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From lessons to practice: Compliance and assurance prototypes for manufactured buildings

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Preface

This report investigates international practice in quality assurance and compliance for manufactured buildings and the enabling factors that make them work well. The aim is to help initiate practice change in supporting new compliance and assurance prototypes in New Zealand by drawing on lessons learned from other countries where manufactured buildings are a more significant part of their building industry.

This report presents the findings from stage one of this research project. In the second stage, an eco-system approach will be used with system dynamics modelling so end users can see what and where constraints exist in the construction sector/processes that handicap the use of a new compliance/assurance method, and what conditions are required to support compliance and assurance for manufactured buildings.

Acknowledgements

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We are indebted to our international research collaborators who assisted with data collection in their home countries. We want to acknowledge the contribution from Professor Lars Stehn and Dr Matilda Höök, Luleå University of Technology (Sweden); Dr René Jähne and Professor Daniel Hall, NCCR Digital Fabrication & ETH Zurich (Switzerland); Dr Kenneth Park, Aston University (UK); Dr Bon-Gang (BG) Hwang, National University of Singapore (Singapore); Dr Yingbin Feng, Western Sydney University (Australia); and Dr Jingke Hong, Chongqing University (China). The common goal of our international collaborators in gathering the practices adopted by their construction industries and sharing for the benefit of the New Zealand construction industry reflects the true genuine spirit of cross-country research collaboration.

Finally, we are grateful for the review comments provided by BRANZ, MBIE Building System Performance Branch and several industry advisors for quality control of this report.

From lessons to practice: Compliance and assurance prototypes for manufactured buildings

Authors

Alice Chang-Richards, Marwan Gharbia and Xun Xu

Reference

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Abstract

Traditional assurance and compliance regimes in New Zealand appear to be insufficient for manufactured buildings. As New Zealand is increasingly exploring greater use of manufacturing in construction and other modernised construction methods, it is essential to learn from countries where manufactured buildings are a more significant part of their building industry. By using a mixed method approach, including a literature review, interviews, a questionnaire survey and workshops, this project discussed the quality assurance methods used in Sweden, Switzerland, UK, Australia, Singapore and China and the implications for New Zealand. A prototype model of QA and compliance, together with a set of recommendations were suggested for stakeholders across the supply chain to consider in order to reduce the regulatory consenting burdens and to improve the performance of manufactured buildings.

Keywords

Quality assurance, compliance, product manufacture, prefabrication, international practice

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Acronyms

BRANZ	Building Research Association of New Zealand
MBIE	Ministry of Business, Innovation and Employment
BIF	Building Industry Federation
QA	Quality assurance
QCPA	Quality Certification Planning Committee (Japan)
BCA	Building consent authority
LBP	Licenced Building Practitioner
OSM	Offsite manufacturing
CSA	Canadian Standards Association
BIP	Building Innovation Panel, Singapore
BBA	British Board of Agrément
BOPAS	The BuildOffsite Property Assurance Scheme
ISO	International Organisation for Standardisation

Executive summary

Manufactured housing solutions/buildings have come afore as a new and perhaps more competitive solution for providing affordable housing options. As New Zealand increasingly explores the greater use of manufacturing in construction, traditional assurance and compliance regimes predominantly focused on individual products and systems may not suffice. It is critical to understand the differences in approach between quality assurance for a whole prefabricated building heading off to multiple destinations, versus the current array of inspections performed on all products, and on all sites; as well as the opportunities to do things differently and better when everything is brought together in one place.

This research project looked at how other countries manage quality assurance for manufactured systems throughout the building process. In particular, it investigated what New Zealand can learn from Sweden, Switzerland, UK, Australia, Singapore and China, where manufactured buildings are a more significant part of their building industry. By identifying the levers for an improved QA and compliance regime, research stakeholders and end users can draw on this research and eliminate barriers and create opportunities for supporting innovation.

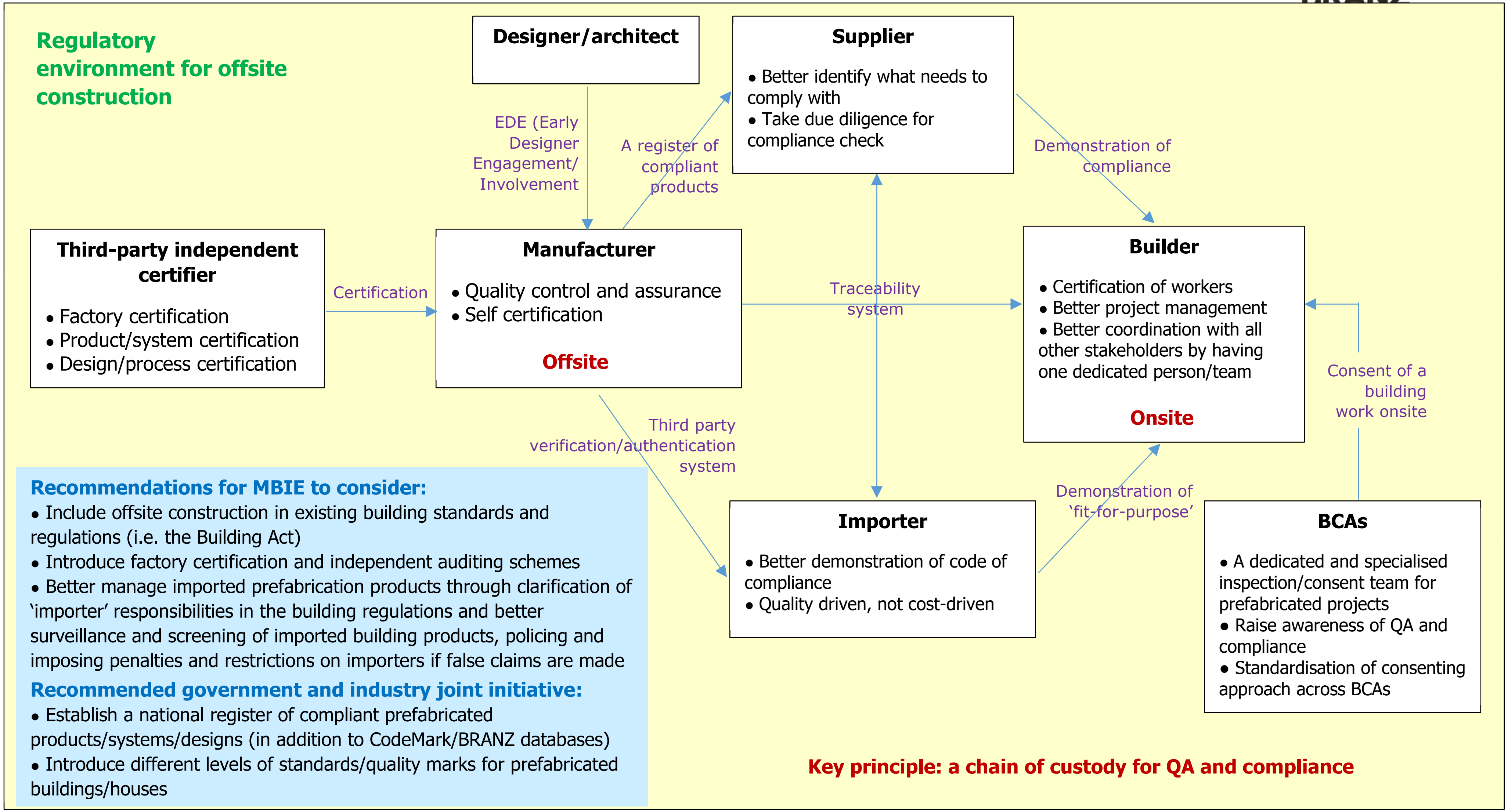
While manufacture-self-certification seems to be the predominant QA method used across the six countries, the survey results highlighted the importance of having a balanced allocation of risk and liability across the supply chain with clearer roles and responsibilities for manufacturers, suppliers and builders. Imposing restrictions and penalties, policing and enforcement of existing regulations, third-party product certification, manufacturer certification and a traceability system were suggested amongst the most essential mechanisms in attaining an effective QA and compliance regime for offsite construction.

Survey responses highlighted the environmental benefits of using offsite construction and provided quantitative information on offsite construction cost saving (26% on average) and time saving (32% on average) in comparison to traditional onsite construction. The primary mechanisms for driving the uptake of offsite construction and perceived barriers to market acceptances were also investigated in this research, along with implications for New Zealand conditions.

For New Zealand's offsite construction industry to flourish, this research suggests that a founding principle for a successful QA and compliance regime is the establishment of a chain of custody across the supply chain where all stakeholders from designers, to manufacturers, suppliers, builders and BCAs take their due diligence. A prototype model of QA and compliance for manufactured buildings in New Zealand is recommended (See the model overleaf). The research findings show that the industry would particularly benefit from a factory certification system that would address differences in approaches between QA for a whole prefabricated building heading off to multiple destinations, versus the current array of inspections carried out on all of products, and on all sites, and therefore reduce the regulatory consenting burdens on BCAs.

The research offers regulatory lessons to inform the current Building System Legislative Reform Programme led by MBIE. For instance, for the MBIE to consider to include offsite construction in existing building standards and regulations (i.e. the Building Act) and introduce factory certification/accreditation and independent auditing schemes, as well as better manage imported prefabrication products. Other initiatives recommended that require industry leadership with support from the government included to establish a national register of compliant prefabricated products/systems/designs (in addition to the CodeMark/BRANZ databases) and to introduce different levels of standards/quality marks for prefabricated buildings/houses.

The final recommendation is to develop industry-led initiatives to increase the visibility and transparency of product lifecycles. To create a more conducive environment in the building regulations for innovation, third-party certification of conformance and compliance should become the industry benchmark. The use of an electronic traceability system and a third-party verification platform would add value to a chain of custody type of QA regime and benefit the New Zealand offsite construction sector by providing confidence in the domestic market, enhancing their credibility and reputation, as well as giving them a competitive edge in a global market.



A prototype model of QA and compliance for manufactured buildings in New Zealand

1. Description of the research

1.1 Research questions

The research seeks to develop new assurance and compliance prototypes for prefabricated products and systems by drawing on lessons learned from other countries. To achieve this goal, the project set out to address three research questions:

1) What the issues are and where traditional/current assurance and compliance regimes are creating problems for supporting the advancement of manufacturing in construction in New Zealand?
2) What lessons about product assurance and compliance for manufactured buildings can be learned from countries where manufacturing in construction is more advanced?
3) How can successful efforts in other countries be transferred to New Zealand that provide potentially novel approaches to QA processes in achieving more efficient production, successful business models and competitive value chains?

1.2 Methodology

1.2.1 Research design

The research project has been divided into two stages as described below. The stage one was addressed and the findings are presented in this report, the stage two is to be addressed.

Stage one (October 2018–August 2019)

1) Review the existing literature on international practice of QA and compliance for offsite construction;
2) Collect empirical data on current product assurance approaches used from the perspectives of manufacturers and importers as well as local authorities in NZ;
3) Collect the same type of data from Sweden, Switzerland, UK, Australia, Singapore and China;
4) Study the enabling factors for the compliance and assurance approaches used across the countries under investigation;

Stage two (under consideration)

5) Identify the critical conditions that will provide conducive environment for new approaches to be introduced/used in NZ; and
6) Construct product assurance and compliance prototypes and empirically validate these against case study manufacturers and suppliers.

The project involves three critical components:

- A review from the literature on current product assurance framework in New Zealand and alternative approaches overseas;
- Engaging MBIE, local Building Consent Authorities (BCAs) and industry groups, such as BRANZ, Building Industry Federation (BIF), PrefabNZ and Manufacturing NZ etc., as key stakeholders in research design, interviews and workshops; and
- Working with research collaborators in countries where manufactured buildings are a more significant part of their building industry to collect data on their product assurance practices.

The methodology adopted for data analysis in stage two is to use the simulation which is based on the system dynamics modelling approach introduced by Jay Forrester (1961). A Vensim modelling technique will be used in this project to give insights into the potential time and cost implications across different assurance and compliance options discovered in other countries, and what might work for New Zealand as novel ways for both BCAs and building manufacturers and suppliers.

The project implementation pathway in Figure 1 shows the staged tasks and deliverables of the timeframe.

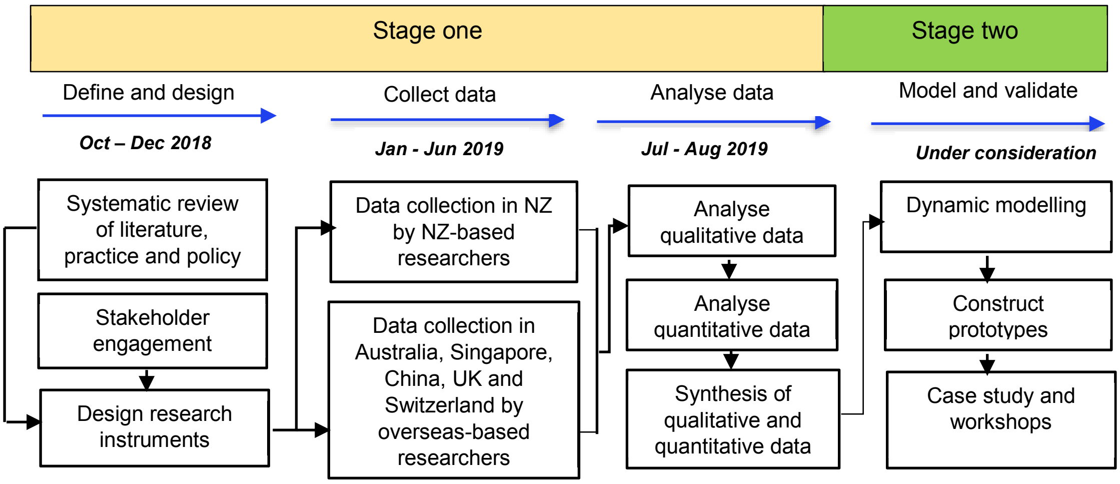


Figure 1: Research project implementation pathway

1.2.2 Research methods

The research methods used for each step to answer the specific research questions are outlined in Table 1. The research received ethical approval from the University of Auckland Human Ethics Committee (Reference number 022976).

Table 1: Research methods used for answering the research questions

Research question	Research methods
1. What the issues are and where traditional/current assurance and compliance regimes are creating problems for supporting the advancement of manufacturing in construction?	• Literature review • Interviews • Workshop
2. What lessons about QA and compliance for manufactured buildings can be learned from countries where manufacturing in construction is more advanced?	• Literature review • Questionnaire survey • Workshop
3. How can successful efforts in other countries be transferred to New Zealand, which provides potentially novel approaches to QA processes in achieving more efficient production, successful business models and competitive value chains?	• System dynamics modelling • Case studies • Workshop

For the purposes of this report, the research methods used to answer the research questions in stage one are reported. Detailed methods for the research in stage two and the findings from stage two will be presented in a later report.

Literature review

A review of documents and publications on current issues within the New Zealand manufactured building industry was conducted, including the challenges of compliance and assurance that MBIE, BCAs, building manufacturers and builders face in regards to using fabricated products and systems. A holistic review of international literature relating to the QA and compliance regimes in other countries was also conducted. Both reviews were undertaken from October to December 2018 and informed the questionnaire.

Interviews

Semi-structured interviews were conducted with eight people between October and November 2018 (See Table 2). The interviews were important as they allowed understanding of the challenges of compliance and assurance that faced the construction sector and the implications for different agencies, especially BCAs and prefabrication companies. The selection of interviewees was based on criteria such as the person's occupation, type of organisation where the person worked, and their experience and work relevance in the building work/product compliance processes.

Table 2: Participants in the interviews

Interviewee code	Type of organisation	Occupation/work relevance
B1	Prefabrication builder	Managing director
C1	Auckland Council	BCA inspector
C2	Bay of Plenty Council	BCA inspector
G1	MBIE	Building systems
G2	MBIE	Building systems
P1	BIF	Building product compliance
M1	Manufacturer	Building product quality control
L1	Architect	Licenced Building Practitioner (LBP)

Questionnaire survey

In order to investigate what New Zealand could learn from other countries including Sweden, Switzerland, UK, Australia, Singapore and China where manufactured buildings are a more significant part of their building industry, a survey was developed. The survey is intended for 1) building product manufacturers, 2) prefab builders/contractors, or 3) building inspectors of local authorities in these six countries. The survey was designed to gather their knowledge about QA and compliance practices for building products/components that are made offsite, as well as their perspectives about what worked well, what did not, and why.

The authors of this report collaborated with lead researchers from research institutions in six countries. The sampling strategy was to use research collaborators' existing networks that in their home country. Data collection was conducted over a six-month period from February to August 2019. The design of the questionnaire included a common structure of questions to gather the same type of information from each country (see Table 3). The survey sought to collect (See Appendix 1 a sample of questionnaire survey):

- QA methods used for prefabricated building products and components and their effectiveness
- Roles and responsibilities for the chain of custody over QA
- Mechanisms for making a successful QA system

- Clarity on definition of the manufactured buildings
- Levers for the prefabricated buildings to become mainstream accepted
- Regulatory settings for compliance/QA of manufactured buildings

Table 3: Structure of the questionnaire survey

Questionnaire structure	Data/ information collected
SECTION A Participant information	Type of organisation
	Type of building products
	Duration of trading
SECTION B QA	Comment on QA system
	QA systems used
	Effectiveness of QA systems used
	What worked well and what did not
	Who guarded the product quality
	Mechanisms needed for a successful prefabrication QA system
	Legal remedies for non-compliant products
SECTION C Manufacturing in construction	Classification of manufactured buildings
	Mechanisms for prefabricated buildings being mainstream accepted
	Barriers to market acceptance
	Benefits of prefabrication/manufacturing in construction
SECTION D Regulatory environment for manufactured buildings	Consent process
	Duration of consent process
	Comments on how to improve consent process
	Channels of QA and compliance education
	Other levers to support QA and compliance of manufactured buildings

As of 23 August 2019, the number of survey responses from each country is shown in Table 4.

Table 4: Questionnaire survey response rate

Country	Number of people the survey was distributed to	Number of responses	Response rate
Sweden	114	29	25%
Switzerland	50	7	14%
United Kingdom	40	10	25%
Singapore	30	13	43%
Australia (NSW)	40	4	10%
China	100	59	59%

Descriptive statistics were used to analyse the questionnaire data collected from individual countries and then a cross-country comparative analysis was performed. By aggregating the questionnaire results in a comparative manner we could identify the primary QA methods and possible relevant mechanisms across the range of countries studied.

Workshops

Two focus groups in the form of industry advisory workshops were organised in Wellington on 5 December, 2018 and 18 July, 2019. The workshops involved advisory committee members, representing government agencies, industry bodies and prefabrication companies. Each workshop was used to discuss the current issues and changes in the regulatory system and consenting practice for the manufactured buildings. Key information from the two workshops included:

- The first workshop raised the profile of product QA and compliance as a critical industry issue that has placed a disproportionate burden on the end of the product supply chain and BCAs. It investigated the challenges of compliance and assurance that MBIE, BCAs, building manufacturers and builders face in regards to using fabricated products and systems, and highlighted the importance of taking a measured and proportionate risk-based approach to addressing the product QA and compliance issues.
- The second workshop evaluated the questionnaire survey results and discussed how the practice learned from other countries can be applied in the New Zealand context, and what potential changes can be made to smooth the risk allocation across the entire supply chain of manufactured products and building systems.

In the following sections, the research results are presented in the form of a synthesis of literature, interviews, and questionnaire and workshop results.

2. The QA and compliance system in New Zealand

2.1 Offsite manufacturing (OSM)

OSM is usually understood as 'prefabrication' or 'modularisation' and is not new in New Zealand. About 85 per cent of the country's current home construction involves prefabrication in some form [1]. The form of manufactured component varies from automated frame and truss, bathroom pods, large scale kitchen joinery, window componentry, wall panels, to construction of transportable housing. The development of building products has been from a component and systems perspective following the incorporation of different components/elements in the construction process. From an industrial perspective, however, there are three types of OSM products used in construction [2]:

- Simple elements: Beams, columns or other parts of a structure that have been manufactured to be easily bolted into place onsite.
- Panelised systems (2D): Elements that are used for walls, such as insulation, utilities, waterproofing and external/internal cladding. These components are designed to allow for rapid assembly and flat pack transportation.
- Volumetric systems (3D): Three dimensional modular objects that comprise the floor, ceiling and wall components for a single room/unit.

The three types of OSM products differ in the degree of prefabrication, although all three involve both offsite and onsite construction work. The development of OSM products in New Zealand has also progressed from fairly open standard components and elements to more closed company specific systems.

2.2 Performance versus prescription

New Zealand's building control system is performance-based with several alternative pathways to ensure that building products, systems and methods meet the specific requirements of the New Zealand Building Code. While most materials, products and systems fit in the product assurance framework/pyramid based on their level of risk, industry practitioners still consider that the full potential of innovation (including access to compliant products) is not being achieved due to a number of operational issues within the system. Perceived barriers include a lack of knowledge and understanding within certain parts of the industry and the broader liability framework providing a bias against innovation [3, 4].

While OSM could provide a potential solution for achieving quality, affordable homes to meet the housing programme ambition, an instrumental regulatory environment to support assurance and compliance for manufactured buildings is needed. Compared to conventional onsite construction, OSM requires a closer working relationship between architects, engineers, fabricators and contractors to ensure that the design translates into seamless production and later assembly [5]. This creates enormous opportunities for the use of different building parts, products, components and systems, either manufactured offshore or onshore, in a building work to achieve productivity and efficiency gains. However, unless each modular component gets 'peeled' and scrutinised by building officials and certifying agencies, the use of those components is considered to pose a great liability risk to local BCAs [5, 6]. Therefore, the performance-based regulatory requirement which only sets the minimum standards for what should be achieved without prescribing the rules, means that compliance demonstration is critical for those builders adopting any innovative techniques [7]. Such legal frameworks have discouraged most New Zealand manufacturers from spending time and money to innovate their products and enhance QA systems [8].

2.3 Regulatory settings for offsite construction

The Building Act defines "building work" as work for, or in connection with, the construction, alteration, demolition or removal of a building [9]. While manufactured buildings comprise many components such as the structural elements in a timber truss, the product versus building work has not been clarified in the Building Act. The stage of construction which identifies if the components of a structure or a building can be considered as building work cannot be captured due to lack of standardisation and in particular, inconsistent application of the building code [10]. This can be attributed to the different interpretations in each BCA, their lack of expertise, and variation in the consenting capability [11].

While one of the ways to work on the lack of standardisation could be through producing guidance documents to specifiers and manufacturers, it would be significantly different for overseas companies as the building code imposes special NZ contextual considerations for soil conditions, seismic issues, wind velocity and prevalence and coastal variations in many cases [1, 10]. Currently, there is no clear idea on how to translate the compliance systems used in other countries to New Zealand code requirements, which results in an extensive workload to consent imported products. Meanwhile, consumers' preference for low cost design and construction may also impact the quality of construction materials being imported into New Zealand [11]. As suggested by views from our first workshop, the Building Act needs to include the responsibilities for 'importers' in addition to 'manufacturer and supplier' in order to assure the performance requirements of offshore products.

