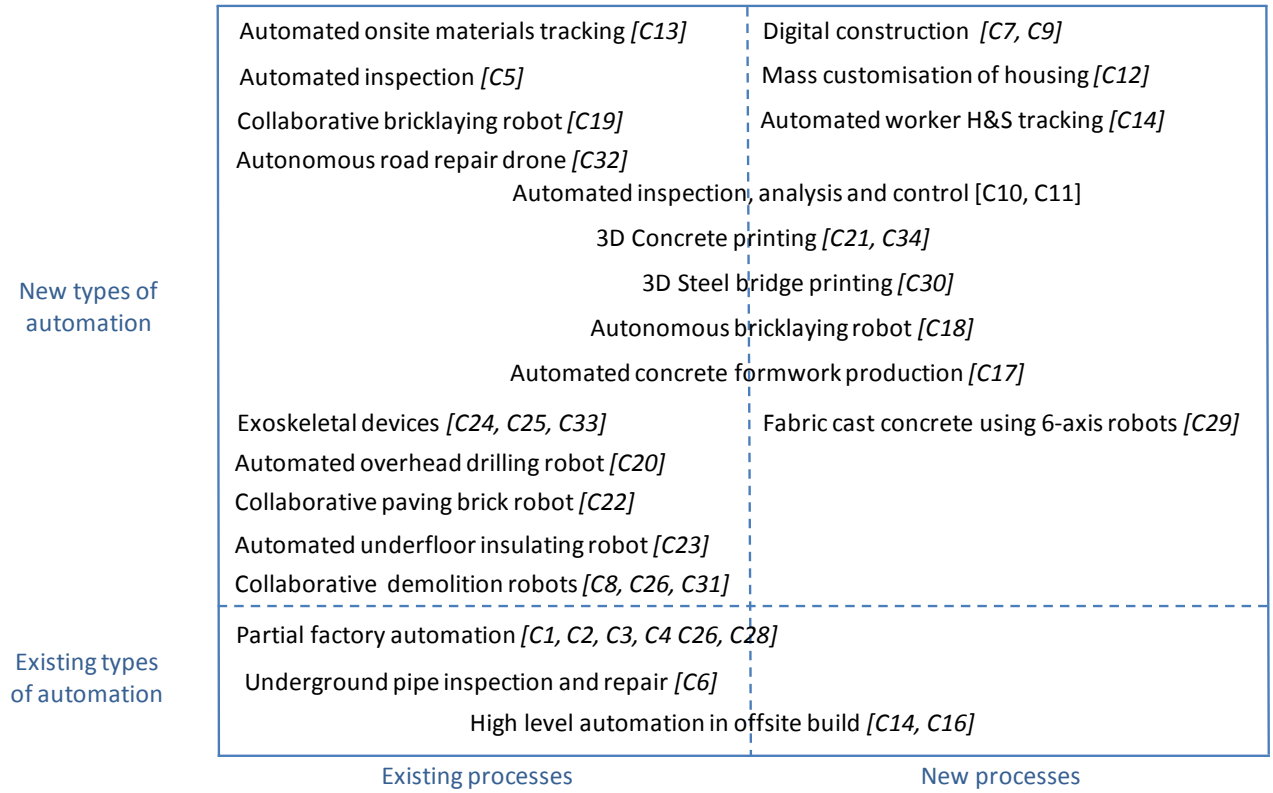

Figure 6 - Examples of current and leading-edge developments

[36] https://nda.blog.gov.uk/2016/06/27/the-role-of-robotics-in-nuclear-decommissioning/
[37] https://engineering.leeds.ac.uk/news/article/228/leeds_wins_42m_funding_to_develop_robot_fixers_of_the_future
[38] http://darbeloff-lab.scripts.mit.edu/darbeloff-lab/?page_id=296
[39] http://digitalconstructionnews.com/2016/05/17/german-team-unveils-large-scale-3d-printed-concrete/

The developments are segmented depending upon whether they directly replace a human process or whether the robot achieves an outcome that could not be achieved by a human in an economic way. The developments are also segmented depending on whether they involve existing automation or will require new technology.

6. Analysis of potential implications

This section summarises the key themes identified in previous sections of the report.

6.1 SWOT Analysis

The strengths, weaknesses, opportunities and threats related to the adoption of automation by the Scottish construction sector are summarised below.