A national multiple-use approval (known as Multiproof) was introduced in 2010 by MBIE to accelerate the consent process for standardised designs and enhance the compliance process for prefabricated buildings with the Building Code. The first workshop held with industry advisory committee suggested that Multiproof needs more flexibility to allow for a wider variety of housing designs and plans to be preapproved. Although there is no difference in consent process whether the prefabricated elements have been manufactured in New Zealand or offshore, the procedure still lacks efficiency. Industry representatives also voiced that the length of time required to develop a standard for alternative solutions for inclusion in the building code has discouraged the use of non-traditional construction methods and systems. For instance, Multiproof approvals could take up to 40 days and cost between $900 and $15,000 in practice [12] and in many cases, they do not allow for much space for design or site variations [11].

Views from our first workshop suggested that the current consenting and regulatory framework has been characterised by the absence of standardised details used for offsite construction. The consent process in particular was found to be complex for offshore products. In addition, construction phase checks by BCAs create delays to the production and are found to be costly. It was suggested that about 20–25% of the cost can be saved if the regulatory consent efficiency can be improved. A BRANZ report recommended that standardisation would help mainstream the process, reduce design and compliance costs, and encourage the broader architecture and design fraternity [8].

In New Zealand, we do not have a formal quality management system for offsite construction [7]. BCAs observed that internal QA is limited in small firms and they often rely on council inspectors to quality assure their work [11]. Furthermore, the first workshop reported that there are often wide-ranging and recurring issues with the quality of the information supplied by the manufacturers as well as suppliers about imported products. Auckland Council is calling for industry to put quality standards in place to help improve consent applications and, in turn, reduce the length of the consent process. The workshop also suggested that the consent process would also likely be improved by having a specialist team within BCAs and by having consistent interpretation of the Building Code and consenting practice for offsite construction. Either an independent contractor or establishing a team within BCAs is an option.

2.4 Current product assurance framework in New Zealand

The term 'product assurance' describes the overall system that product manufacturers or suppliers can use to establish and prove compliance with the performance requirements of the Building Code. Therefore, QA is the responsibility of manufacturers and suppliers to demonstrate/provide evidence that the product is sufficiently reliable for anyone to use. There are two compliance path choices for most manufacturers or suppliers [12]:

- Provide products that perform according to the methods set out in a compliance document, as part of an Acceptable Solution, or, where the product does not fully comply as an Acceptable Solution
- Investigate other options to demonstrate a product meets the performance requirements of the Building Code, as part of an alternative solution or verification method.

The New Zealand Product Assurance Framework[1] contains five assurance options [12] (see Figure 2).

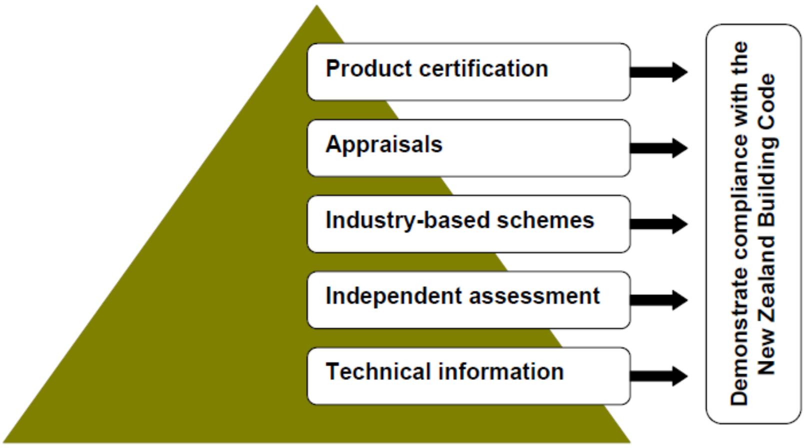


Figure 2: The New Zealand Product Assurance Framework (Source: [12])

- Technical information: This is the product information supplied by the manufacturer or supplier with technical details, including QA systems, product specifications, scope of use, and installation requirements or test results for the product.
- Independent assessment: Independent and often accredited assessors (such as Chartered Professional Engineers), or reputable testing laboratories carry out the verification and endorsement of product information.
- Industry schemes: These schemes are usually specific sector-based and self-audited for products assessed by a recognised organisation against specified industry requirements (e.g. glasses and concrete).
- Appraisals: This if often called third-party verification which involves testing and verification of all aspects of a product and results in a technical opinion.

[1] MBIE, Last updated: 21 March 2016. https://www.building.govt.nz/building-code-compliance/product-assurance-and-multiproof/product-assurance/products-and-building-code-compliance/

- Product certification: The product certification body (CodeMark or BRANZ) will issue a product certificate which provides independent confirmation that a building product complies with the Building Code. For a product that is new to the market or is highly innovative or novel, or can have significant consequences if it fails, the best route for a manufacturer or supplier to take is product certification.

3. Review of international QA practice for manufactured buildings

A review of overseas documents on certification schemes for the manufacturing industry suggests that there are three common forms.

- **Factory certification**: The factory certification process comprises defining a quality management standard, auditing the manufacturing facility against the standard and then issuing a "certificate of compliance" if the manufacturing facility meets every element of the standard.
- **Third-party certification**: An independent entity that audits and issues certificates stating that a product or process complies with a specific set of standards.
- **Product identification and traceability**: Product identification comprises codes, numbers, labels, names and other forms to enable products with one set of characteristics to be distinguished from others.

There has been considerable work performed overseas that provides evidence for good practice in ensuring assurance and compliance for OSM products in construction.

Canada [13-20]

The Canadian Standards Association (CSA) developed three standards that apply primarily to factory-constructed buildings.

- CSA A277: Procedure for the certification of prefabricated buildings, modules and panels. This standard is used to specifically certify the factory.
- CSA Z240 MH Series: Sets standards for constructing manufactured homes. In British Columbia, for instance, all prefabricated buildings, prefabricated modules, and prefabricated panels must comply with the technical requirements of the Building Code.
- CSA Z240.10.1: Site preparation, foundation and anchorage of manufactured homes. This standard is referenced in the Canadian Building Code.

In 2013, the Canadian Housing Observer reported that there were 123 factories certified under CSA A277 in Canada. CSA certification ensures each manufacturing facility maintains strict quality control and inspection programmes and utilises well trained labour, a design staff with thorough building code knowledge, and skilled inspectors who monitor and inspect each home at each stage of the production process. The QA and compliance process in Canada is shown in Figure 3. The manufacturer is responsible for maintaining a quality programme and design procedures to ensure that products consistently comply with applicable requirements. After completing the initial evaluation process, periodic in-factory surveillance inspections are carried out by a third-party firm to ensure continued operation and implementation of the quality programme and to ensure that construction of the buildings continues to comply with the relevant requirements.

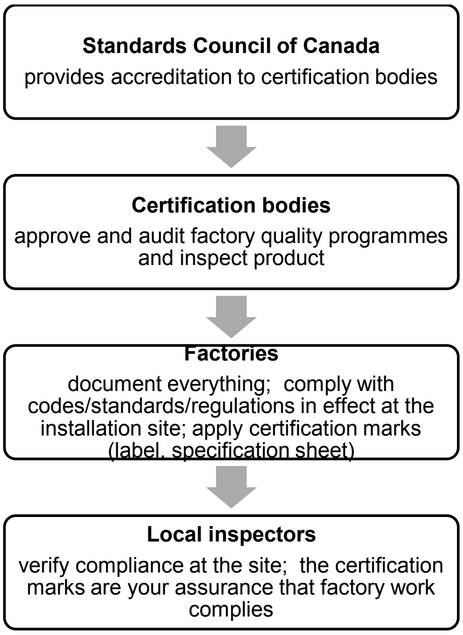


Figure 3: The QA and compliance process in Canada for manufactured buildings (Source: [17])

Japan [21-28]

For many Japanese, the brand name associated with large companies offers QA and a guarantee that the company's product will prove to be defect-free and that the company would be accessible and willing to fix or replace it at no cost to the consumer. Meanwhile, many manufacturers inspect houses at regular periods after completion to obtain feedback on their products and to offer aftersales services. Since the introduction of the "Home Guarantee System" and "After Sales and Maintenance Services System" in the 1960s, all major prefabrication companies followed this strategy by establishing service systems in which companies can use the prefabricated buildings inherent modularity for upgrades, renovation, re-arrangement and re-customisation services.

The establishment of certification standards is deliberated by the Quality Certification Planning Committee (QCPA), and the duty of inspections is entrusted to third-party certifiers. Quality is inspected rigorously after each production step, as every company has developed quality checklists with 200–300 different items for each house for early detection of mistakes and to save time and cost. The Ministry of Land, Infrastructure, Transport and Tourism established the housing performance labelling system and certifies private companies to conduct the assessments (with 108 agencies as of 2005) and issue housing performance evaluation, in addition to the housing QA law to ensure that buildings are properly rated for structural stability and fire safety. The mixed cohort of strategies used in Japan to ensure the manufactured buildings meet the quality and compliance standards are show in Figure 4.

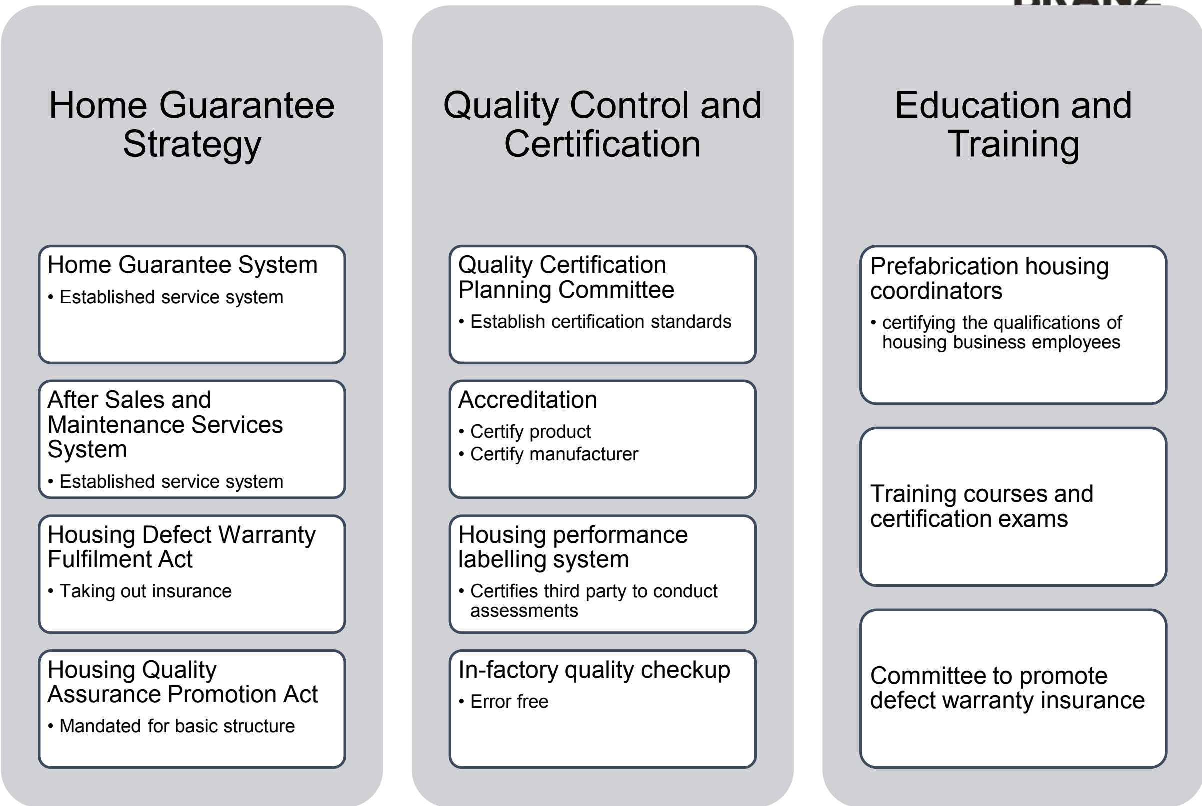


Figure 4: Strategies used in Japan to ensure quality and compliance of manufactured buildings (Source: [21])

Singapore [29-40]

Suppliers and manufacturers who intend to supply their systems to be used at development sites in Singapore must first ensure that their systems meet the performance requirements. They are required to submit their applications and proposals to the Building Innovation Panel (BIP) with documentary evidence of compliance with codes of practice (Singapore or overseas), track record, material specifications, and quality certifications or test reports by accredited laboratories. The proposed systems are then subjected to the evaluation and acceptance of the BIP (see Figure 5).

The production facilities that have been accepted through the BIP are required to be accredited under the Manufacturer Accreditation Scheme, which is managed by the Singapore Concrete Institute and the Structural Steel Society of Singapore as part of the effort to promote greater self-regulation by the industry. Moreover, BIP has set-up an acceptance framework[2] to certify each supplier and manufacturer to ensure the reliability and durability of the different systems. The accreditation assessment emphasises capabilities, processes and specific quality criteria for the system. The scheme ensures QA and control in the production and sets the process for manufacturers to produce high quality prefabricated prefinished volumetric construction systems and maintain high quality standards.

[2] Building and Construction Authority, Singapore Government https://www.bca.gov.sg/BuildableDesign/ppvc-acceptance-framework.html

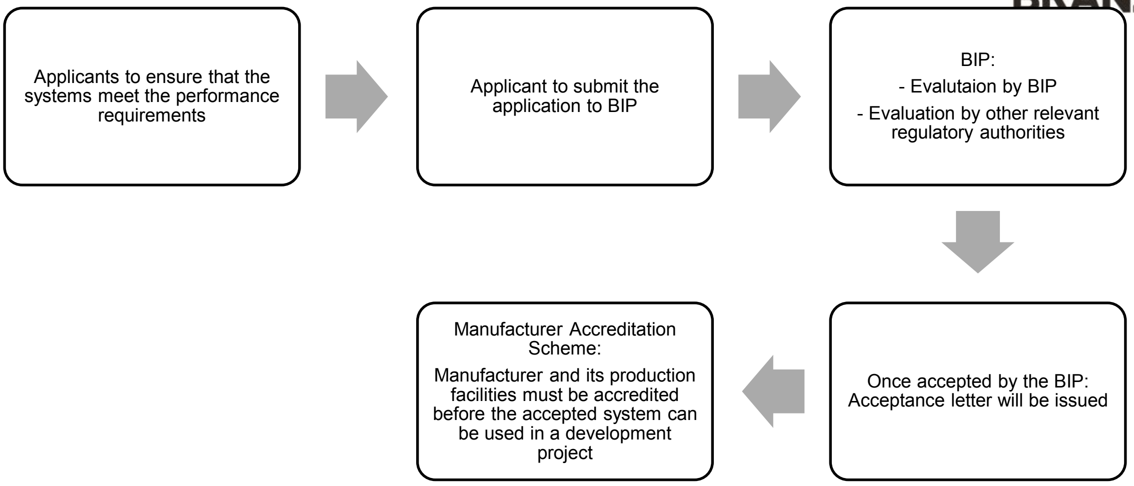


Figure 5: QA and compliance schemes used in Singapore for manufactured buildings (Source: [39])

UK[3]

The British Board of Agrément (BBA) is an independent UK organisation that offers an approval service for construction products, systems and installers. They are the UK's major authority for providing reassurance to consumers, and achieve this through Agrément certificates with the following services. An Agrément certificate is issued for a successful product or system following a detailed assessment including both laboratory testing and inspections. In addition, the manufacturer is audited to ensure they have an adequate quality management system. Repeated testing is undertaken for the duration of the certificate’s validity period.

The BuildOffsite Property Assurance Scheme (BOPAS) was launched in 2013 to address the perceived risks associated with innovative construction and is recognised by the principal mortgage lenders as providing the necessary assurance underpinned by a warranty provision. The Property Assurance Scheme has been jointly developed by BuildOffsite, The Royal Institute of Chartered Surveyors, Lloyds’ Register, BLP Insurance and the Council of Mortgage Lenders to provide assurance to the lending community that non-traditional constructed properties against which they may be lending, will be sufficiently durable as to be readily saleable throughout the duration of two mortgage terms, which may equate to 60 years. Further, that the structural integrity will not intrinsically have a negative impact on the mortgage security during that term. The BOPAS comprises:

- Assessment and accreditation against best practice by Lloyd’s Register EMEA.
- A 60-year durability assessment by BLP Insurance.
- A web-based database comprising properties constructed under the BOPAS scheme with details of construction.

[3] Cited from a report prepared by our research collaborator Dr Kenneth Park, From lessons to practice: compliance and assurance prototype for manufactured buildings: UK offsite construction case study, see Appendix 3

4. Lessons learned from six countries – comparative analysis of questionnaire survey results

The uptake of OSM has been measured in a number of different ways at a point in time. In some countries, nearly 80% of newly-built homes are prefabricated off-site (in Sweden it is 90% uptake), whereas in New Zealand it's about 10% in construction. In the housing residential sector, a recent report by McKinsey[4] suggested that the current offsite share of housing is on average 45% in Finland, Norway and Sweden. It highlighted growth potential in markets such as Australia (5%), China (6%), UK (5%), Singapore (6%) and the US West Coast (3%). Although McKinsey's figures seem to be lower than that reported elsewhere, it is believed that the manufacture construction in those countries has played a larger part in their building and construction industry than it is in New Zealand and the momentum of OSM uptake in those countries is still growing. As New Zealand is increasingly exploring greater use of manufacturing in construction and other modernised construction methods, it is essential to learn from those countries. Between February and August 2019, a survey was conducted of prefabrication industry stakeholders concerning QA and compliance in six countries: Sweden, Switzerland, UK, Australia, Singapore and China. The results from this survey are presented in this section.

4.1 Survey of prefabrication industry stakeholders

The purpose of the survey was to:

- Understand the types of QA methods currently used in those countries for prefabrication/manufactured buildings, and
- Ascertain a configuration of good practice for an efficient QA and compliance regime.

A survey link and electronic copy of the survey were distributed by the overseas research collaborators in the six countries to their network of prefabrication industry stakeholders. As shown in Table 4, the survey was sent to a total of 374 stakeholders and 122 completed the survey, giving a response rate of approximately 33%. The number of responses received are broken down according to their type of organisations (see Figure 6).

[4] McKinsey: Modular construction: From projects to products https://www.mckinsey.com/~/media/mckinsey/industries/capital%20projects%20and%20infrastructure/our%20insights/modular%20construction%20from%20projects%20to%20products%20new/modular-construction-from-projects-to-products-full-report-new.ashx, June 2019

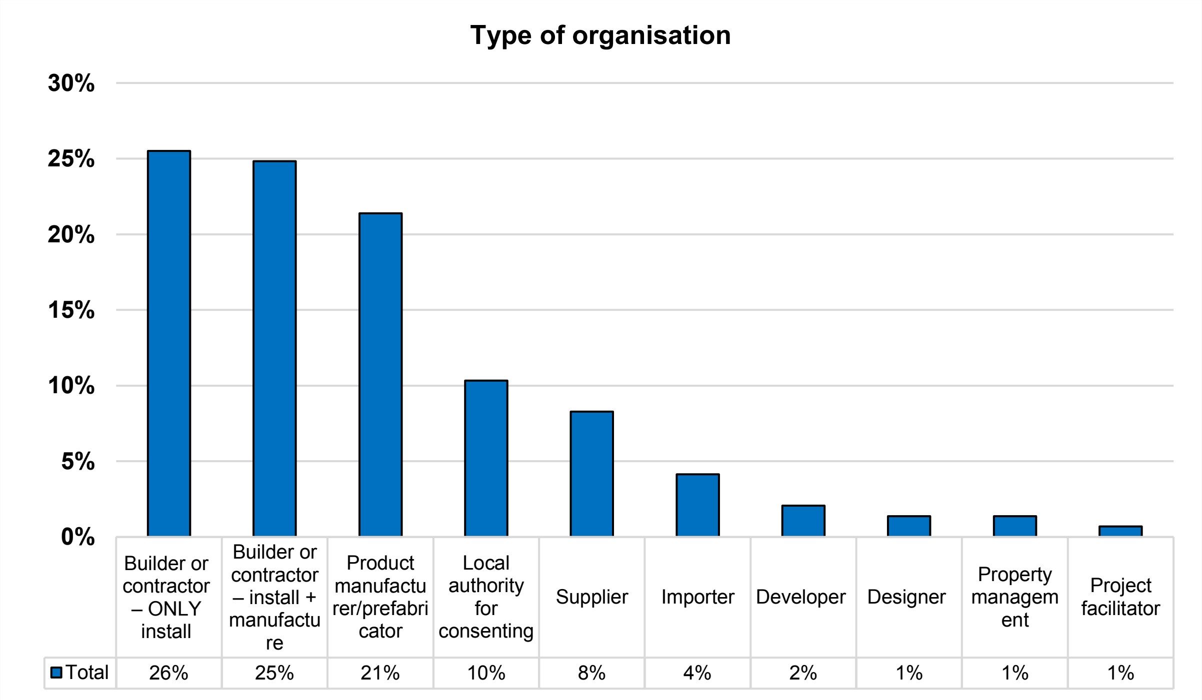


Figure 6: Organisations of survey participants

Figure 6 shows that 26% of survey participants were builders who only assemble and install prefabricated components onsite, while another 25% are those who have the capability to manufacture offsite and construct onsite. There were 21% of survey participants who were prefabrication product manufacturers/prefabricators, followed by 10% representing building inspectors in local government. Only 8% of respondent identified themselves as building product suppliers and 4% were product importers. A small percentage of surveyed stakeholders were developer (2%), designer (1%), property manager (1%) and project facilitator (1%). When asked about the length of operation related to prefabrication business, a large number of respondents (39%) reported that their company had been operating for less than five years. A fair number of respondents (28%) reported that their company had been established for more than 20 years. A total of 24% of respondents reported that their company was relatively young and had been in the industry for more than five years but less than ten years. Of the respondents, 9% of them reported that their company had between 10 to 20 years industry experience in prefabrication.

For those whose organisation had the capability to manufacture prefabricated products and buildings (56 out of 122 respondents), 35% reported that their company produced volumetric (3D) systems, while 28% of respondents reported that their factory manufactured panelised (2D) systems. Another 35% of respondents suggested that their company produced simple elements. Only 1% of those manufacturers made a whole house and another 1% of companies specialised in making trusses (see Figure 7).

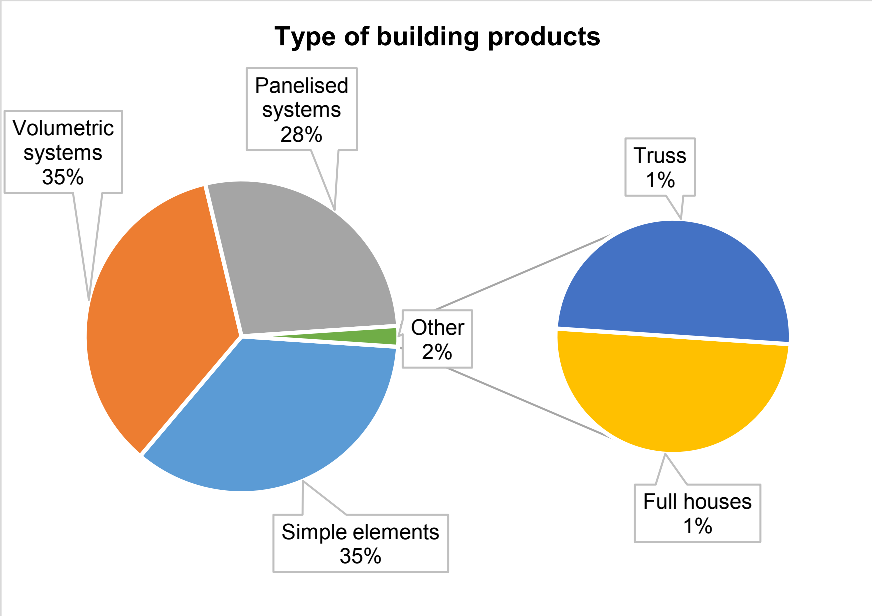


Figure 7: Types of building products manufactured by the respondents' companies

4.2 QA systems used for manufactured buildings

When asked about the QA methods used for prefabricated building products and components, more than half of respondents thought a robust QA system for prefabricated products should be a combination of both a chain of custody across the product supply chain from manufacture to builder and a traceability-based system. Figure 8 shows the types of QA methods cited by the survey respondents.

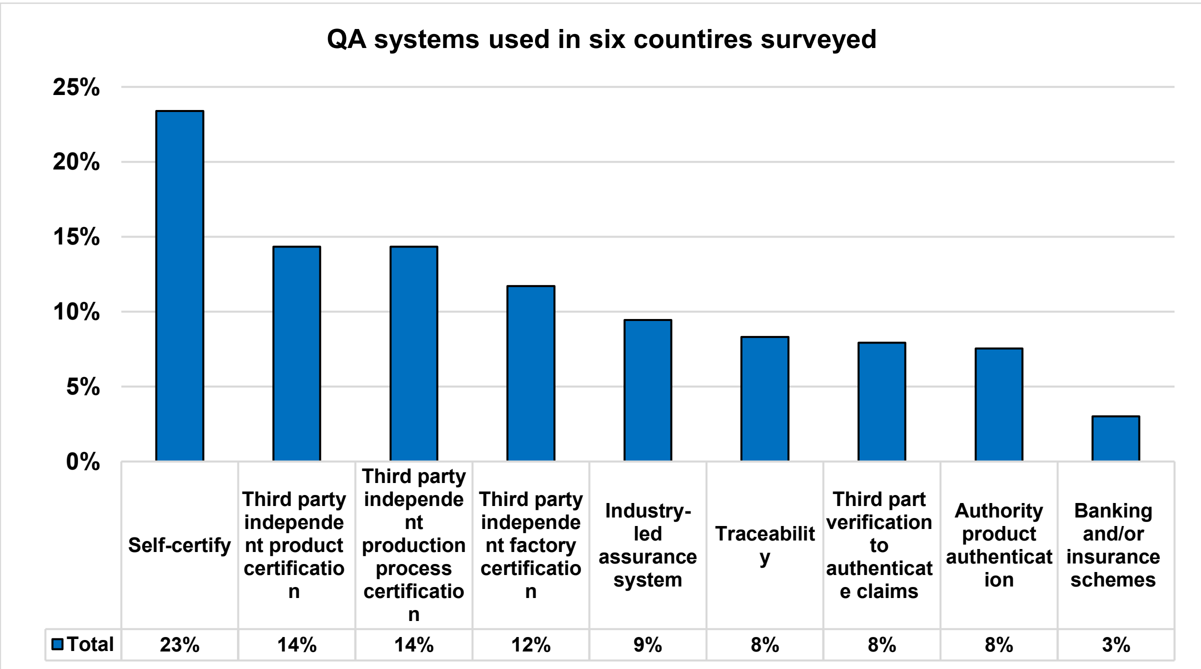


Figure 8: QA systems used for manufactured buildings

4.2.1 UK

If we look closely at the specific systems used in individual countries (see Appendix 2), we find that in the UK the third-party independent certification seems to play a major role in future proofing the quality of prefabricated components, whether they are panelised or volumetric. The main types of third-party certification included (see Figure 9):

1) Certification of the product design and production process,

2) Certification of factory, and

3) Certification of products.

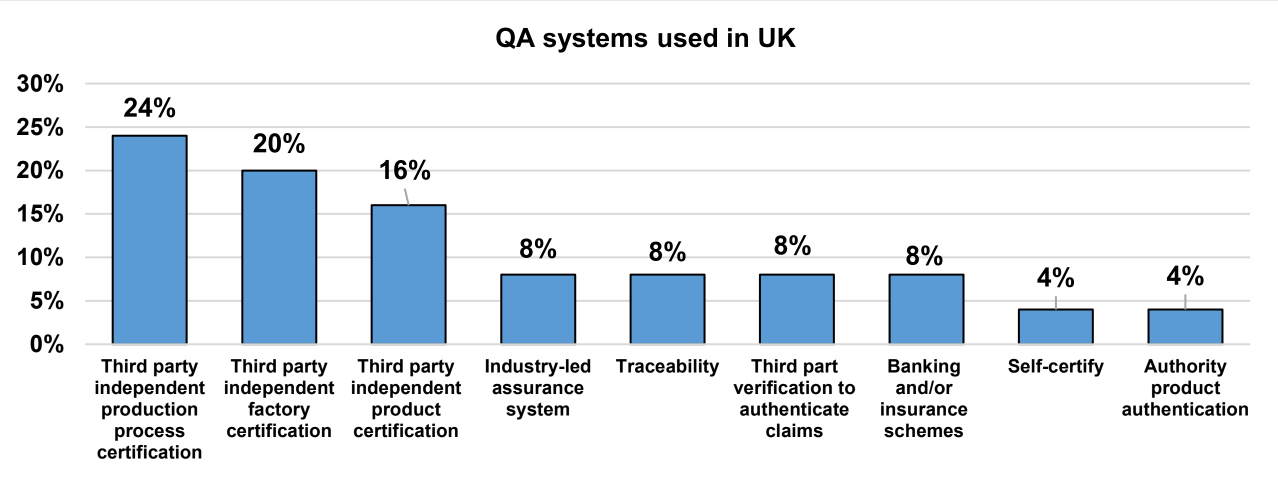


Figure 9: QA systems used for manufactured buildings in UK

It is also not surprising to see that 43% of respondents in the UK found such a certification regime to be effective, while another 43% found it to be extremely effective. Additionally, respondents suggested the following measures which they considered to work well for QA:

- Industry supported assurance schemes, especially BOPAS
- Digitisation of QA at a factory level integrated with enterprise resource planning systems
- Manufacturers setting up shop floor metrics for quality control and assurance
- Better supervision and monitoring of construction workers who assemble or install prefabricated components onsite

In comparison, the majority of the respondents did not consider regulations to be the only solution to assessing the QA and compliance issues for construction manufacturing. As show in Figure 10, the current QA and compliance regime used in the UK is a chain of custody. The individual manufacturing companies control the quality for their own products with their process, design, product and factory being certified by third parties (e.g. BBA certification and BOPAS) with tremendous support and involvement of prefabrication industry bodies, building sector associations, lending institutions and insurance companies. Detailed information about certification and assurance schemes for offsite construction in the UK can be found in Appendix 3 – a review report prepared by Dr Kenneth Park, Aston University, UK.

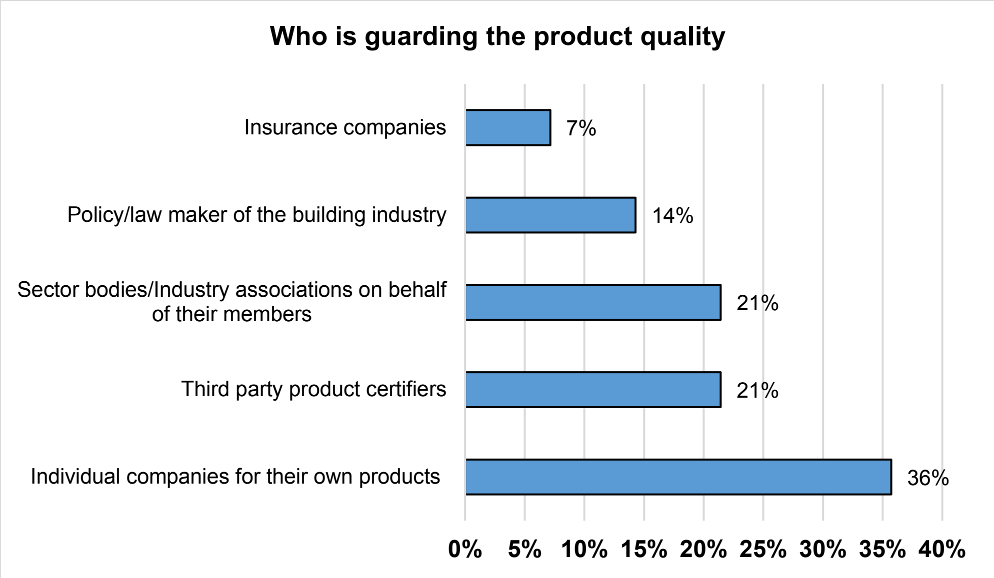


Figure 10: Roles and responsibility for QA of manufactured buildings in UK

The survey results and the two primary QA schemes (BBA certification and BOPAS) in the UK suggest that sector bodies are best placed to lead the QA and compliance schemes.

4.2.2 Switzerland

Although the response rate was low, all seven survey participants in Switzerland came from an organisation that had been operating in the prefabrication industry for more than 20 years, with nearly half identifying as a product manufacturer/prefabricator. As shown in Figure 11, the Swiss participants suggested that their current QA approach is led by a self-certification measure, backed through third-party independent certification and a system of traceability of products. Four of the seven respondents believed that their QA systems seemed to work well, while the other three held neutral opinions about the effectives of their QA systems. It is therefore not surprising that all seven participants suggested that it is the individual companies who guard and are responsible for the quality of their own products.

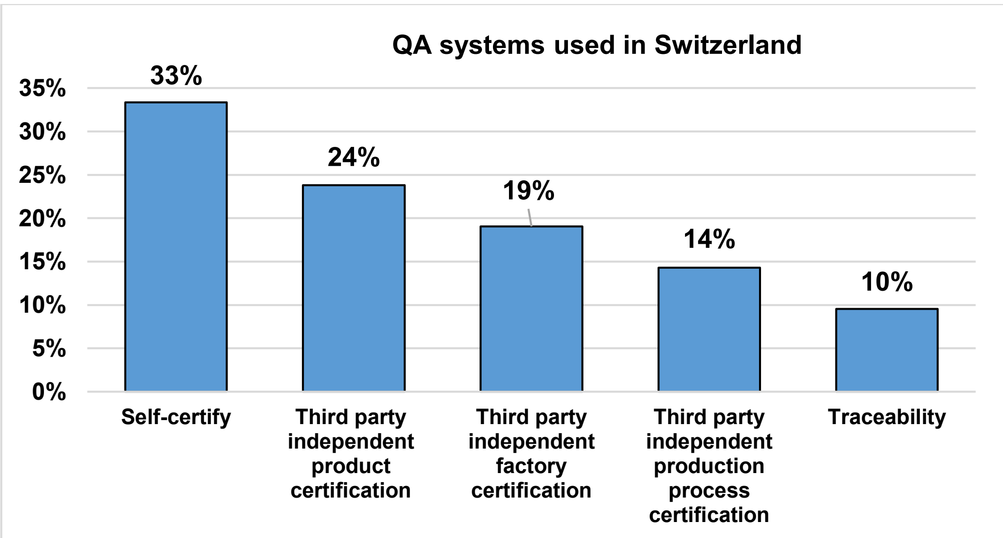


Figure 11: QA systems used for manufactured buildings in Switzerland

4.2.3 Sweden

The survey results from Sweden seem to present a slightly different picture in comparison with the UK and Switzerland. As shown in Figure 12, out of 29 survey participants, 43% indicated that self-certification is the primary mechanism used for QA in their construction manufacturing industry. In addition to having product authentication systems operated by local authorities (8%) and third-party bodies (7%) to certify products, there is an emphasis on inspecting and certifying the factory production process (15%) and factory facilities and capacity (11%). As Sweden has more than 90% uptake of prefabrication in the housing sector, the quality focus for prefabrication seems to be a norm for both prefabricators and builders. Such QA systems were positively commented on by those surveyed, with 7% rating them as extremely effective, while 57% of respondents rating them as effective and the remaining 37% being in a neutral position.

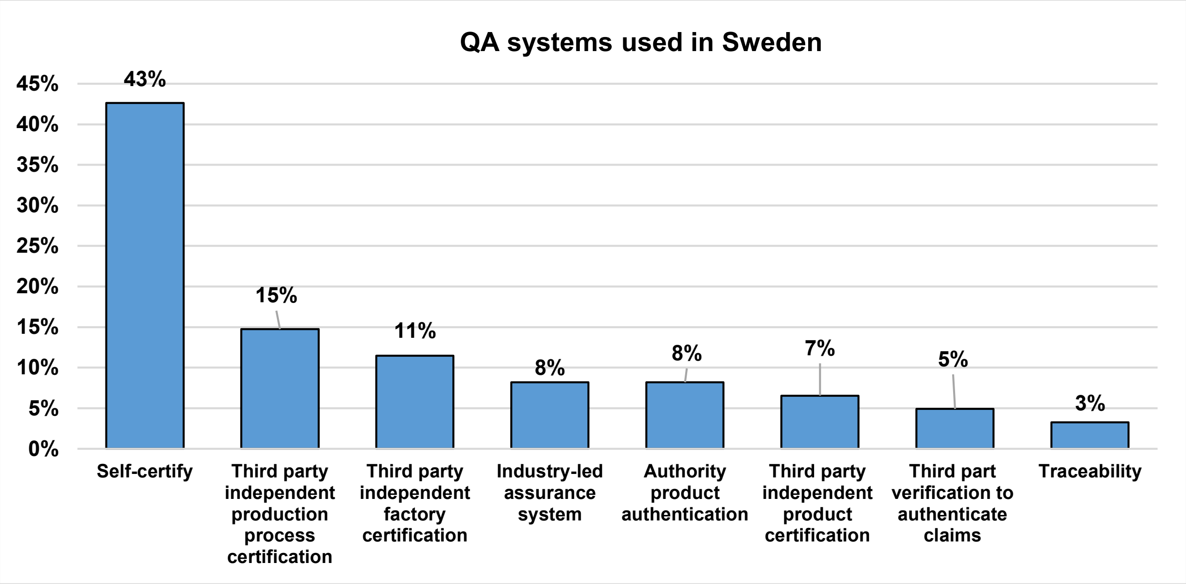


Figure 12: QA systems used for manufactured buildings in Sweden

The surveyed practitioners also suggested that the following measures have worked well in their QA systems:

- Self-monitoring for QA is critical for prefabricators during the production process
- Production processes being ISO audited and products being self-certified or approved by a third party
- Raising QA awareness at the factory level by undertaking cost and benefit analysis for QA and quality deviation.

There is a quality stewardship culture in the Swedish prefabrication industry with fewer regulatory interventions. In line with Figure 12, Figure 13 shows that individual companies (38%) have taken the due responsibility for the QA and compliance of their products, followed by third-party product certifiers. Several large modular home manufacturers in Sweden applied Toyota's production method that minimises waste and relies on factory workers to suggest ways to maximise efficiency of production lines. By employing assembly line robotics, these companies can streamline their production methods and gain competitive advantages. The law makers and regulators only play a significant part in providing legal remedy solutions for non-compliant products, such as consumer purchase law, consumer right of complaints, warranty, and a legal process for penalty.

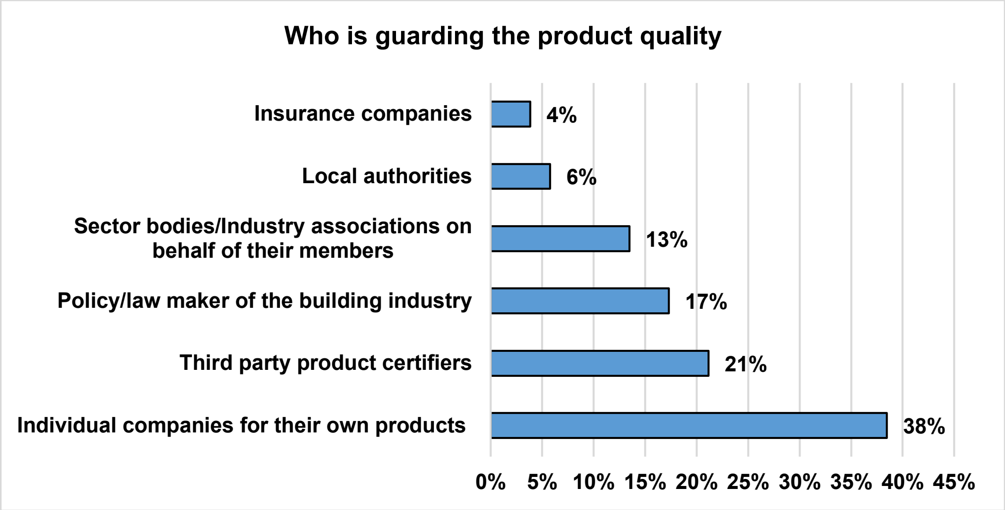


Figure 13: Roles and responsibilities for QA of manufactured buildings in Sweden

4.2.4 Australia

Current records held by prefabAUS and PrefabNZ suggests that there is only a 3% uptake of prefabrication in the Australian housing sector, with an ambition to achieve 10% of the market by 2020. Similar to New Zealand, there is a perceived gap in regulating imports of prefabricated products made offshore and that enter the building and construction industry supply chain. The state and territory building legislation is primarily focused on regulating the licencing and conduct of builders, not building products. Therefore, the regulatory framework in Australia seems to place a disproportionate burden at the end of the product supply chain (builder, installer and building certifier/surveyor) for QA and compliance issues.

Due to the small number of respondents (four survey participants) in New South Wales, Australia, findings cannot be considered as statistically representative. However, the findings provide some useful insights about the practice reported by these four participants (Figure 14) and what they see an ideal QA and compliance regime looking like for managing construction manufacturing.

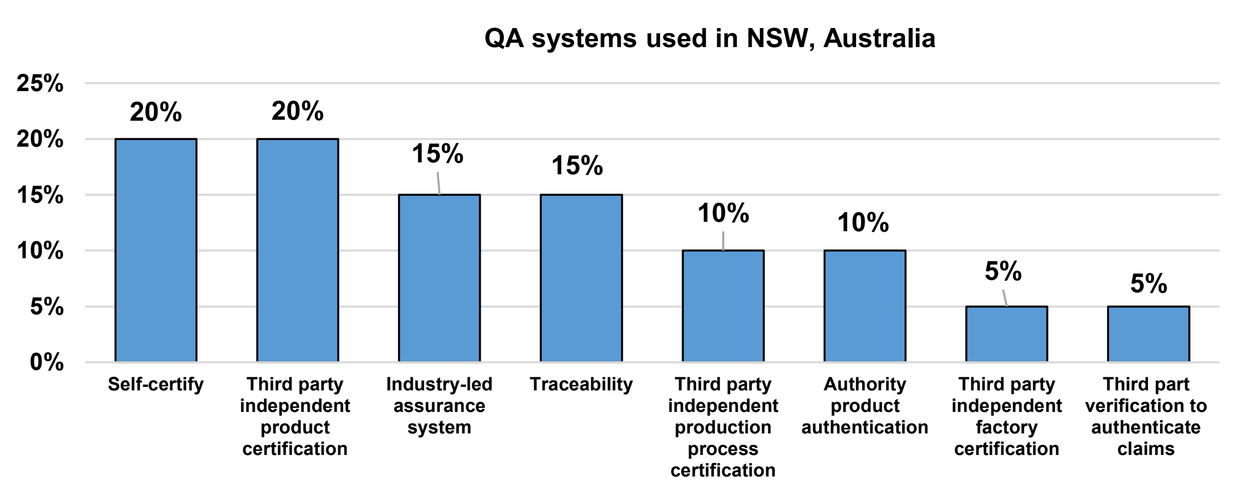


Figure 14: QA systems used for manufactured buildings in NSW, Australia

Respondents noted the value and importance of existing building industry initiatives, such as self-certification and industry third-party certification schemes. Other measures to address QA issues associated with manufactured/prefabricated products and buildings included having a traceability system and an authority product authentication platform. All the four participants thought the current QA measures were effective. In particular, they suggested that the following mechanisms worked well:

- Law and regulations (Australian Building Act, Consumer Law)
- Third-party certification schemes in identifying instances of building product non-conformity
- A QA system initiated by the manufacturer to be used throughout the supply chain

As the industry certification schemes are voluntary in Australia, individual prefabrication companies and manufacturers take the main responsibility for ensuring quality of their own products (Figure 15). The Australian Government is also making possible improvements to current regulatory frameworks for ensuring that prefabricated products and systems made both onshore and offshore conform to Australian standards, with particular reference to the effectiveness of:

- Policing and enforcing existing regulations for buildings (Building Act) and products (Consumer Law)
- Voluntary versus mandating independent verification and assessment systems
- Restrictions and penalties for non-conforming building products
- Surveillance of imported building products

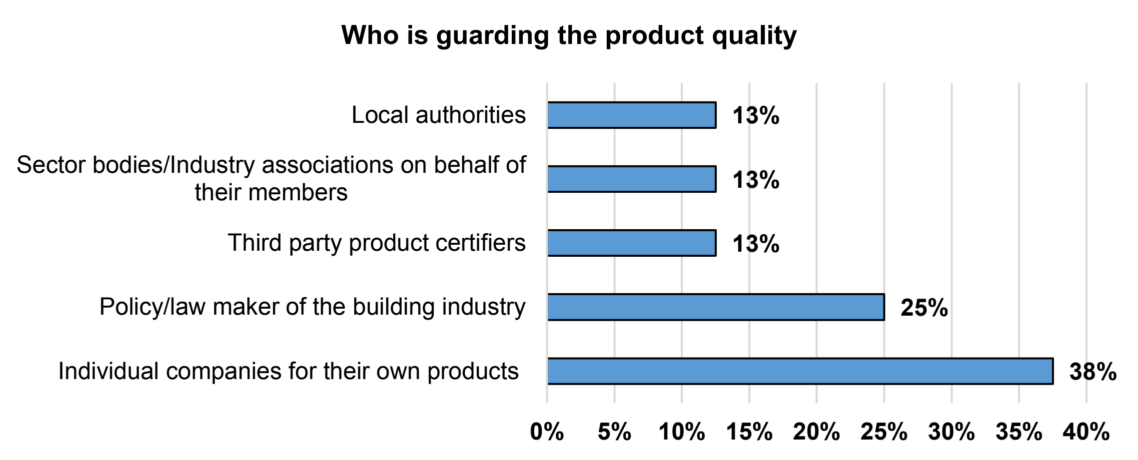


Figure 15: Roles and responsibilities for QA of manufactured buildings in Australia

4.2.5 Singapore

As mentioned in the previous review section, Singaporean suppliers and manufacturers who intend to supply their systems to be used at development sites must first ensure that their systems meet the performance requirements. They are required to submit their applications and proposals to the BIP with documentary evidence of compliance with codes of practice (Singaporean or overseas), track record, material specifications, and quality certifications or test reports by accredited laboratories. Such a requirement results in significant involvement of third-party certification schemes. As shown in Figure 16, survey respondents reported that modular home manufacturers and builders tend to have varying degrees of cooperation with third-party certifiers and different approaches to the QA of prefabricated products and buildings.