Strengths	**Weaknesses**
- There is a significant push to increase the adoption of digital construction (BIM) by the Scottish construction sector - Developments are already underway (by CSIC) to launch a facility to enable construction companies to assess and test automation options - Automation of remote vehicles is a well-developed area in other sectors (e.g. subsea). Could learn from this - Expertise to support the development of the automation supply chain in specific areas already exists across various academic research centres covering, robotics, sensors and digital	- Weak base of labour with experience of automation - Currently Scotland is not leading in any area of automation in the construction sector - The structure of the demand and supply sides of the construction sector is such that certainty of future demand is limited and this constrains capital investment in large scale automation - No major robotics suppliers with an established presence in Scotland (although there are other specialist engineering companies in Scotland that work with robotics suppliers for local delivery) - Requirement for short pay-back periods in Scotland and UK, compared to companies in mainland Europe, restricts investment opportunities
Opportunities	**Threats**
- Increased automation will accelerate the existing trend to offsite manufacturing in controlled environments - Practical training of experienced construction operatives in robotics (linked to CSIC facility and possible cross-sector opportunities, particularly in factory automation) - Automated asset inspection is a short to medium term opportunity for construction (also applicable to oil & gas, energy transmission infrastructure and renewables sectors) - Automated monitoring of onsite components and materials has been identified as a development opportunity - Learn from other sectors on automated decommissioning (e.g. nuclear) and automated manufacture (e.g. automotive)	- A continued lack of stable long term demand for housing (of sufficient scale) is likely to limit the justification for investment in high levels of off-site automation by existing players - Large off-site automated factories (based in the North of England) may compete in Scottish housing market – displacing onsite activity - Disruptive innovation from outwith the industry eg Legal & General Homes, potentially other financial services companies

Table 1 - Adoption of automation in Scottish construction – strengths, weaknesses, opportunities and threats

6.2 Key market barriers and potential solutions

The table that follows summarises the key barriers identified through the consultations and secondary research. Solutions to overcome these barriers are also summarised.

Barriers	Solutions
Limited market size and uncertainty of demand limiting investment in automation in offsite housing manufacture	The Scottish Government has attempted to support investment in the civil engineering sector by publishing an Infrastructure Investment Plan[40]. In housing, The Scottish Government has developed an Affordable Housing Supply Programme, which targets 50,000 additional affordable homes by 2021[41]. Feedback suggests further certainty of demand is required to justify investment in higher levels of automation
Interoperability of commercial and proprietary Building Information Modelling (BIM) systems acting as a partial barrier to the adoption of digital construction	Initiatives already in place, such as open source standards for BIM data exchange[42]
Limited Scottish based examples of automation in construction is a barrier to increasing awareness	Construction Scotland Innovation Centre is in the process of launching a centre where the construction sector can view and trial automation technologies
Limited automation skills of workers in the construction sector	CSIC are working with Further Education colleges to provide exposure to automation technologies to construction related students
Regulatory environment will, correctly, constrain functioning of automated inspection drones	Develop a better understanding of how technology opportunities in this area interact (and are constrained by) regulations

Table 2 - Summary of barriers and solutions to increasing automation in construction

6.3 Strategic implications for the construction sector

Achieving the vision, described in section two, requires the construction sector to continue to invest time to develop and evaluate the business case for adopting automation technologies. This includes considering automation technologies that are already developed, those at demonstration stage and those at research stage requiring collaboration with the automation supply chain to develop new solutions.

In some cases adopting automation technologies can be carried out on a modular basis by piloting equipment/software on individual projects to evaluate the benefits before deciding whether to adopt more widely. This is a practical approach where capital expenditure is relatively low, such as exoskeletal suits for use on construction sites and overhead drilling

[40] http://www.gov.scot/Resource/0049/00491180.pdf
[41] https://beta.gov.scot/policies/more-homes/affordable-housing-supply/
[42] http://www.buildingsmart-tech.org/

robots. In such cases the action for the construction sector is to identify opportunities to pilot the automation solutions and evaluate the benefits.

Where new automation solutions are being developed then the action for the construction sector is to act as a lead market for the supply chain and become involved in the innovation process so that the end solution matches market need. This requires activities to create links between companies in the construction sector and new or existing innovators in the supply chain. The construction sector could then express a credible level of future demand by for new automated technologies to drive innovation in the supply chain. Working with the soon to be launched CSIC automation facility, the wider network of expertise in universities and innovative solution providers is a key action to enable this collaboration.