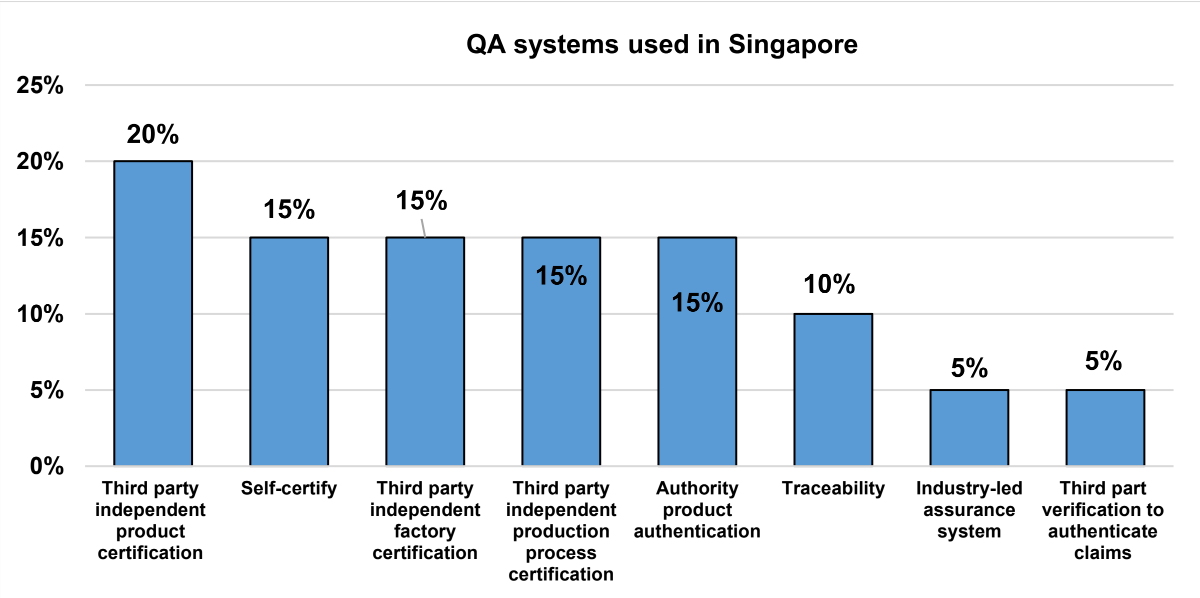


Figure 16: QA systems for manufactured buildings in Singapore

In response to the question about effectiveness of existing QA systems, most respondents expressed a positive attitude towards the current approach, with 80% indicating they thought existing QA systems were effective and 10% indicating they were extremely effective. The remaining 10% indicated they were neutral in opinion. When asked what worked and what did not, the response from the majority of respondents echoed what is reported in Figure 16. They reported the positive outcomes of manufacturers using:

- international QA scheme, such as ISO;
- third-party certification for products, factories and production lines/processes; and
- QA control during the factory production process and QA check upon the delivery of products.

In answering the question of what did not work well, one respondent reported performing QA checks after fabrication has been completed due to the high cost of rework. When analysing the roles and responsibilities in guarding the QA of manufactured products, individual companies (44%) (i.e. manufacturers and builders with manufacturing capacity), third-party certifiers (22%) and local authorities (17%) were seen as playing major roles. Those seen as playing minor roles were the central government building regulators (6%), insurers (6%) and industry bodies (6%) (see Figure 17).

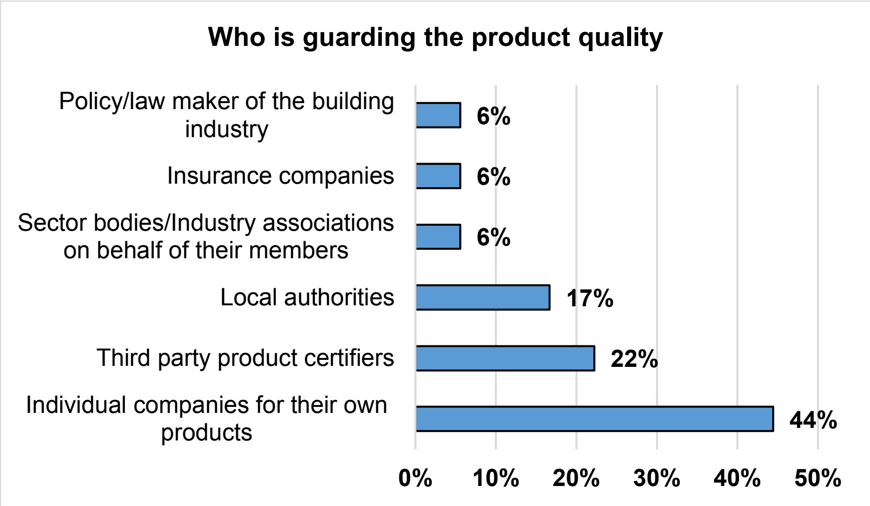


Figure 17: Roles and responsibilities for QA of manufactured buildings in Singapore

4.2.6 China

Figure 18 shows a wide range of QA methods used by manufacturers and prefabrication builders in China. The survey results show that self-certification (18%) is used for construction products of a lower risk of non-compliance. There were also options of access to third-party independent certification for products (14%), production line (13%) and factory facilities (9%). However, construction projects considered as being subject to high risk of non-compliant building products were based on a combination of traceability (9%) and authority-led product authentication (8%). Respondents also reported the use of lending agencies and insurance companies (5%) to insure against the quality issues for commercial building projects.

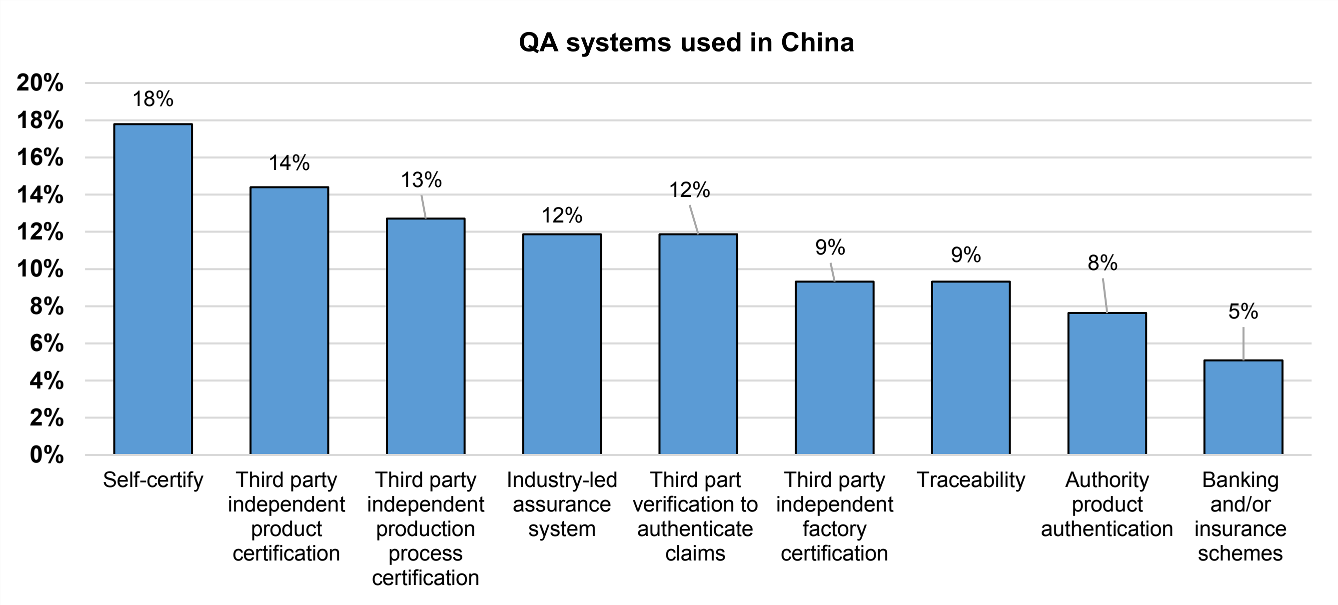


Figure 18: QA systems used for manufactured buildings in China

Out of the 59 respondents, 19% thought the QA systems applied were extremely effective, while 40% thought the QA systems were effective. Only a small number of respondents (8%) did not consider the existing approach to be effective. The most commonly stated measures that worked well included:

- Manufacturer self-certification via in-house QA
- ISO certification of products so that the products certified can be exported to countries that recognise ISO certification
- Traceability – this greatly increased the information sharing and transparency across the supply chain and the liability of product quality could be easily identified and addressed
- Third-party certifying workers who assemble or install prefabricated components onsite – this is mostly done through the accredited training agencies or those training agencies authorised by the local authority
- Enforcement of consumer law and bond requirement in the construction contract

Similar to the situation in Sweden, Figure 19 shows that in China, individual companies (35%) take the due responsibility for the QA and compliance of their products, followed by third-party product certifiers. Policy/law makers in the building industry in the areas of construction contract law, the Building Act and Consumer law have taken guardian roles in ensuring that builders fulfil their legal obligations when procuring building products.

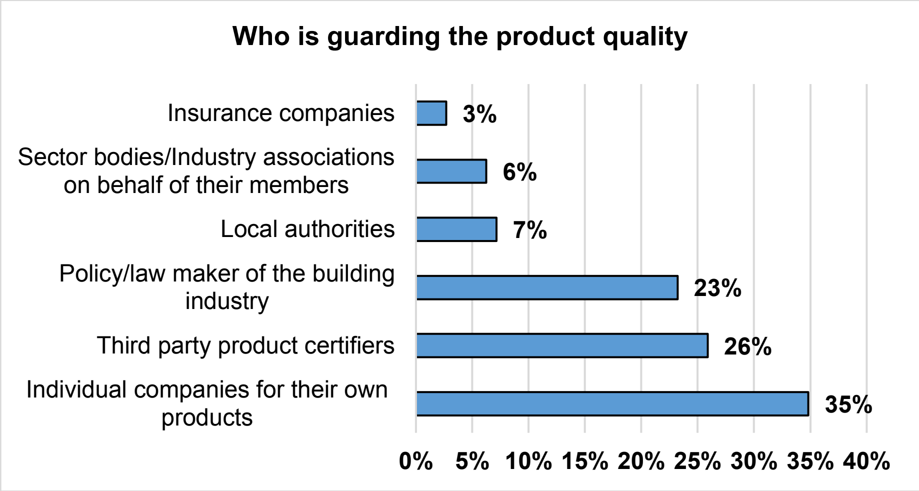


Figure 19: Roles and responsibilities for QA of manufactured buildings in China

4.3 Mechanisms needed for a successful prefabrication QA system

Figure 20 shows that half of the respondents (50%) thought a balanced allocation of risk and liability across the supply chain was essential, which highlights the importance of taking a measured and proportionate risk-based approach to addressing QA and compliance issues of manufactured buildings. Restrictions and penalties, and policing and enforcement of existing regulations were considered equally important (46%). Respondents also emphasised the importance of having third-party product certification (37%), factory certification (36%) and a traceability system (33%).

The key measures that were considered as 'nice to have' included:

- Surveillance and screening of imported building products (44%)
- Traceability system (43%)
- Factory certification (42%)
- Standardisation of interpretation of code compliance within local authorities across all regions (43%); A dedicated team in local authorities to review and address building consents for prefabricated/manufactured buildings (39%)
- Certification of workers who install or assemble prefabricated houses/buildings onsite (38%)

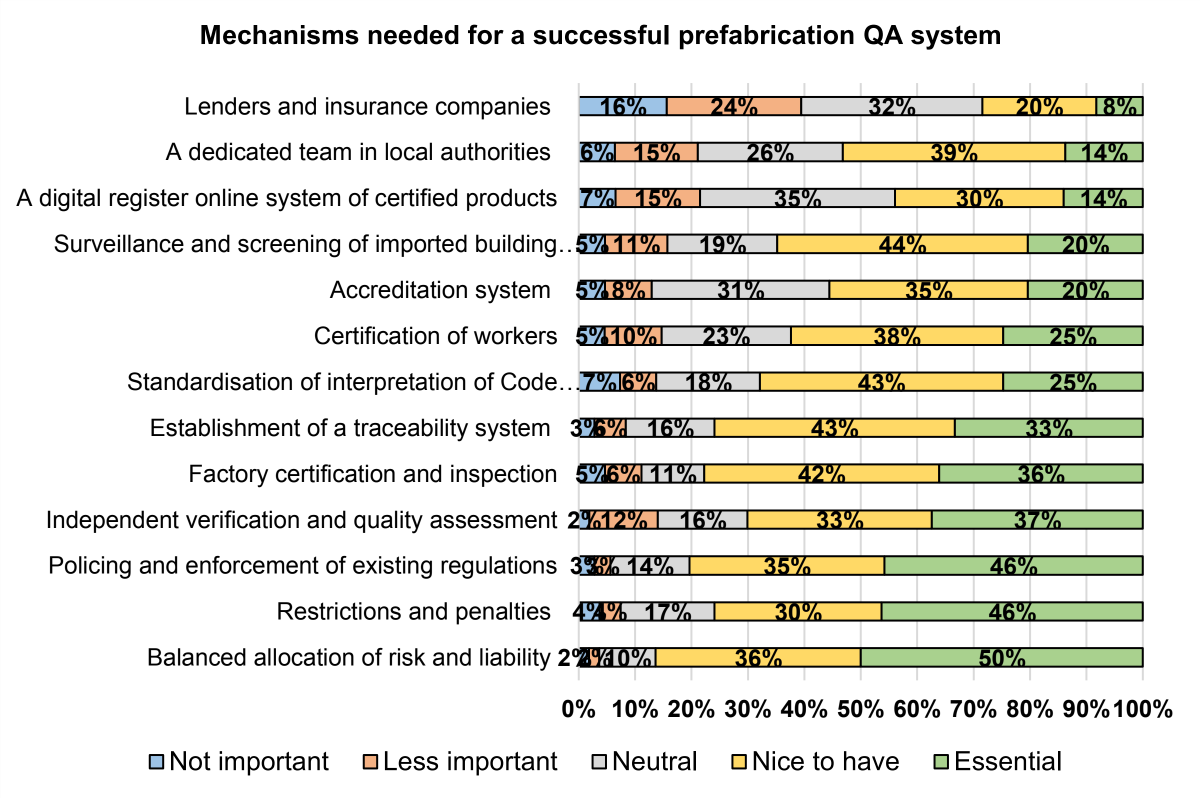


Figure 20: Mechanisms needed for a successful QA system

Across the board, on average the respondents from six countries considered having the lending agencies and insurers to guarantee QA is the last resort. There was a general sense that:

- A chain of custody from manufacturer, supplier to builder and BCAs is an appropriate way for allocating the risks and liability for products made locally or onshore. The emphasis is on manufacturers to take their due diligence responsibility for quality control and work with third-party certifiers to certify at different levels (product, process and factory).
- However, for those products made offshore, a third-party verification to authenticate claims made by manufacturers or importers is needed, in addition to existing compliance and enforcement legislation for regulating imports. It is essential to have independent verification and quality assessments to check if imported products are 'fit for purpose' and are compliant with the local Building Code. This can also empower stakeholders including architects, builders, policy makers, BCAs and clients to carry out due diligence on sourced offshore products and control the chain of responsibility.
- Regardless of the source of the product, factory certification and a traceability system can ensure that all suppliers compete on a level playing field. The current practice from Canada about factory certification can be a good early adopter example (see the review section). A traceability system will assist the industry to better track and validate building products, and help other stakeholders to check the compliance, certification and sustainability credentials of products.
- Respondents revealed that self-certification is the primary QA method used in Switzerland, Sweden, Australia and China, while third-party independent certification plays a major role in UK and Singapore; it is important to recognise that self-certified products are subject to subjective assessment of whether they are fit for purpose. As shown in Figure 20, the

importance of validation and third-party certification should be recognised and considered in the chain of custody to maintain the integrity of QA and compliance systems.

4.4 Raising QA and compliance awareness

It is important to clarify when a prebuilt part is a product which will need to be pre-consented in factory, versus, a building work which requires consent in factory as well as at site, because such a clarification have implications for building consent process, inspections and liability. When asked about the classification of manufactured buildings, 60% of respondents considered it as a building work and 25% considered as a product (Figure 21). Only 9% of respondents felt the classification should be decided case by case, and another 6% of respondents were not sure about the classification. By looking deeper into the responses from individual countries, it shows a split on respondents' opinions from the UK, while the majority of respondents from the other five countries thought that manufactured buildings should still be considered as a building work, which is to be regulated under the umbrella of building regulations.

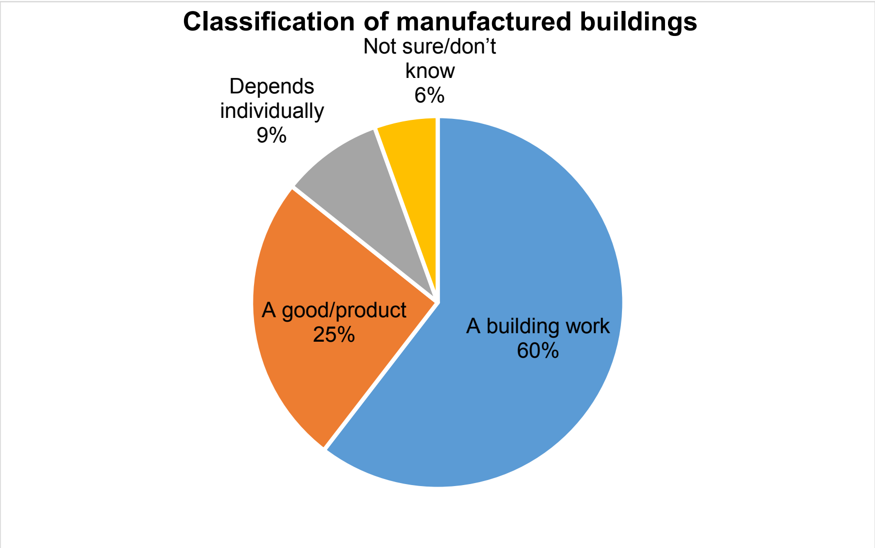


Figure 21: Classification of manufactured buildings

Across-country comparisons show there is a need to address complexity within the prefabrication consent process. In particular, developers and customers (homeowners/clients) need to understand not only the benefits of prefabrication, but also the associated QA and compliance process. When asked about how to raise the QA and compliance awareness for the prefabrication and manufactured buildings, Figure 22 shows that 35% of respondents believed that sector bodies/trade associations are best placed to lead the campaign and 32% thought this would be best undertaken through a partnership between industry and authorities. Manufacturers were most in favour of QA and compliance education being led by local authorities.

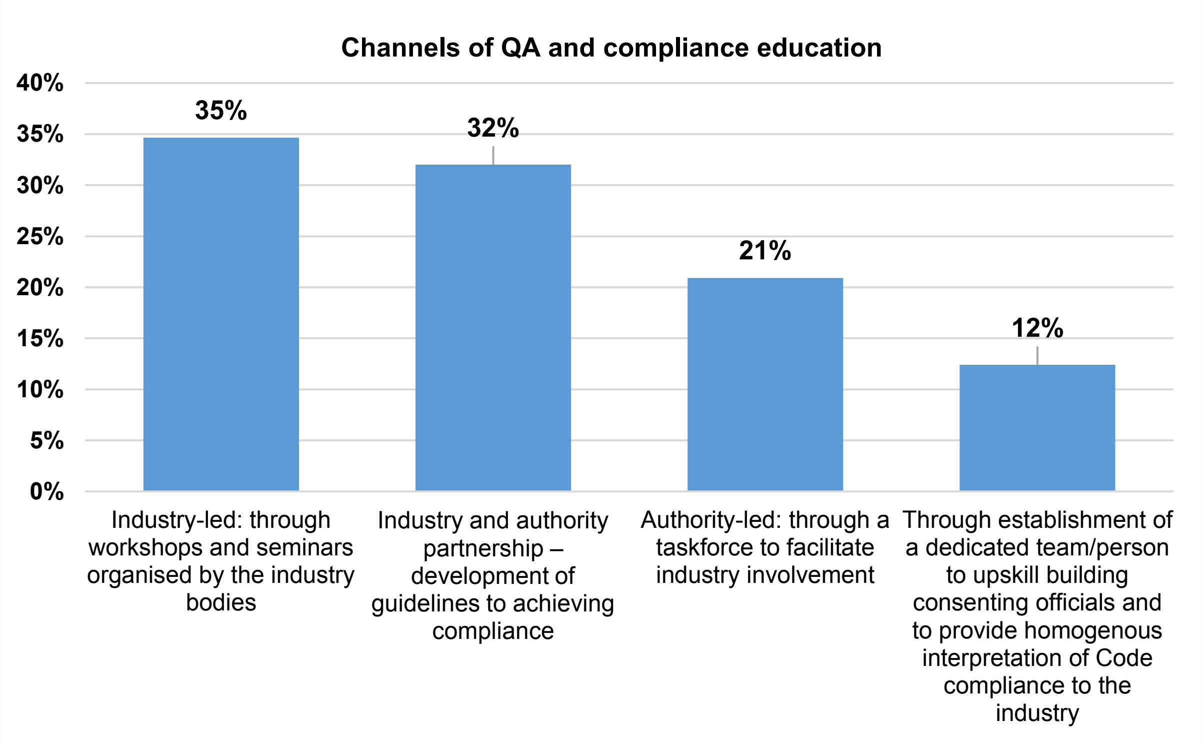


Figure 22: Suggested channels for raising QA and compliance awareness for manufactured buildings

5. Mechanisms for prefabricated buildings being mainstream accepted

5.1 Benefits of using prefabricated buildings

There are growing international trends towards increased use of offsite construction. It is important that New Zealand not only learns from Scandinavian and Northern European countries (Switzerland and Sweden) that face similar climate and population conditions, but also learns from other countries where their prefabrication industry is becoming mature (UK, Singapore), or has started gaining momentum (China, Australia).

In New Zealand, there is a renewed focus on productivity and the effective use of technology to improve the performance of the building industry. The questionnaire collected quantitative data on the potential benefits of prefabrication. As shown in Figure 23, respondents from six countries reported that on average, a saving of 26% in construction costs can be made for offsite construction, in comparison with the conventional method of onsite construction. The time saved is up to 32% on average compared to onsite construction. The attitude of respondents towards the perceived benefits that offsite construction provides was fairly split, with waste reduction and environmental benefits (24%) slightly outweighing the other benefits.

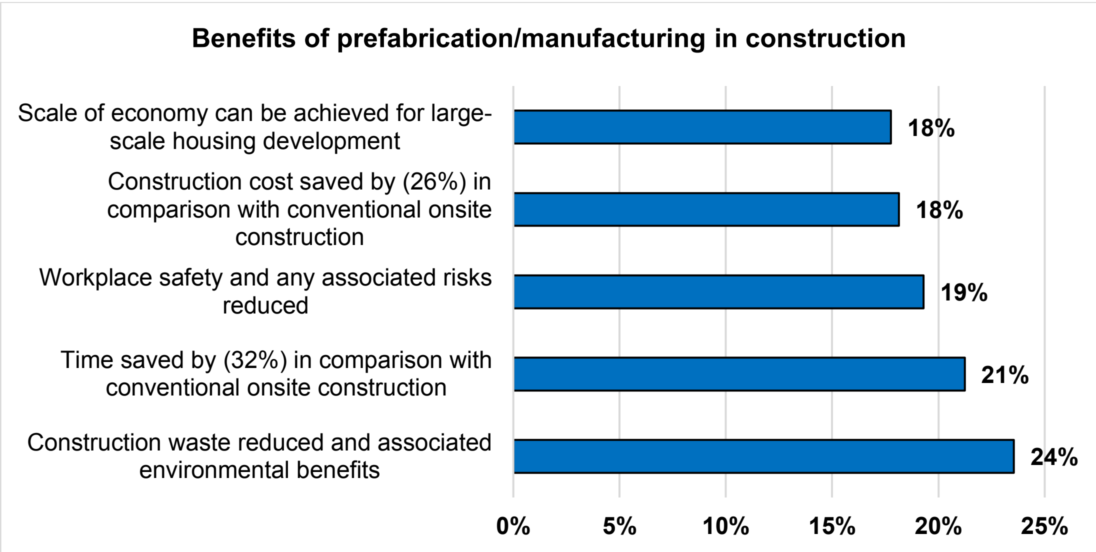


Figure 23: Perceived benefits of offsite construction

5.2 Mechanisms for mainstreaming prefabricated buildings

Figure 24 shows that across six countries, there is a clear rank for four mechanisms (policy, cost, market, technology) in considering their contribution towards mainstreaming prefabrication in the building industry. Overall, 32% of respondents believed that policy is the number one mechanism for prefabricated buildings to become mainstream accepted. The cost of constructing a building with prefabrication as a main approach, compared to traditional construction approaches was seen as another driver. Although the market demand was on average ranked third, followed by technology, it was not clear whether this represents the situations in all six countries, or only those countries where the changes to demographics of population and less use of/investment in advanced automation technology have failed to attract demand from the market.

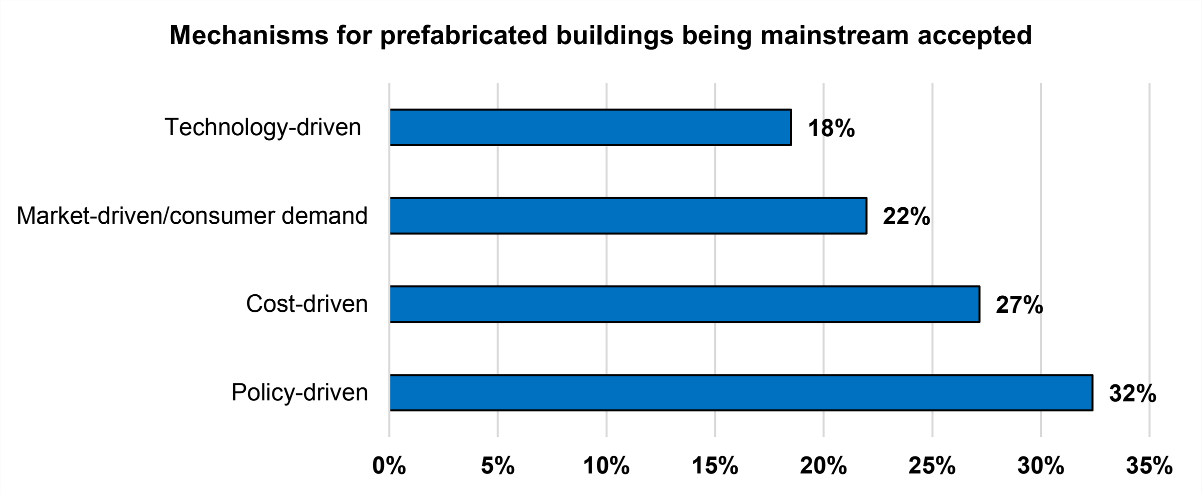


Figure 24: Mechanisms for prefabricated buildings becoming mainstream accepted

Table 5 shows a summary of responses from individual countries. There were differing views concerning the mechanisms for driving prefabrication to be mainstream.

- The majority of respondents in Sweden viewed cost of prefabrication (44%) as providing strong drivers, followed by the market demand (31%). Policy, in their opinion, played a minor role. The responses from Switzerland are similar to those from Sweden.
- Respondents from Singapore and China saw policy from the central government as providing a stronger driver, followed by cost benefits.
- In UK, there was an equal view about the role of policy, market demand and prefabrication technology itself (27%) in driving the uptake of prefabrication.
- In Australia, cost of prefabrication and the maturity of technology were considered as two drivers, followed by market demand and policy requirements. However, as the number of responses received from Australia is low, a cautious interpretation of the data needs to be exercised.

Table 5: Summary of responses from individual countries

Country	Number 1	Number 2	Number 3	Number 4
Sweden	Cost (44%)	Market (31%)	Technology (20%)	Policy (4%)
Switzerland	Cost (36%)	Market (36%)	Technology (21%)	Policy (7%)
UK	Policy (27%)	Market (27%)	Technology (27%)	Cost (18%)
Australia	Cost (29%)	Technology (29%)	Market (21%)	Policy (21%)
Singapore	Policy (40%)	Cost (27%)	Technology (27%)	Market (7%)
China	Policy (41%)	Cost (25%)	Market (21%)	Technology (13%)

5.3 Barriers for prefabricated buildings to market acceptance

Of the six countries investigated, Sweden is a world-leading exponent of prefabricated building systems, followed by Switzerland. Adopting automation for the manufacturing of housing panels in Sweden can be dated back 50 years. The country is also home to Randek, a leading manufacturer of automation equipment used in prefabrication factories. The ETH centre for digital fabrication in Switzerland is also a testbed for the country to develop advanced automation technology in building manufacturing. While the UK and Singapore can be considered as quick followers of these early adopters, it has only been in recent years that the automation of panel manufacturing for housing and other buildings has attracted much attention in China and Australia. Figure 25 shows the survey results about the barriers to prefabrication market acceptance across the six counties.

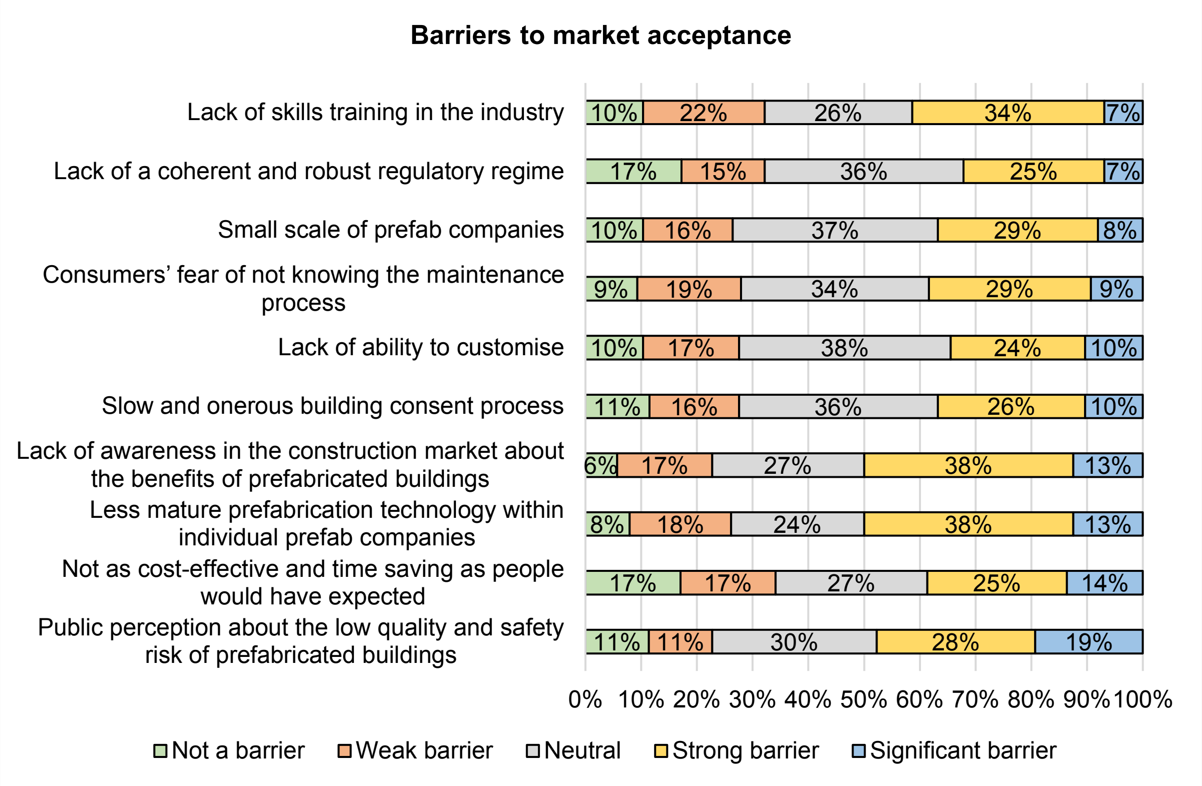


Figure 25: Barriers for prefabricated buildings to market acceptance

Public perception about the low quality and safety risk of prefabricated buildings was seen as providing the highest potential barrier (19%) to getting prefabricated buildings publicly accepted. While on average 'not as cost-effective and time saving as people would have expected' (14%), 'less mature prefabrication technology' (13%) and 'lack of awareness about the benefits of prefabricated buildings' (13%) scored high as a significant barrier, it is not the case for countries such as Sweden where automation technology is advanced to help reap the construction time, quality and labour efficiency advantages. Table 6 summarises the top barriers perceived by respondents in different countries.

Table 6: Summary of top barriers perceived by respondents

Country	Perceived top barriers
Sweden	N/A – see the Appendix 2 for data report for Sweden, the majority of the respondents do not consider any item listed in the survey as a barrier.
Switzerland	1. Lack of awareness in the construction market about the benefits 2. Public perception about the low quality and safety risk 3. Lack of ability to customise 4. Less mature prefabrication technology
UK	1. Public perception about the low quality and safety risk 2. Slow and onerous building consent process 3. Lack of awareness in the construction market about the benefits 4. Less mature prefabrication technology
Australia	1. Lack of awareness in the construction market about the benefits 2. Consumers' fear of not knowing the maintenance process 3. Public perception about the low quality and safety risk; Less mature prefabrication technology; Lack of a coherent and robust regulatory regime
Singapore	1. Less mature prefabrication technology 2. Lack of skills training in the industry 3. Small scale of prefabrication companies 4. Lack of ability to customise
China	1. Public perception about the low quality and safety risk 2. Less mature prefabrication technology 3. Lack of awareness in the construction market about the benefits 4. Consumers' fear of not knowing the maintenance process; Lack of skills training in the industry

When we drill down further by analysing the categories of the perceived barriers in each country, it seems that public awareness and perception and level of technology maturity are the main two obstacle areas that require attention from the policy makers and prefabrication industries. The matrix in Figure 26 below shows where each country sits in facing the barriers to mainstream acceptance of prefabricated building solutions.

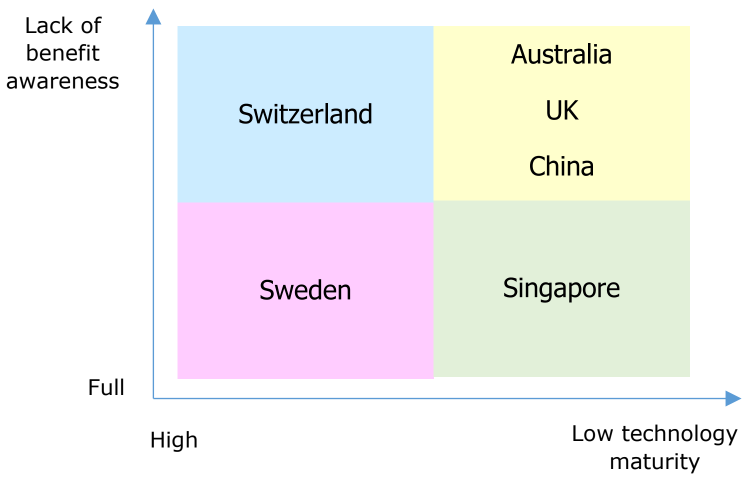


Figure 26: A matrix of perceived barriers facing six countries

Apart from Sweden and Singapore, a large part of the problem with market acceptance for prefabricated buildings in Switzerland, Australia, UK and China revolves not so much around a lack of policy and regulation, but a lack of communication between the industry and the general public. In

Singapore, the survey results seem to show that technological limitations have constrained the industry's ability to construct high quality prefabricated buildings. The results cannot be taken as statistically representative due to the insufficient sample size in some countries. The matrix in Figure 26 does appear to indicate amongst those who responded that as the prefabricated technology becomes more cost-effectively competitive, more benefits and value for prefabrication can be shown to the public, which would fundamentally result in increased uptake of construction manufacturing in the building industry.

5.4 Consent timeframe for prefabricated buildings

Respondents were asked to comment on the consent process and the timeframe on average to get consent for offsite construction. Figure 27 shows that in total, 63% respondents in all six countries reported that the consent process for manufacturing buildings were different from those used for onsite construction, while the other 37% reported similarities. The complicated 'tick box' nature of consent and time delays in the process were discussed in the survey responses. The reported duration of consenting process ranged from a minimum of 28 days to a maximum of 120 days. The average duration was 74 days across the six countries.

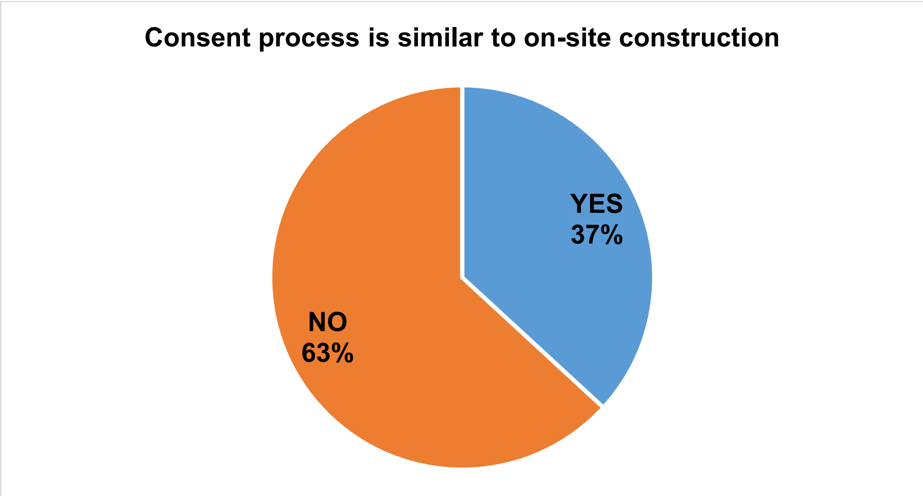


Figure 27: Consenting process for offsite construction compared to onsite construction

5.5 Reported challenges in consenting prefabricated buildings in NZ

The consenting process for prefabricated buildings was raised by both practitioners and BCAs during the two industry advisory workshops as a real hurdle to improving the effective use of prefabrication in New Zealand. In particular, BCAs need multiple factory visits for inspecting units of a same or similar design. While each unit receives a building consent from the authority for its offsite factory prefabrication based on the structural assessment, when the same units are dispatched to different locations a separate building consent is required for the building work associated with installation. In many cases, the decision on the consent for the same prefabricated units to be used in different locations largely depends on how the local BCAs view the associated risks. Although manufacturers can seek MultiProof and Acceptable Solutions, the common concern raised was that more flexibility is needed in the MultiProof programme to enable a wider range of housing design and plans to be pre-approved based on a set of standard details, such as materials used and junctions. It is believed that standardisation of consenting processes for prefabricated buildings and specific training for inspectors with prefabrication specialisation should take place within all BCAs across New Zealand to maintain transparency and consistency of consenting approach.

6. Implications for New Zealand

6.1 A chain of custody for risk and liability allocation

All the data collected in New Zealand and from overseas highlights the issues related to QA and compliance for manufactured buildings, which are all tied with the concept of risk and liability and where they lie in the supply chain. BCA representatives in the workshops voiced their concerns about a lack of due diligence from manufacturers, importers and builders in the QA and compliance process, resulting in the risks being passed to BCAs. On the other hand, manufacturers and builders voiced that over-regulation and risk-averse attitude from the authority always seems to translate into cost increases and time delays which are borne at their end. Overall there was a reluctance of prefabrication uptake and resistance to innovation and using new ways of construction in the country.

Research findings suggest that one of the most important enabling principles for a successful QA and compliance regime is the establishment of a chain of custody across the supply chain (see prototype model in Figure 28).

- Early **Designer** Engagement: It is essential for the design team to engage with the manufacturer early at the planning stage. As most current generation architects and designers work predominantly with traditional onsite construction, building their capability for offsite construction requires manufacturers to engage and/or teach them about the process and compliance requirements.
- **Manufacturer** self-certification plus third-party certification for product, factory and process: As certification is voluntary in New Zealand (through CodeMark, BRANZ or ISO), there is a lack of incentive for prefabrication manufacturers to opt for costly certification. Product certification is also individual product-based, which is not cost-effective from the manufacturer's perspective. One way to address the cost and time effects caused by existing certification schemes is to expand the certifier's capability for factory and process certification. It is still debatable whether certification for products through either factory or process should be mandated. However, lessons from the six countries suggest that the certainty outcome as a result from third-party certification, a traceability system and accreditation will surely provide a competitive advantage for prefabrication manufacturers.
- **Suppliers and importers** to demonstrate the code of compliance: Suppliers of prefabricated products and systems/units are seen to be lax in providing sufficient information about the products they supply. Often the non-conforming and non-compliant products enter the market due to misleading or false claims made by suppliers/importers. It is important that suppliers/importers work with manufacturers to demonstrate that their products are compliant with regulations, design criteria and intended purposes (fit for purpose). This will reduce the regulatory burden and risks to all stakeholders in the chain of custody.
- **Builders** to seek better project management: A dedicated person/team is needed in the building team to engage with designer, architect, manufacturer and site manage the construction workers to ensure quality workmanship. The Industry Training Organisations (ITOs), especially the Building & Construction Industry Training Organisation (BCIOT) might want to consider the skill requirements and training schemes needed for workers who install or assemble prefabricated components for different types of buildings.
- **Lending agencies and insurers** house/building assurance: Traditional mortgages usually cannot be applied to homeowners who want to build a prefabricated house until the house is assembled and installed on site. Westpac's recent 'Prebuilt' programme is the first in New Zealand that aimed at customers building or purchasing prefabricated homes. In our survey, the majority of respondents held a conservative position when commenting on the role

lending agencies and insurers can play in the QA and compliance process. The UK's Build Offsite Property Assurance Scheme, a partnership between building authority, prefabrication industry body, bank and insurance company may also provides a good example for other banks in New Zealand if a similar scheme is to follow. This will provide prefabrication manufacturers and builders a boost of confidence to increase their investment in/use of prefabricated building solutions.

- **BCAs** to raise the awareness of QA and compliance: Most BCAs are risk-averse towards consenting prefabricated buildings, and this is in part due to complexities surrounding ownership of the different materials, products and structures that go into a prefabricated building. There is a need to smooth complexities within prefabrication consent process by BCAs establishing a specialised team (as in Auckland Council as a pioneer) to assist developers and builders in clarifying the regulatory compliance process.
- **Central government building regulators** (i.e. **MBIE**): For the QA and compliance barriers to be reduced, it will be critical for MBIE to consider offsite construction in existing building standards and regulations (i.e. the Building Act). The research findings offer regulatory lessons to inform the current Building System Legislative Reform Programme.
    - To make offsite construction industry flourish in New Zealand, it is critical to supplement/add rigorous standards and introduce mandatory/voluntary factory certification/auditing schemes. MBIE is best positioned to introduce different levels of standards to meet the varied requirements in the offsite construction market, ranging from the minimum standard quality mark to the highest standards including energy efficiency and occupant comfort standards. Mandatory factory certification and independent auditing would be a way forward to address the shortcomings of current inspection regimes that heavily relies on local BCAs.
    - Possible improvements to the current regulatory frameworks for ensuring imported prefabrication structures and systems comply with the New Zealand Building Code and standards include: 1) the responsibilities of building product importers should be made more explicit and clear – although 'manufacturers and/or suppliers' are used as the general reference terms in building regulations as 'manufacturers and suppliers of building products' including importers, distributors, direct marketers, trade merchants and retailers; 2) MBIE to work with Immigration New Zealand and Ministry for Primary Industries to better record and carry out surveillance and screening of imported building products; and 3) restrictions and penalties should be made clear for importers and imposed on any false claims about product credentials and importing non-compliant building products.

Other initiatives recommended that can be led by the industry, but require substantial support from the government, include:

- To develop a set of guidelines for developers, prefabrication manufacturers, designers and builders about how to demonstrate quality and performance of buildings when using modern methods of construction, such as offsite manufacturing.
- Industry would benefit from a national register of compliant products, building systems and design solutions made both onshore and offshore, that are certified by accredited third parties. The register would assist suppliers and importers to know the code requirements and building standards for compliance and enable architects and designers to know with confidence which products they could specify. As builders could select certified products from the register, this would significantly reduce the regulatory and consenting burdens on BCAs.

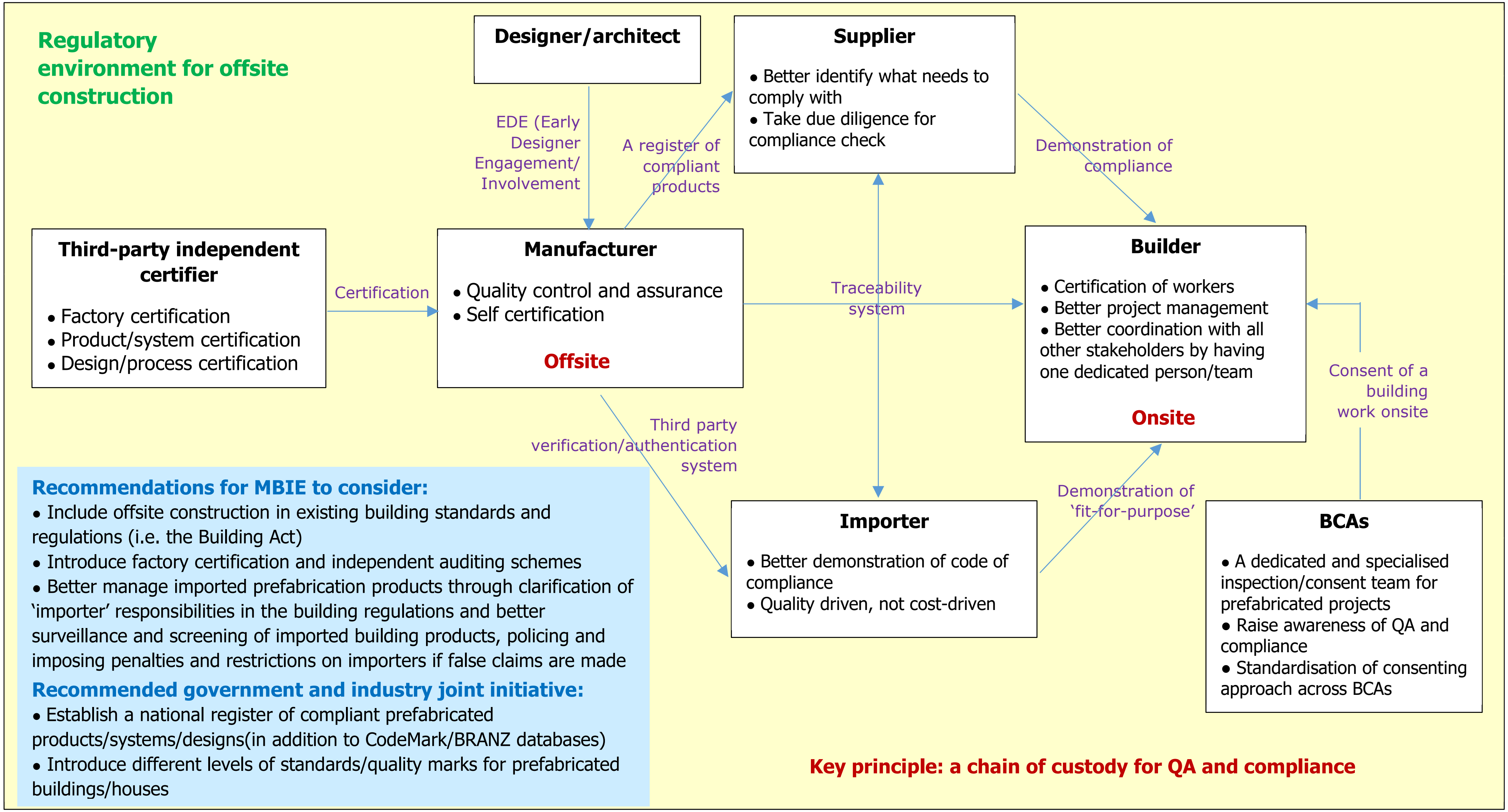


Figure 28: A prototype model of QA and compliance for manufactured buildings in New Zealand

6.2 Increasing the visibility and transparency of product lifecycle

There is opportunity to incorporate digitalisation into the proposed QA and compliance model for manufactured buildings. Based on these research findings, we recommend the following two digital platforms be considered and their feasibility and proof of concept to be tested:

- An electronic traceability system
- Third-party verification/authentication system

BRANZ researchers have undertaken a feasibility study of electronic traceability of construction products in 2017 and concluded that an electronic traceability system looks feasible as a means to reduce non-conforming products [41]. It is an important mechanism needed for a chain of custody QA system which allows any users to track products in the supply chain and know where they have come from.