The task of adopting automation technology is relatively more difficult where capital expenditure is much higher. For example, investment in automated production processes for offsite manufacture of buildings can require millions of pounds of investment. In these situations feedback from stakeholders has suggested that lack of certainty of future market demand limits the level of investment that can be justified within acceptable payback periods. Key actions to address this issue are required by other stakeholders. This includes actions by the public sector on the demand side (to build upon announced plans for investment in housing and infrastructure) and on the supply side (a clear path of tightening regulations on energy efficiency standards in housing and provision of financial and business support to the construction sector).

6.4 Strategic labour market implications 2015-25

The adoption of automation by the Scottish construction sector offers the opportunity to add to existing efforts to increase the attractiveness of the sector to new entrants. Reducing repetitive and potentially hazardous tasks required to be carried out by human labour and increasing the technological content of various job functions are actions which will help attract new entrants.

A key action for the construction sector is to identify existing and emerging solutions that have the potential to reduce health and safety risks (e.g. remote controlled demolition robots, automated inspection at height, overhead drilling robots and automated H&S monitoring devices).

A shift of labour from mobile site based work to single site factory based labour is also a trend that some stakeholders suggest will make the construction sector a more attractive career destination.

A key action for the construction sector is to work with education sector to ensure that employers' investment in upskilling supports the existing workforce as well as new entrants. In addition, the industry and the education sector should agree the technical capabilities needed among the future labour force. This includes the need for expertise in operation of automated equipment and digital tools including, but not limited to, automation equipment operation, maintenance and repair, aerial drone control, 3D printing and BIM systems.

In response to trends of an ageing workforce and the increases in state retirement age, the construction sector faces a key action to increase adoption of automation to improve abilities to cope with fatigue and the resultant increased risk to health and safety of the labour force (for example through the use of exoskeletal suits).

7. Conclusions and recommendations

This section describes the conclusions and recommendations arising from the research.

7.1 Conclusions

The key conclusions of this research are:

- Based on feedback from a stakeholder in the robotics supply chain, Scotland currently has a low level of adoption of automation and robotics in the construction sector relative to the rest of the UK and other leading countries such as Japan, Germany, France, Sweden and Denmark
- There is already a co-ordinated effort to increase the uptake of digital construction amongst the Scottish construction sector supply chain
- The Scottish Government has a procurement target to specify BIM Level 2, where appropriate, for its construction projects. This will increase adoption of digital construction
- There are a number of new solutions emerging on the market to exploit the data captured in a BIM model and it is likely there will be further opportunities for a supply base to expand in this area (and these solutions offer export potential for the Scottish economy, if an indigenous supply chain can be developed)
- The planned facility to be opened by the Construction Scotland Innovation Centre, to demonstrate automation and robotics, will help raise awareness and reduce perceived risk
- Stakeholder feedback indicates that the Construction Scotland Innovation Centre will site some robotic equipment at a small number of further education colleges to support training of the current and future workforce
- There is a range of academic research expertise in various Scottish Universities and greater co-ordination of the key research centres around specific areas of opportunity could be beneficial for the construction sector and the (currently small) Scottish automation and robotics supply chain. Feedback from stakeholders highlighted that opportunities to be investigated could include automated inspection of infrastructure and automated monitoring and tracking of onsite materials and components
- There are many examples of offsite and onsite automation technologies already being used (or at trial stage) in other countries. These offer good opportunities to adopt in Scotland in the next five years. This includes the use of exoskeletal wearables (both onsite and offsite), drone inspection (and use alongside BIM data, positioning systems and laser scanning) offsite collaborative robots (e.g. for pick and place operations) and repair and maintenance opportunities such as automated underfloor insulation robots
- A number of technologies are at research stage and these may be taken up by early adopters in the Scottish construction sector in the 5 to 10 year period. These technologies include 3D printing and onsite collaborative robots for functions such as bricklaying and block paving.