New Zealand's prefabrication manufacturing industry would be well placed to lead the creation of an electronic traceability system together with the certification bodies. This set-up will effectively incentivise innovation and encourage proactive practice among manufacturers and suppliers to demonstrate the performance and quality of their products. However, as a traceability system that features both a chain of custody and authentication relates to the risk of non-compliant products or the risk of failure of a product, it is important to distinguish the QA options used for high-risk products and low-risk products, as well as for NZ-made products and offshore-made products (see Figure 29).

	Product made onshore	Product made offshore
High risk	Product certification Factory/process certification	Third-party verification/authentication
Low risk	Other assurance methods	Product certification

Figure 29: QA options for prefabricated building products

The majority of products should require less extensive forms of assessment to prove Building Code compliance. This group may include products that have been made and in use in New Zealand for a long period of time. For the NZ-made products that are new to the market and new or innovative, options such as appraisals, product certification, and factory/process certification can be applied. To ensure that we create a level playing field for local manufacturers and suppliers in New Zealand, it is important to leverage third-party verification to authenticate claims made by overseas manufacturers, suppliers and importers, especially for imports of modules or full buildings for assembly in New Zealand. A good practice on this matter comes from an Australian construction industry specialist Peter Mulherin (https://www.buildfit.net/) who is developing a digital online product compliance verification tool called BuildFit to achieve the following objectives:

- Every producer or supplier can demonstrate within the system that their products are compliant with regulation, design criteria and intended purpose.
- Users can filter products according to design criteria and obtain information about what is available in the Australian market, including compliance with Australian standards, the amount of Australian content and sustainability outcomes of a product.
- The claims made about the product by manufacturer or supplier/importer can be cross-checked by the system with the relevant third parties.

Looking to the future, the New Zealand construction industry is likely to innovate more in offsite construction while embracing global products in building systems. The prefabrication manufacturers in New Zealand may not only look to efficient imports of buildings components/units, but also the possibility to export our design solutions and building systems. The third-party certification of conformance and compliance will therefore become the industry benchmark. The use of an electronic traceability system and a third-party verification platform will surely add value to a chain of custody QA regime and benefit the New Zealand offsite construction sector by giving them a competitive edge in a global market. These two digital tools will also help promote equality between the onsite and offsite compliance requirements and encourage innovation in the construction sector.

7. Conclusions

Manufacturing in construction provides a potential solution for achieving quality, affordable homes to meet the construction pipelines ambition. An instrumental regulatory environment in supporting assurance and compliance for manufactured buildings is needed. To address this need, this project provided evidence-based research to gather compliance and assurance learnings from countries where manufactured buildings are a more significant part of their building industry and involve best practices from the manufacturing industry.

A mixed methods approach was used to first review the existing product assurance framework in New Zealand and investigate the current compliance challenges MBIE, BCAs, building manufacturers and builders face in regards to using fabricated products and systems. While most materials, products and systems fit in the product assurance framework/pyramid based on their level of risk, the full potential of innovation (including access to compliant products) is not being achieved due to a number of operational issues within the system, including such as the heavy reliance on BCAs for building consent at both the point of manufacture and during the phase of construction, and the broader liability framework providing a bias against innovation.

The second part of the report looked at research findings gathered from six countries, namely: Sweden, Switzerland, UK, Australia, Singapore and China, in particular the QA and compliance methods used in these countries and the perceived effectiveness and improvement requirements. While manufacturer self-certification seems to be the predominant QA method used, the survey results highlighted the importance of having a balanced allocation of risk and liability across the supply chain, restrictions and penalties, and policing and enforcing of existing regulations, third-party product certification, factory certification and a traceability system in attaining an effective QA and compliance regime for manufactured buildings.

The report also provided information on the cost, time savings and environmental benefits of using offsite construction in comparison to traditional onsite construction across the six countries. The primary mechanisms for driving the uptake of offsite construction and perceived barriers to market acceptances were also investigated, as well as the implications of findings from overseas for the New Zealand conditions.

For an offsite construction industry to flourish, this research suggested a prototype model of QA and compliance for manufactured buildings in New Zealand. The founding principle for a successful QA and compliance regime is the establishment of a chain of custody across the supply chain where all the stakeholders from designers, to manufacturers, suppliers, buildings and BCAs perform their due diligence. The industry would particularly benefit from a factory certification system that would address differences in approaches between QA for a whole prefabricated building heading off to multiple destinations versus the current array of inspections carried out on all of products, and on all sites, and reduce the regulatory consenting burdens on BCAs.

The research offers regulatory lessons to inform the current Building System Legislative Reform Programme led by MBIE. For instance, for the MBIE to consider to include offsite construction in existing building standards and regulations (i.e. the Building Act) and introduce factory certification/accreditation and independent auditing schemes, as well as better manage imported prefabrication products. Other initiatives recommended that require industry leadership with support from the government included to establish a national register of compliant prefabricated products/systems/designs (in addition to the CodeMark/BRANZ databases) and to introduce different levels of standards/quality marks for prefabricated buildings/houses.

The final recommendation of this report is to develop industry-led initiatives to increase the visibility and transparency of product lifecycles. To create a more conducive environment in the building regulations for innovation, the third-party certification of conformance and compliance should become the industry benchmark. The use of an electronic traceability system and a third-party verification platform will add value to a chain of custody type of QA regime and will benefit the New Zealand offsite construction sector by boosting confidence in prefabrication uptake in the domestic market, enhancing their credibility and reputation, as well as giving them a competitive edge in a global market.

For future research, the research team will continue onto the second stage of this project by using system dynamics modelling that will allow more sophisticated decision making analysis (e.g. does a certain assurance option lead to a quicker production and adoption in building projects or just smoother? Or what happens to the overall consenting time if regulatory delays are decreased by 50%?). This modelling can also be used by any product importers and business owners to assess the likely time and cost of importing certain building products and the effects on their businesses. The proposed QA and compliance prototype in this report will be validated in the second stage using case studies of manufacturers in the offsite construction sector.

References

1. Kohn, B. (2018), Prefab construction unlikely to be cheaper than building on-site, New Zealand Herald, 19 July, 2018

2. Australian Research Council Training Centre for Advanced Manufacturing in Prefabricated Housing

3. New Zealand Building Industry Federation, MBIE: Residential Construction Sector Market Study: Options Paper. 2013.

4. New Zealand Institute of Architects, Residential Construction Sector Market Study: NZIA Submission to the Ministry of Business, Innovation and Employment (MBIE). 2013.

5. Smith, R. E. (2010), Prefab Architecture: A Guide to Modular Design and Construction, John Wiley & Sons, Incorporated. ProQuest Ebook Central

6. New Zealand Institute of Architects, Residential Construction Sector Market Study: NZIA Submission to the Ministry of Business, Innovation and Employment (MBIE). 2013.

7. Page, I. (2017), BRANZ Study Report. What is quality in building? Retrieved online: https://www.branz.co.nz/cms_show_download.php?id=3a755303151dbaf4a9fe04e56f5be968f6991633

8. Bucket, N.R. (2014), BRANZ Study Report. Advanced Residential Construction Techniques: Opportunities and Implications for New Zealand. Retrieved online: https://www.branz.co.nz/cms_show_download.php?id=4a8fe57f274e0906d2c312acc538db1187fa89d7

9. MBIE (2014), New Zealand Building Code Handbook. Retrieved online: https://www.building.govt.nz/assets/Uploads/building-code-compliance/handbooks/building-code-handbook/building-code-handbook-3rd-edition-amendment-13.pdf

10. PrefabNZ (2014), Levers for Prefab: How offsite construction can deliver better cost-effective housing to more New Zealanders.

11. PWC (2016), A report to the Construction Strategy Group in association with Construction Industry Council and BRANZ: Valuing the role of construction in the New Zealand economy.

12. Department of Building and Housing (2010), Using the product assurance framework to support building code compliance: A guide for manufacturers and suppliers of building products. April 2010

13. The Manufactured Housing Association of British Columbia, (MHABC) (2015), Information Bulletin Building and Safety Standards Branch. Online: https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/construction-industry/building-codes-and-standards/bulletins/b15-01_determining_compliance_of_a277certified_buildings.pdf

14. Canadian Manufactured Housing Institute (2015), Certification. O-line: http://www.cmhi.ca/magazine/certification

15. BC Housing, MHABC, REIBC (Canada) (2014), Modular and Prefabricated Housing: Literature Scan of Ideas, Innovations, and Considerations to Improve Affordability, Efficiency, and Quality.

16. CMHC (Canada Mortgage and Housing Corporation) (2013), Housing Observer Timely updates on Canada's housing conditions and trends. Online: https://www.cmhc-schl.gc.ca/en/housing-observer-online

17. Canadian Manufactured Housing Institute (CMHI) (2015), Standards for Prefabricated Buildings. Online: http://firstnationshousingconference.com/wp-content/uploads/2017/12/Standards-for-Prefabricated-Buildings.pdf

18. Canadian Home Builders' Association and Modular Construction Council. Online: https://www.chba.ca/CHBA/CommitteesCouncils/Modular_Construction_Council/CHBA/CommitteesCouncils/Modular_Construction_Council.aspx?hkey=8d3e09e4-d034-464f-b3d6-4a4bbd2c621a

19. Manufactured Housing Association of Prairie Provinces (Canada) (2013), Evolution to Information Modern-Day: GUIDE Modular Homes. Online: https://adoa.net/wp content/uploads/2016/11/Evolution-to-Modern-Day-Homes-.pdf

20. QAI Laboratories. Factory Built Structures Certification. Online: https://qai.org/factory-built-structures-2/

21. Linner, T. & Bock, T. (2012), Evolution of large - scale industrialisation and service innovation in Japanese prefabrication industry, Construction Innovation, Vol. 12 Issue 2, pp.156-178

22. Gerhard, G. (2010), New perspective in industrialisation in construction: a state-of-the-art report.

23. Barlow, J., Childerhouse, P., Gann, D., Hong-Minh, S., Naim, M. & Ozaki, R. (2003), Choice and delivery in housebuilding: lessons from Japan for UK house builders, Building Research & Information, Vol. 31 Issue 2, pp. 134-145

24. Bennett, J. (1993), Japan's Building Industry: The New Model, Construction Management and Economics, Vol. 11 Issue 1, 3-17

25. Johnson, W. (2007), Lessons from Japan: A comparative study of the market drivers for prefabrication in Japanese and UK private housing development. Master thesis, UCL (University College London).

26. Fujimoto, T. (2000), The Evolution of a Manufacturing System at Toyota. The Academy of Management Review.

27. Japanese Prefabricated Construction Suppliers and Manufacturers Association (JPA). Introduction. Online: https://www.purekyo.or.jp/English/index.html

28. Ministry of Land, Infrastructure, Transport and Tourism, Japan. Online: http://www.mlit.go.jp/en/index.html

29. Kiong, T., Seng & F. Jin, H. (2000). Prefabrication in the Singapore Construction Industry

30. BCA's new roadmap to raise construction productivity. 2016. Online: https://www.propertyguru.com.sg/property-management-news/2016/10/138553/bcas-new-roadmap-to-raise-construction-productivity

31. Singapore Government. MEDIA RELEASE. SPEECH BY ASSOC. PROF. KOO TSAI KEE, SENIOR PARLIAMENTARY SECRETARY (MINISTRY OF NATIONAL DEVELOPMENT) AT THE OPENING OF THE NEW L&M STRUCTURAL SYSTEMS BUILDING AND NEW PRE-CAST FACTORY ON 31 OCT 2000. Online: http://www.gov.sg/sprinter/

32. Building & Construction Authority; Singapore. investment Allowance Scheme for the Construction Industry. Online: https://www.bca.gov.sg/AssistanceSchemes/assistance_schemes.html

33. Enterprise Singapore. Local Enterprise and Association Development (LEAD) Programme. Online: https://www.enterprisesg.gov.sg/financial-assistance/grants/for-partners/local-enterprise-and-association-development-programme

34. DBCSoft Pte Ltd. Local Enterprise Technical Assistance Scheme (LETAS). Online: http://www.dbcsoft.com/article_psb_grant.php

35. Global Construction Reviews. (2014), How Singapore plans to push its construction industry into the 21st Century. Online: http://www.globalconstructionreview.com/markets/how-singap98ore-pla37ns-pu90sh-it0s-constru36ction/

36. Building Control Act, Singapore. 2011. Building Control (Buildability and Productivity) Regulations. Online: https://www.bca.gov.sg/BuildingControlAct/others/building_control_buildability_regulations.pdf

37. Park, M., Ingawale-Verma, Y., Kim, W. et al. KSCE J Civ Eng (2011) 15: 771. https://doi.org/10.1007/s12205-011-1243-4

38. Building & Construction Authority, Singapore. Online: https://www.bca.gov.sg/

39. Building & Construction Authority, Singapore. Prefabricated Prefinished Volumetric Construction (PPVC). Online: https://www.bca.gov.sg/BuildableDesign/ppvc.html

40. Singapore Concrete Institute. PPVC Manufacturer Accreditation Scheme. Online: http://www.scinst.org.sg/page.php?70

41. Dowdell, D., Page, I. & Curtis, M. (2017), Electronic traceability of New Zealand construction products: Feasibility and opportunities. BRANZ Study Report SR365.

Appendix

- Appendix 1: Research questionnaire survey (A sample used in Sweden)
- Appendix 2: Data analysis reports from individual countries
- Appendix 3: Review report prepared by Dr Kenneth Park about the QA and compliance practice in UK

From lessons to practice: Compliance and assurance prototypes for manufactured buildings

About the survey

New Zealand is increasingly exploring greater use of manufacturing in construction. Traditional assurance and compliance regimes are predominantly focused on individual products and systems. Commissioned by the Building Research Association of New Zealand (BRANZ), this research project is co-designed with the Ministry of Business, Innovation and Employment (MBIE) to help support New Zealand to develop approaches that can support compliance and assurance for manufactured buildings. This survey investigates what New Zealand can learn from countries (Australia, Singapore, China, UK, Switzerland and Sweden) where manufactured buildings are a more significant part of their building industry.

The survey is intended for 1) **building product manufacturers**, 2) **prefab builders/contractors** or 3) **building inspectors of local authorities**; it gathers your knowledge about quality assurance (QA) and compliance practice for building products/components that are made offsite, as well as your perspective about what worked well, what did not and why.

As the quality of building products and their compliance to building code/standards has a significant impact on the building and construction industry, your contribution to this survey is crucial for improving our understanding of how we can design effective QA and compliance frameworks for manufactured buildings and reduce the regulatory burden and risks to stakeholders.

We appreciate your kind support and participation.

This survey will take 15 minutes of your time. Your response will be confidential and anonymous.

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SECTION A: Participant information (anonymous)

1. Which type of organisation are you affiliated with? (You can select one or more options)

☐ Product manufacturer/prefabricator
☐ Supplier
☐ Importer
☐ Builder or contractor – ONLY install or assemble manufactured buildings
☐ Builder or contractor – not only install/assemble manufactured buildings, but also manufacture/prefabricate building elements
☐ Third party building product certifier
☐ Local authority for building inspection and consenting
☐ Other (please specify) ……………………………

2. If your company manufactures building products, what type(s) of building products does your company manufacture? (You can select one or more options)

☐ Simple elements: e.g. beams, columns or other parts of a structure that can be easily bolted into place onsite
☐ Panelised systems: e.g. elements that are used for walls, such as insulation, utilities, waterproofing and external and internal cladding
☐ Volumetric systems: e.g. three-dimensional modular objects that comprise the floor, ceiling and wall components for a single room/unit
☐ Other (please specify) ……………………………

3. How long has your company been trading in the prefabricated building market?

☐ Less than 5 years
☐ Between 5 and 10 years
☐ Between 10 and 20 years
☐ More than 20 years

SECTION B: Quality assurance (QA)

4. What are the QA methods used for prefabricated building products and components? (You can select one or more options)

☐ The QA systems used include:
- ☐ Self-certify: Manufacturer has its own quality control and assurance schemes to demonstrate compliance
- ☐ Third party independent **product certification**
- ☐ Third party independent **factory certification/factory production control**
- ☐ Third party independent **production process certification/management systems certification**
- ☐ Industry-led assurance system
- ☐ Traceability such as using barcodes or QR codes or radio frequency identification (RFID) for prefabricated products
- ☐ Third part verification to authenticate claims made by product manufacturers
- ☐ Authority product authentication
- ☐ Banking and/or insurance schemes for assurance of prefabricated buildings
- ☐ Other QA models (please specify) ……………………………

☐ No QA system exists
☐ Don't think we need a QA system
☐ Don't know

5. How effective or helpful do you think your QA systems are for ensuring the quality of building products?

Not effective at all	Less effective	Neutral	Effective	Extremely effective
☐	☐	☐	☐	☐

6. In your opinion, what QA measures you think have worked well and what have not?

……

……

7. In the supply chain, who have taken the responsibility in guarding the product quality? (You can select one or more options)

☐ Individual companies for their own products
☐ Third party product certifiers
☐ Sector bodies/Industry associations on behalf of their members
☐ Insurance companies
☐ Local authorities
☐ Policy/law maker of the building industry
☐ Other (please specify) …………………………

8. What do you think should be in place to make a successful QA system for prefabricated products and buildings?

	Not important	Less important	Neutral	Nice to have	Essential
Policing and enforcement of existing regulations	☐	☐	☐	☐	☐
Balanced allocation of risk and liability with clear roles and responsibilities of everyone involved	☐	☐	☐	☐	☐
Independent verification and quality assessment systems	☐	☐	☐	☐	☐
Factory certification and inspection	☐	☐	☐	☐	☐
Establishment of a traceability system for individual products/components	☐	☐	☐	☐	☐
Accreditation system for manufacturers, suppliers and importers	☐	☐	☐	☐	☐
Standardisation of interpretation of Code compliance within local authorities across all regions	☐	☐	☐	☐	☐
A dedicated team in local authorities to review and address building consent for prefabricated/manufactured buildings	☐	☐	☐	☐	☐
Certification of workers who install or assemble prefabricated houses/buildings onsite	☐	☐	☐	☐	☐
Banks/mortgage lenders and insurance companies play a role in quality assurance for prefabricated buildings	☐	☐	☐	☐	☐
A digital register online system of certified products	☐	☐	☐	☐	☐
Surveillance and screening of imported building products	☐	☐	☐	☐	☐
Restrictions and penalties imposed on non-conforming building products	☐	☐	☐	☐	☐
Other (please specify)	☐	☐	☐	☐	☐
Other (please specify)	☐	☐	☐	☐	☐

9. What is the current enforcement regime/legal remedies for non-compliant products in your country? – What happens if things go wrong (e.g. consumer law, warranties, dispute resolution, or other liability resolutions)?

……………………………………………………………………………………………………

10. How would you like an efficient QA system to work?

……………………………………………………………………………………………………

SECTION C: Manufacturing in construction

11. In your country or region, are the manufactured buildings being considered as *a building work* or *a product* such as cars, light bulbs, etc.?

☐ A building work ☐ A good/product ☐ Depends individually ☐ Not sure/don't know

12. How did the prefabricated buildings become mainstream accepted in your country/region? (You can select one or more options)

☐ Policy-driven
☐ Market-driven/consumer demand
☐ Technology-driven
☐ Cost-driven
☐ Other enabling factors (please specify) …………………………

13. What barriers were/are there to the market acceptance of prefabricated buildings?

	Not a barrier	Weak barrier	Neutral	Strong barrier	Significant barrier
Lack of a coherent and robust regulatory regime	☐	☐	☐	☐	☐
Less mature prefabrication technology within individual prefab companies	☐	☐	☐	☐	☐
Slow and onerous building consent process	☐	☐	☐	☐	☐
Public perception about the low quality and safety risk of prefabricated buildings	☐	☐	☐	☐	☐
Lack of ability to customise	☐	☐	☐	☐	☐
Small scale of prefab companies	☐	☐	☐	☐	☐
Lack of awareness in the construction market about the benefits of prefabricated buildings	☐	☐	☐	☐	☐
Consumers' fear of not knowing the maintenance process	☐	☐	☐	☐	☐
Lack of skills training in the industry	☐	☐	☐	☐	☐
Not as cost-effective and time saving as people would have expected	☐	☐	☐	☐	☐
Other (please specify)	☐	☐	☐	☐	☐
Other (please specify)	☐	☐	☐	☐	☐

14. From your experience, what are the improvements gained by using prefab in construction? (You can select one or more options)

☐ Time saved by ……………(%) in comparison with conventional onsite construction
☐ Overall construction cost saved by ……………(%) in comparison with conventional onsite construction

☐ Workplace safety and any associated risks reduced
☐ Scale of economy can be achieved for large-scale housing development
☐ Construction waste reduced and associated environmental benefits
☐ Other (please specify) ……………………….

SECTION D: Regulatory environment for manufactured buildings

15. Is the consent process for the offsite construction the same as onsite?

☐ Yes ☐ No

16. How long does your building consent process usually take for prefabricated buildings/houses?

……………………………. ..……… (working days)

17. In your opinion, how can the consent process for manufactured buildings be more efficient (e.g. save time and cost)?

………

18. How do your authorities educate the construction industry on product quality standards and compliance process? (You can select one or more options)

☐ Industry-led: through workshops and seminars organised by the industry bodies
☐ Authority-led: through a taskforce to facilitate industry involvement
☐ Industry and authority partnership – development of guidelines to achieving compliance
☐ Through establishment of a dedicated team/person to upskill building consenting officials and to provide homogenous interpretation of Code compliance to the industry
☐ Other (please specify) ……………………….

19. What other supporting settings/levers does your country/region have in order to support compliance/quality assurance (QA) of manufactured buildings?

………

………

THANK YOU FOR PARTICIPATION

Please leave your contact details below, if you would like to (please tick)

☐ Provide us with more detailed information, we can arrange interviews by either skype or in person at a time that would most suit you.
☐ Receive a copy of the research report by email.

Your name: Email/Phone:

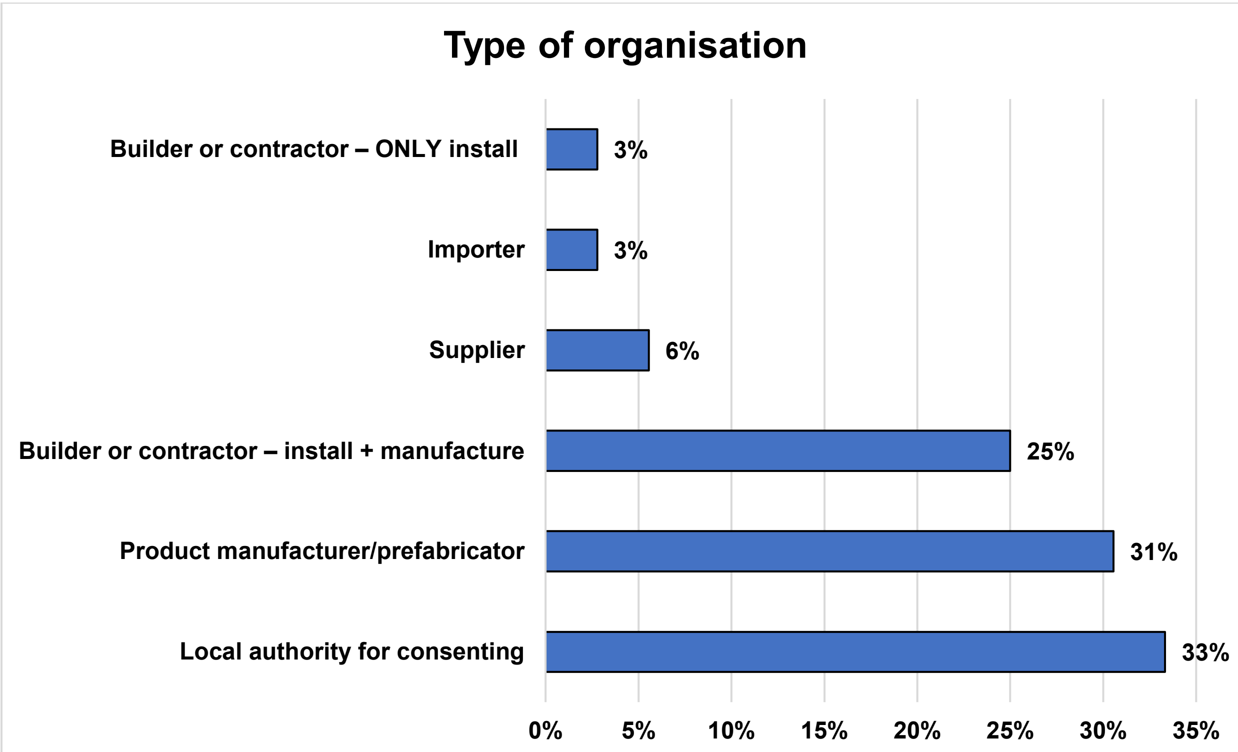
…………………………………………………………………………………………………….

(Your identify and contact details provided will be kept confidential under the University of Auckland Human Ethics Reference Number 022976)

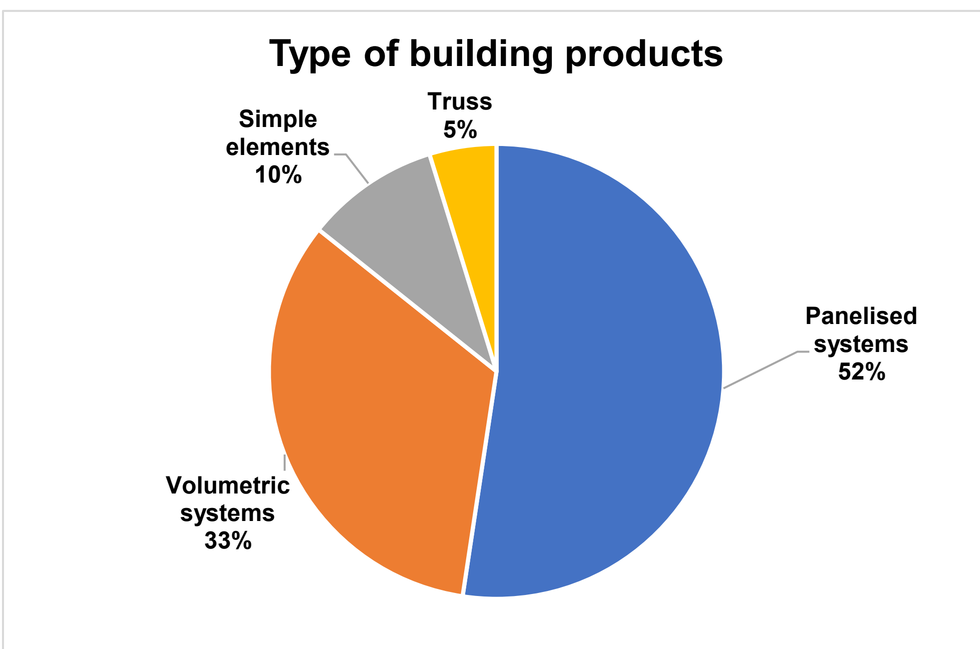
Compliance and assurance prototypes for manufactured buildings research project

QUESTIONNAIRE SURVEY RESULTS: SWEDEN

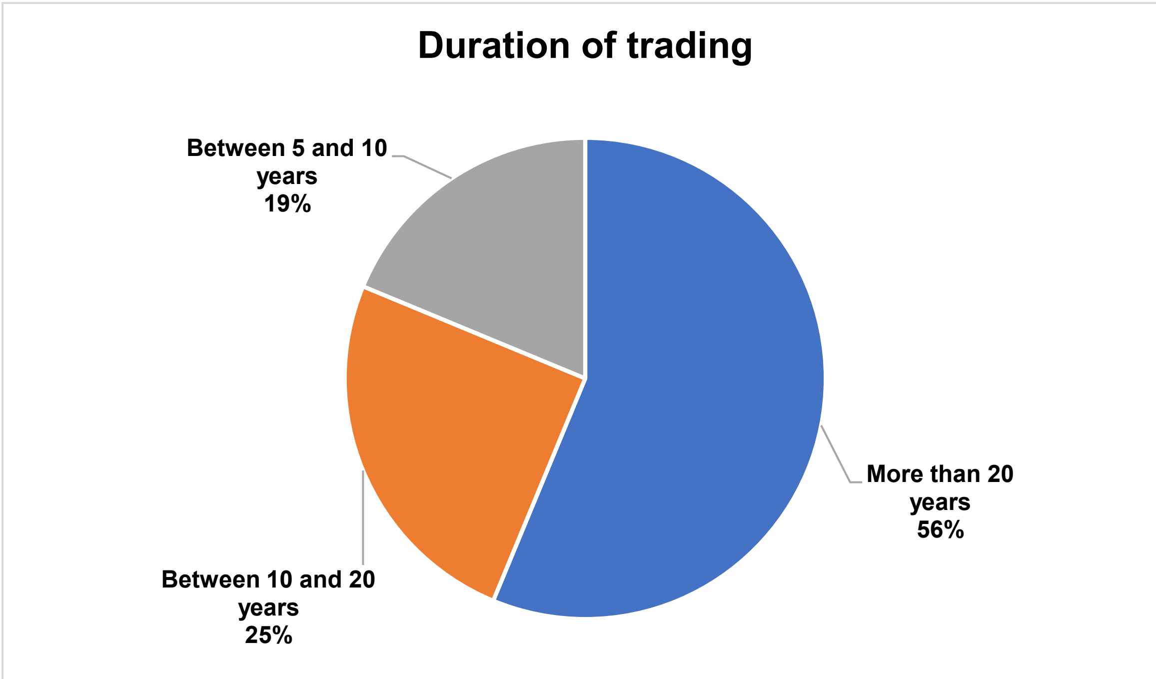
1. Type of organization



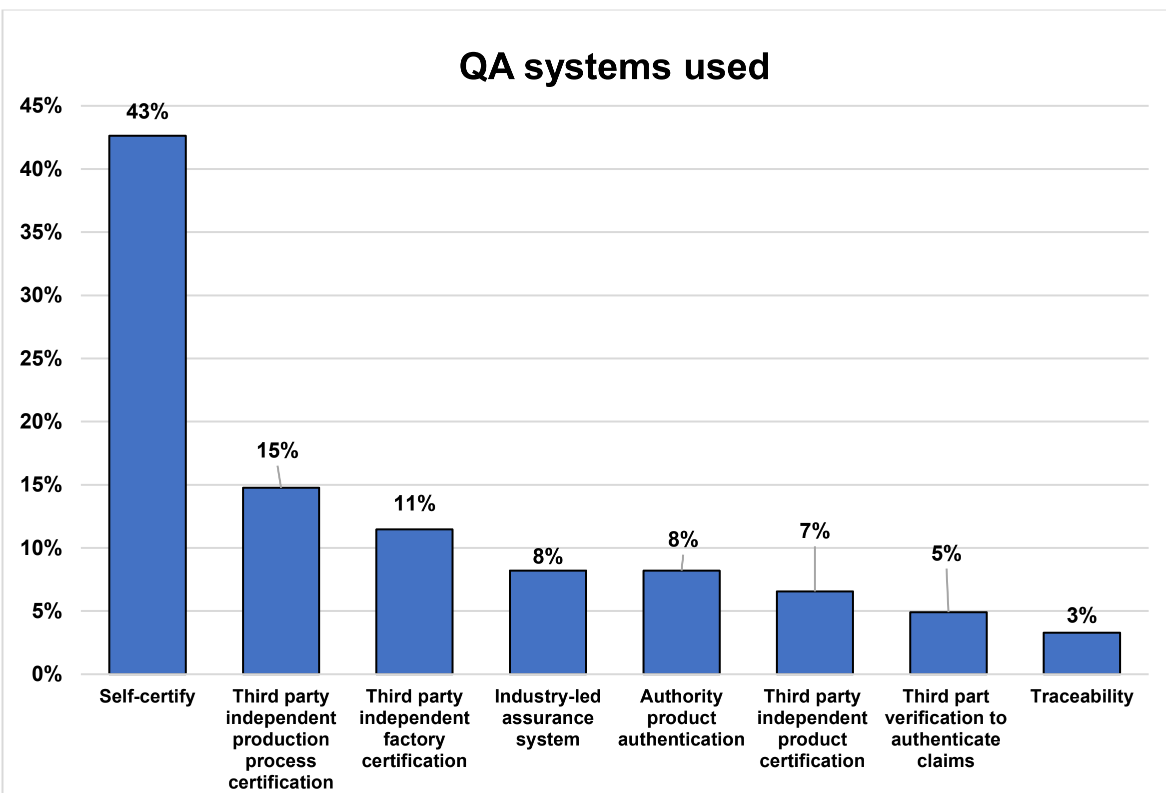
2. Type of building products



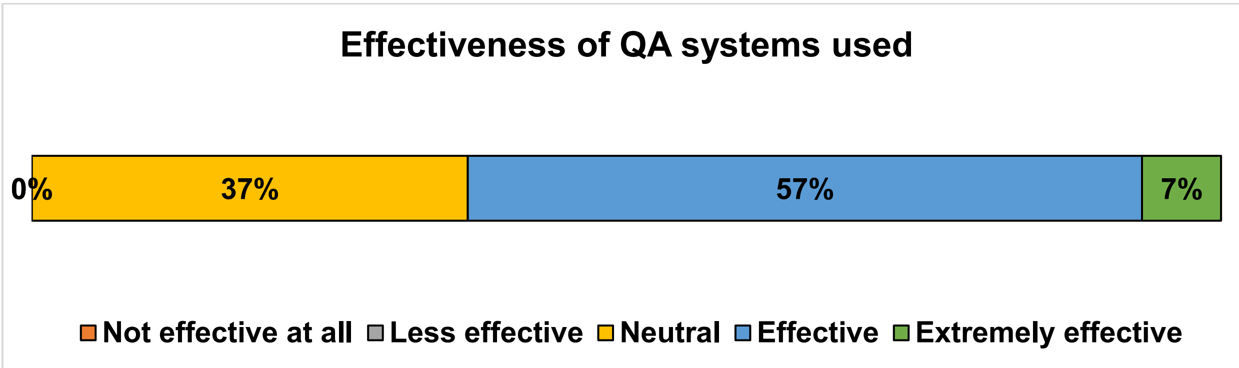
3. Duration of trading



4. QA systems used



5. **Effectiveness of QA systems used**



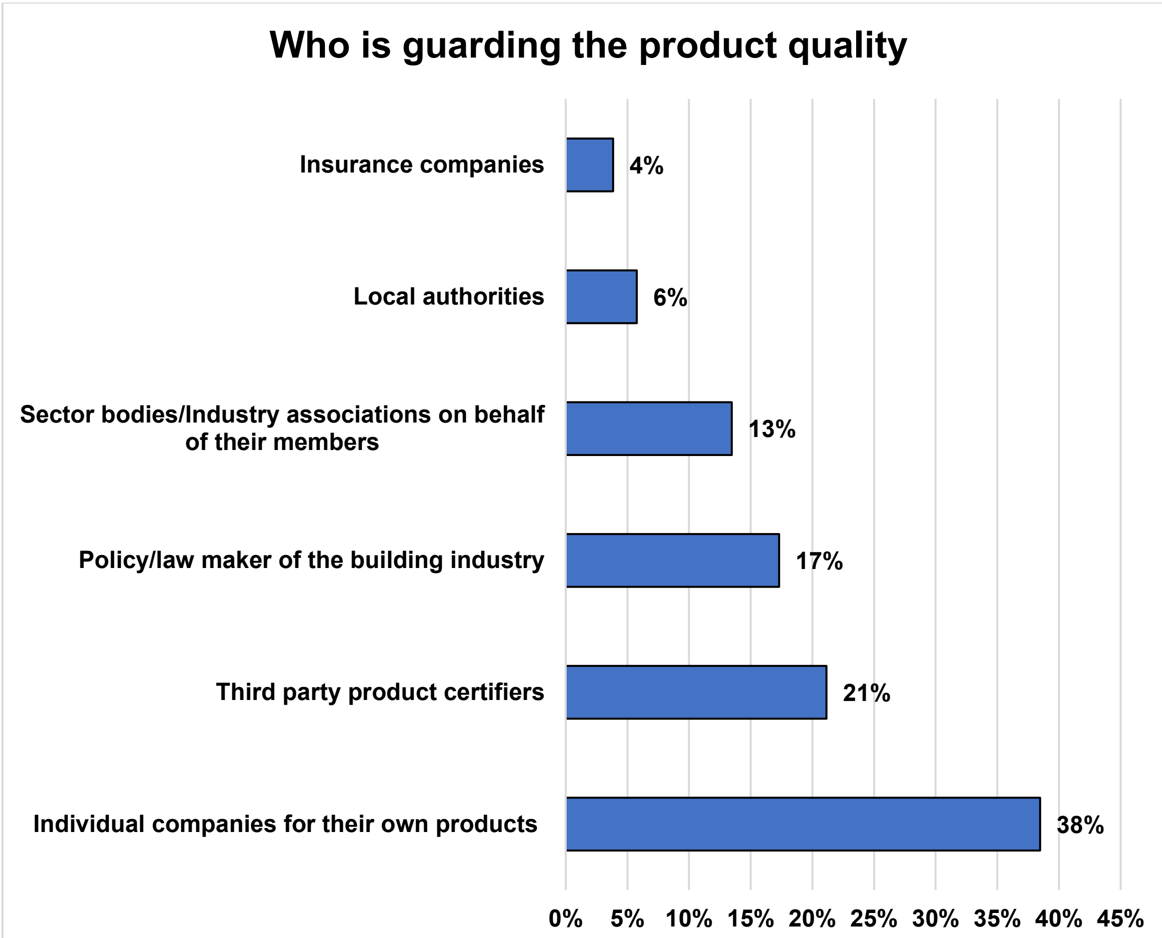
6. **What worked well and what have not?**

+

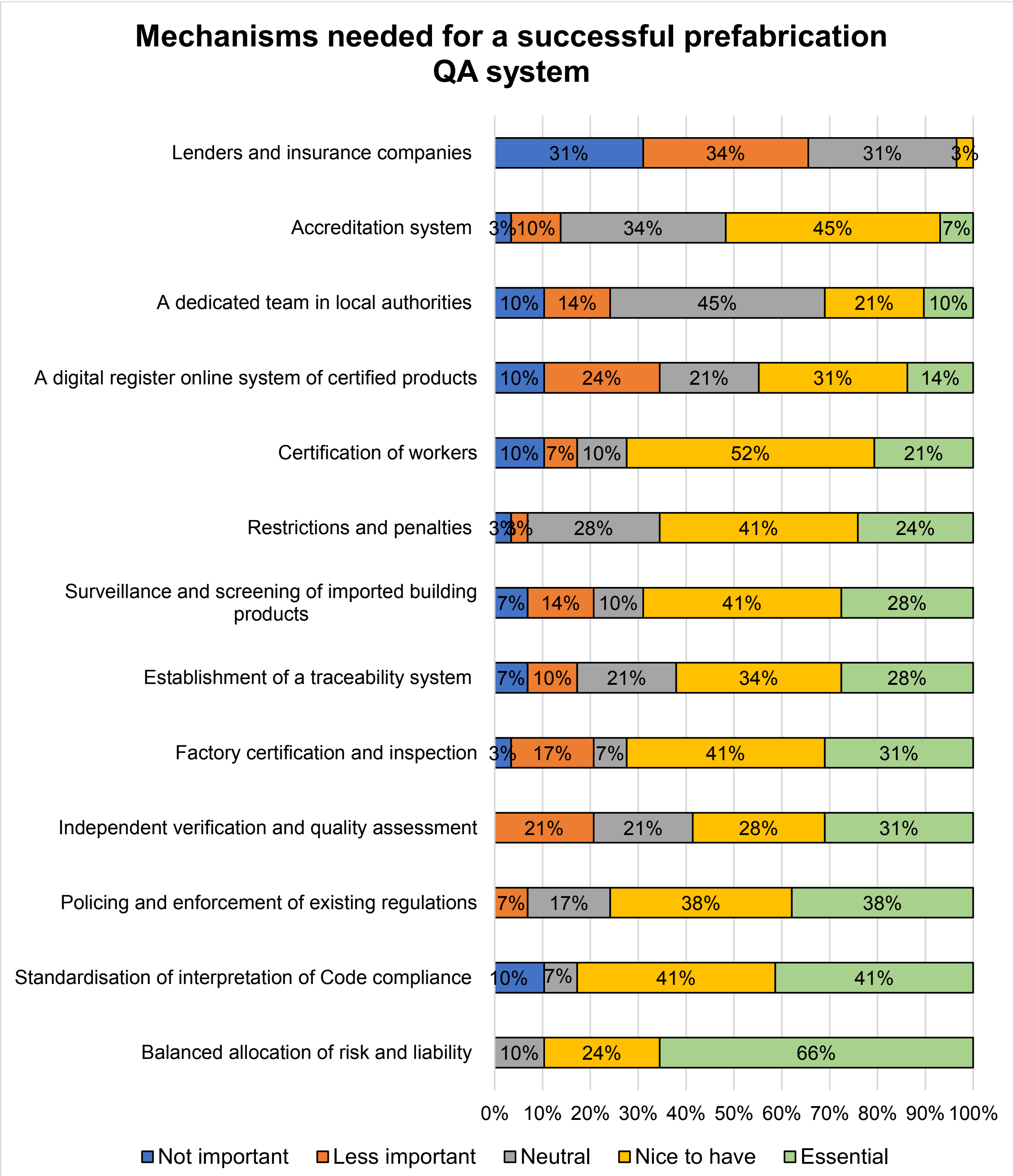
1. Self-monitoring
2. Audits production process
3. ISO Audits
4. Product certification
5. Follow-up of costs related to quality
6. Handling of deviations 5. 3rd party approvals

−

7. Who is guarding the product quality?



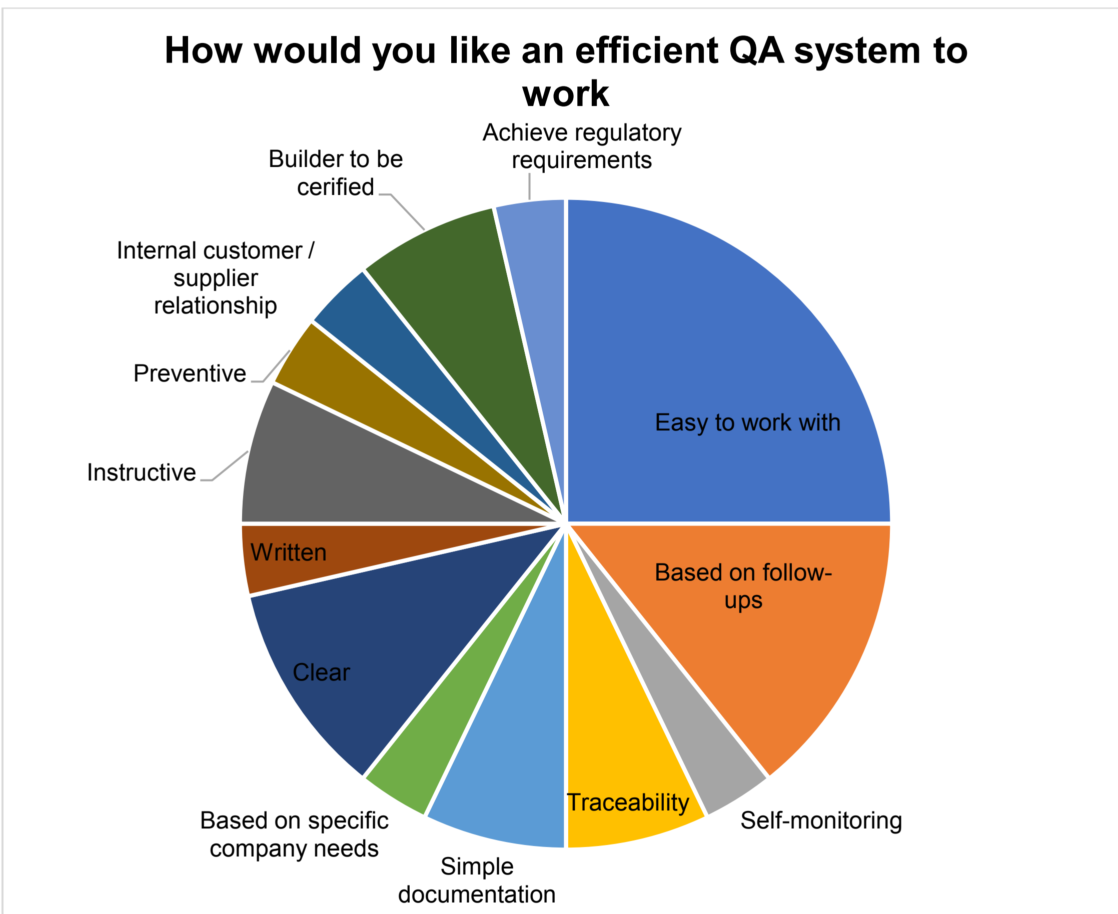
8. Mechanisms needed for a successful prefabrication QA system