- There is a strong example of disruption in the existing supply chain with a new entrant from the financial services sector. The move into offsite home building by Legal and General Homes (and the intended use of a level of automation on a par with that used in the automotive sector) promises to offer the market a level of customisation and end product quality beyond that which currently exists. If this is demonstrated to be a successful model there is the potential for other financial service companies to follow Legal and General into the market and target the Scottish market for new build housing. However, one stakeholder suggests the impact on the Scottish market of this model could be limited as the build cost of the houses is significantly higher than other existing offsite manufactured solutions and that the market opportunity was restricted to the South East of England.

7.2 Recommendations

To increase levels of adoption of automation in the Scottish construction sector the following recommendations could be considered (segmented by actions to be led by construction sector companies and the automation supply chain, industry bodies and the public sector):

7.2.1 Construction sector companies and the automation supply chain

- Identify opportunities to pilot automation technology that has been demonstrated and operated elsewhere
- Identify opportunities to collaborate with the current and emerging automation supply chain to develop new automation solutions. For example:
  - Investigate the potential to develop of automated inspection solutions relevant to construction, energy infrastructure and oil & gas sectors (involving industry users and universities via CSIC)
  - Investigate the potential to develop automated monitoring and tracking of onsite components and materials (involving industry users and universities via CSIC)
- Promote the benefits to productivity, resource use and health and safety performance of adopting automation solutions
- Invest in workforce development to support the wider adoption of automation solutions.

7.2.2 Industry bodies

- Raise awareness of the productivity, resource use and health and safety benefits that have been achieved by others in the construction sector as a result of adopting automated solutions
- Work to catalyse joint development projects in areas of common unmet need where a number of construction sector companies can act as credible sources of future demand and active participants in the development of new innovative automation solutions (for example, automated onsite materials tracking and automated inspection, analysis and control solutions)

- Work with a cross section of construction sector companies and the automation supply chain to articulate future labour market skills requirements arising as a result of higher levels of adoption of automated solutions

7.2.3 Public sector

- Continue to optimise certainty of future demand in housing via credible expression of public sector housing demand (this will support the case for investment in higher levels of automation in offsite construction)
- Continue to increase minimum energy efficiency standards in domestic dwellings (this will support demand for offsite manufacture of houses as higher energy efficiency standards become easier to achieve with offsite relative to onsite build)
- Support the development of automation training opportunities at the soon to be launched CSIC facility (through working with supply chain companies to develop a training presence in Scotland)
- Provide support to construction sector companies interested in investigating adoption of automation (for example, via the CSIC facility using funded PhD students)
- Continue to provide access to research, development and innovation funding for innovative suppliers seeking to develop automated solutions (for example SMART Grants and the R&D Grant Scheme operated by Scottish Enterprise)

Appendix A – Bibliography/ List of sources

In addition to the footnote references to specific case examples and other evidence, the following sources were used to inform this report:

- Imagining construction's digital future, Capital Projects and Infrastructure, McKinsey & Company, June 2016
- The UK Landscape for Robotics and Autonomous Systems, Innovate UK, 2015
- Digital in Engineering and Construction – The Transformative Power of Building Information Modelling, The Boston Consulting Group, March 2016
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- Frans van Gassel and Ger Mass (2008), 'Mechanising, Robotising and Automating construction processes', Robotics and Autoation in Construction, Carlos Balauer and Mohamed Abderrahim (Ed), ISBN: 978-953-7619-13-8, InTech
- Baselining and research into the construction sector in Scotland, SQW, 2012
- Exploring the impact of the ageing population on the workforce and the built environment, CIOB, 2015

Appendix B – Glossary of terms

Term	Definition
Automation	The substitution of human labour by machine labour to carry out physical, cognitive and organising tasks
Autonomous Aerial Vehicle	Also known as 'drones', this is a particular class of automation technology which ranges from direct human control to fully automated inspection combined with provision of data to allow further automated commands to be issued
Building Information Modelling (BIM)	A standardised approach to digital construction being adopted by the construction sector and its supply chain (see definition of digital construction below)
Digital construction	A computer based class of automation that allows virtual construction of buildings and structures with accompanying cost and performance data that can be updated automatically as a result of changes to design specification. Digital construction offers the ability to share detailed information across the supply chain and is an enabler of other automated product and service development
Exoskeletal devices	Physical devices 'worn' by workers to reduce fatigue, reduce health and safety risks and improve performance capabilities beyond human levels
Robotics	A class of automation where programmed machines perform task to replace or collaborate with human workers. Robotic systems are typically suited to standardised repeatable tasks

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