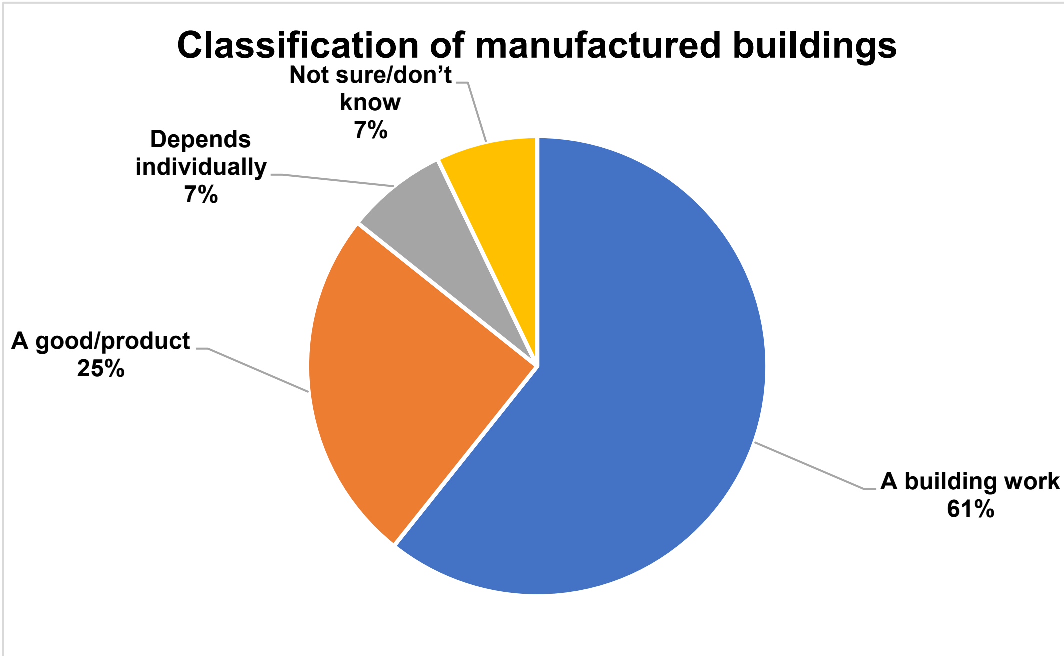
9. Legal remedies for non-compliant products

The product is retracted	Agreements between the supplier and the client regulate the penalty	The manufacturer and builders are responsible
A legal process	Consumer purchase law	Following regilations
Third-party certifications	Consumer right of complaint	Warranty

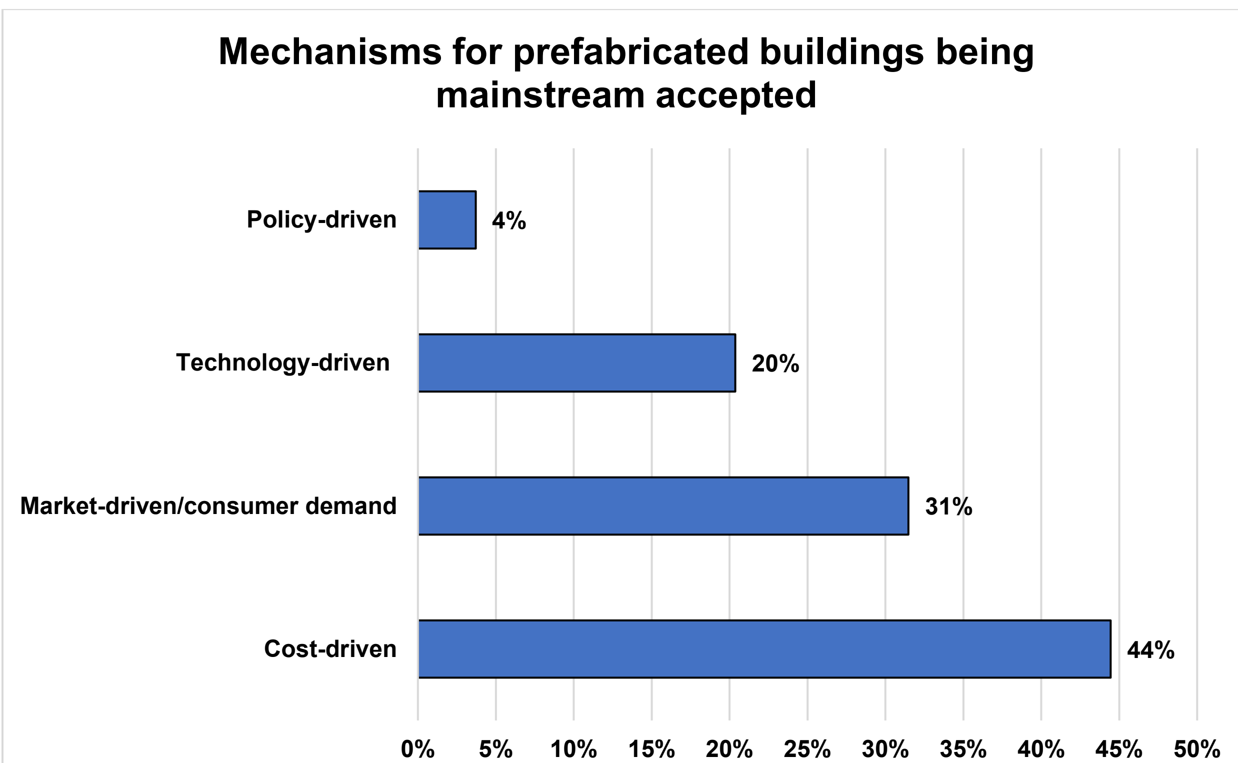
10. How would you like an efficient QA system to work?



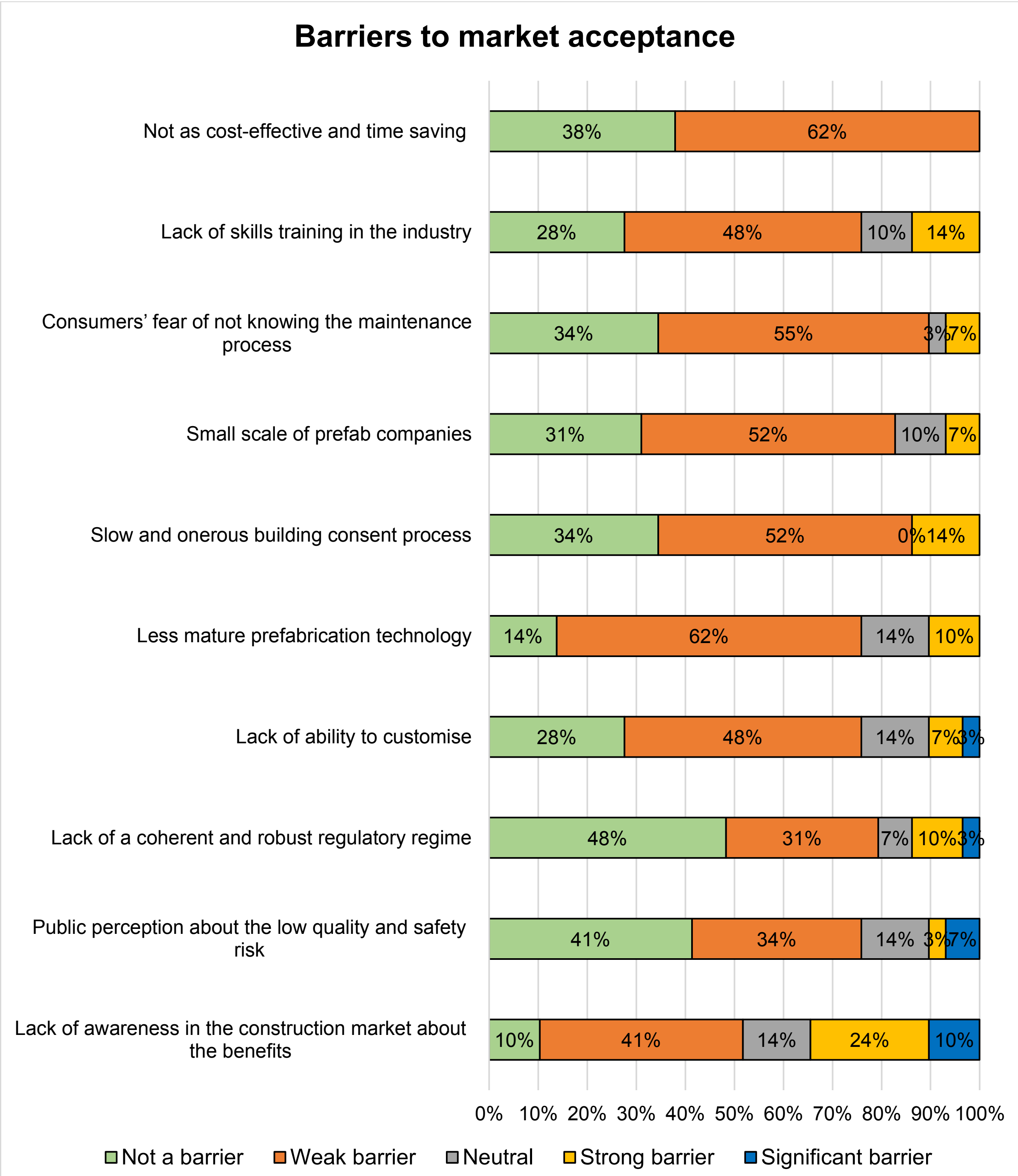
11. Classification of manufactured buildings



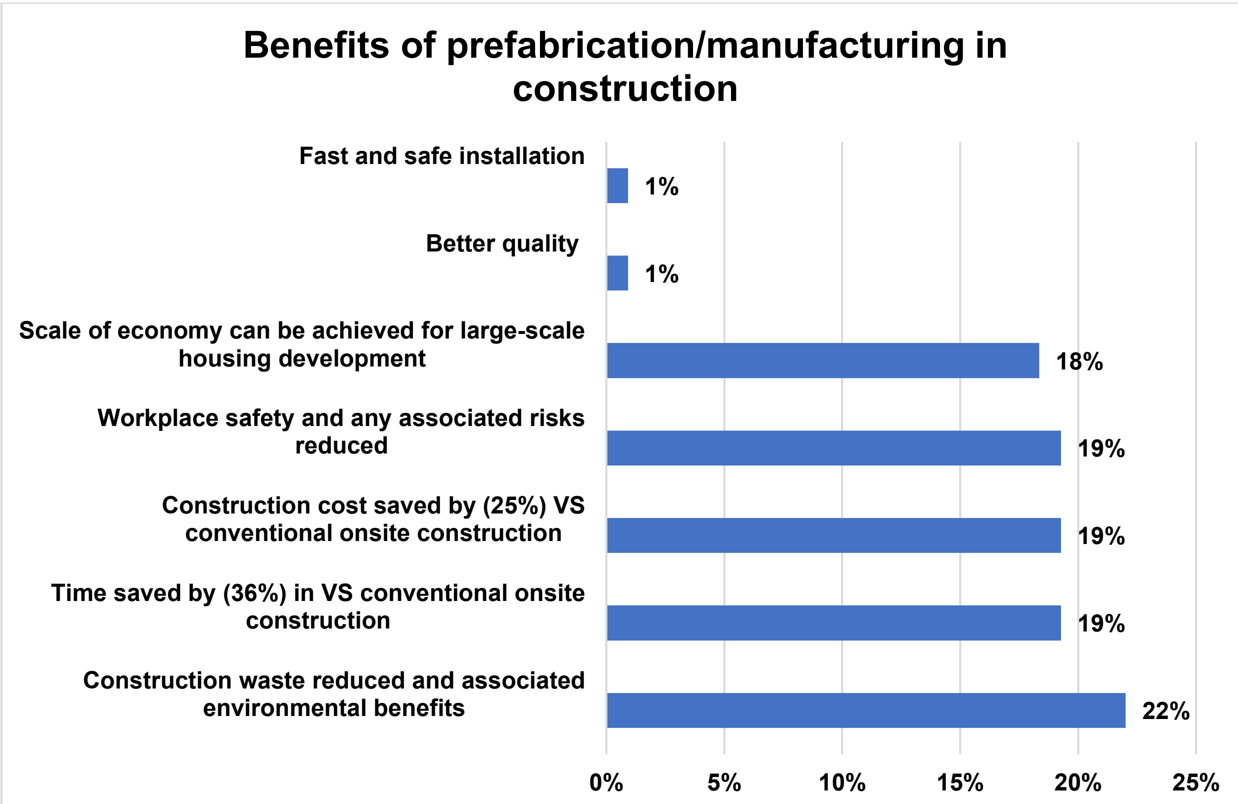
12. Mechanisms for prefabricated buildings being mainstream accepted



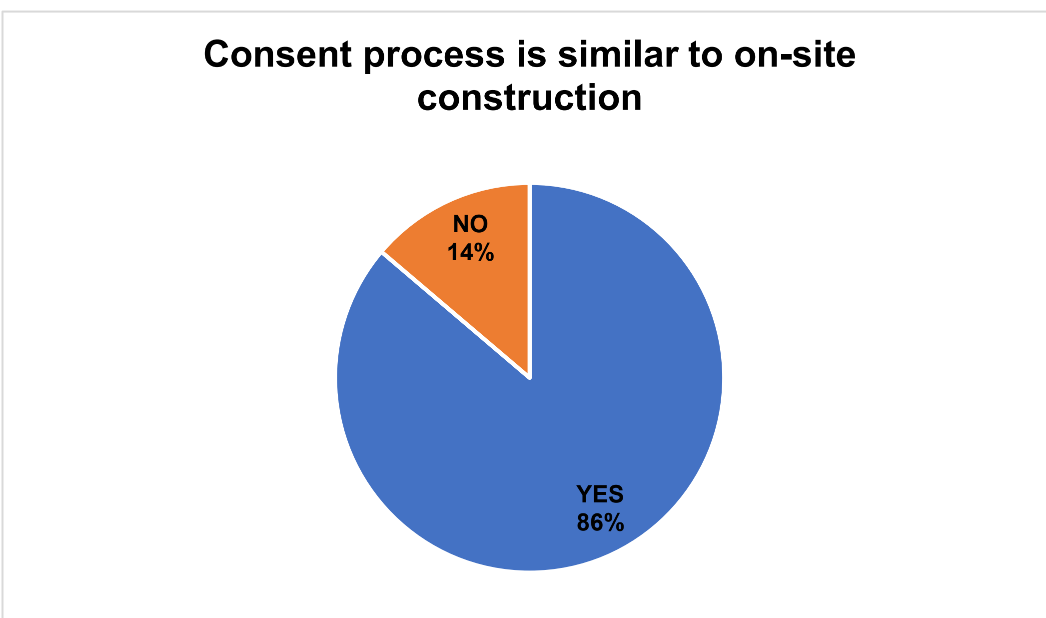
13. Barriers to market acceptance



14. Benefits of prefabrication/manufacturing in construction



15. Consent process is similar to on-site construction



16. Duration of consenting process

Minimum
15 days

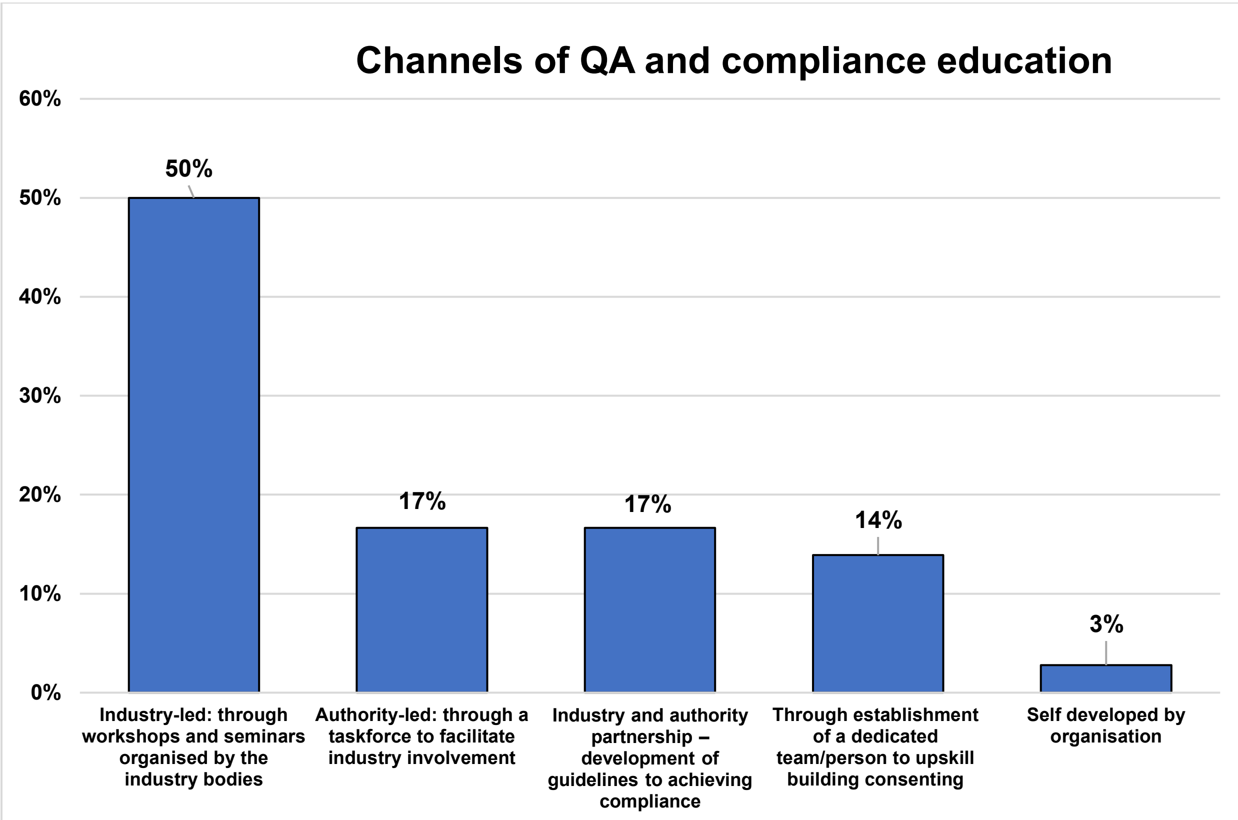
Average
42 days

Mximum
85 days

17. Comments on how to improve consent process

- More personnel resources in municipalities
- Licensing authority could approve solutions in advance
- Same regulations in all councils
- Authorities to invest
- Standardize
- Pre-approved building systems and products

18. Channels of QA and compliance education



19. Other levers to support QA and compliance of manufactured buildings

- Technical consultation prior to construction start
- Increased demand for certification of quality
- Legal support
- Team audits
- PBL (the Swedish planning and building act)

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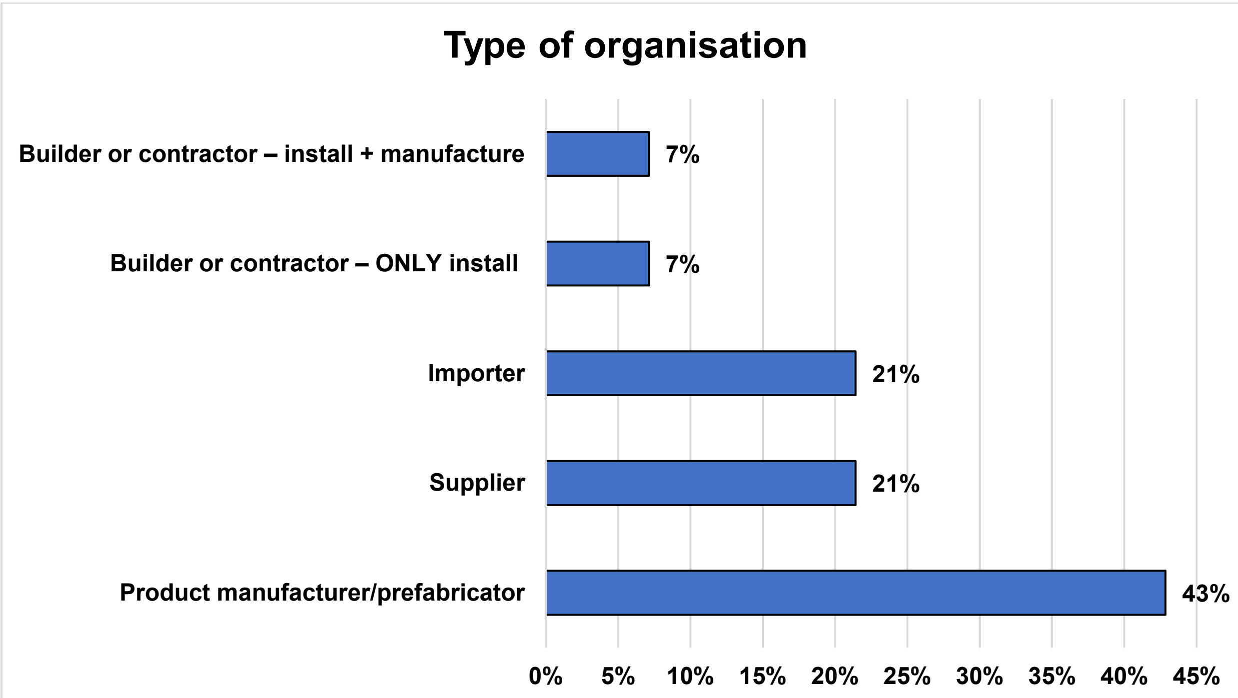
MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

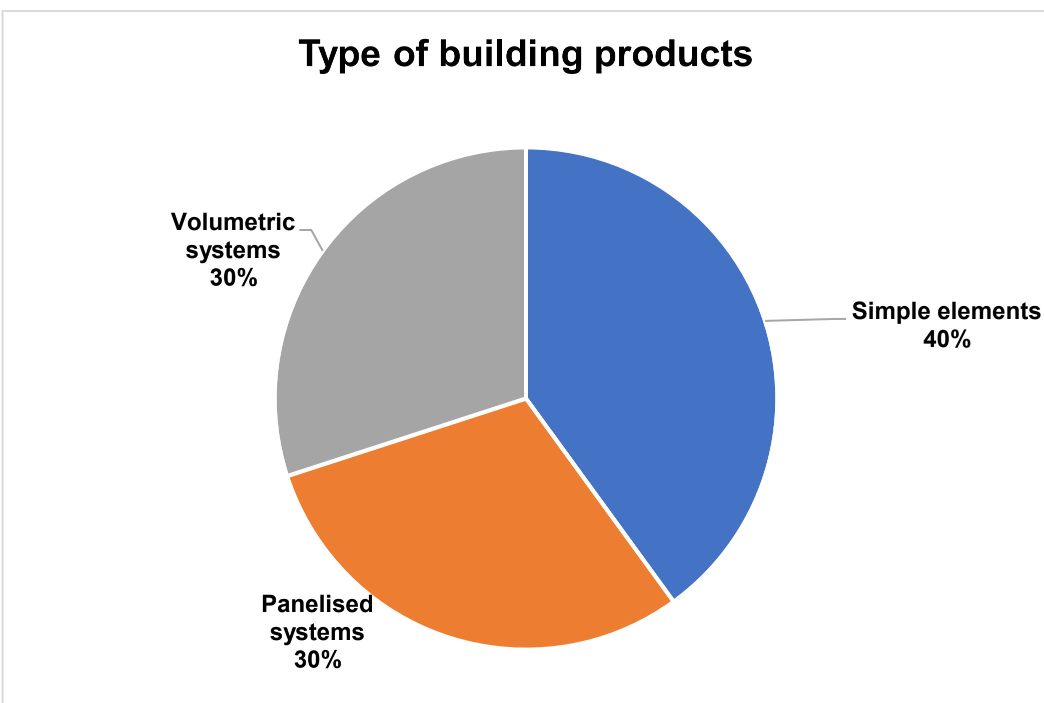
Compliance and assurance prototypes for manufactured buildings research project

QUESTIONNAIRE SURVEY RESULTS: SWITZERLAND

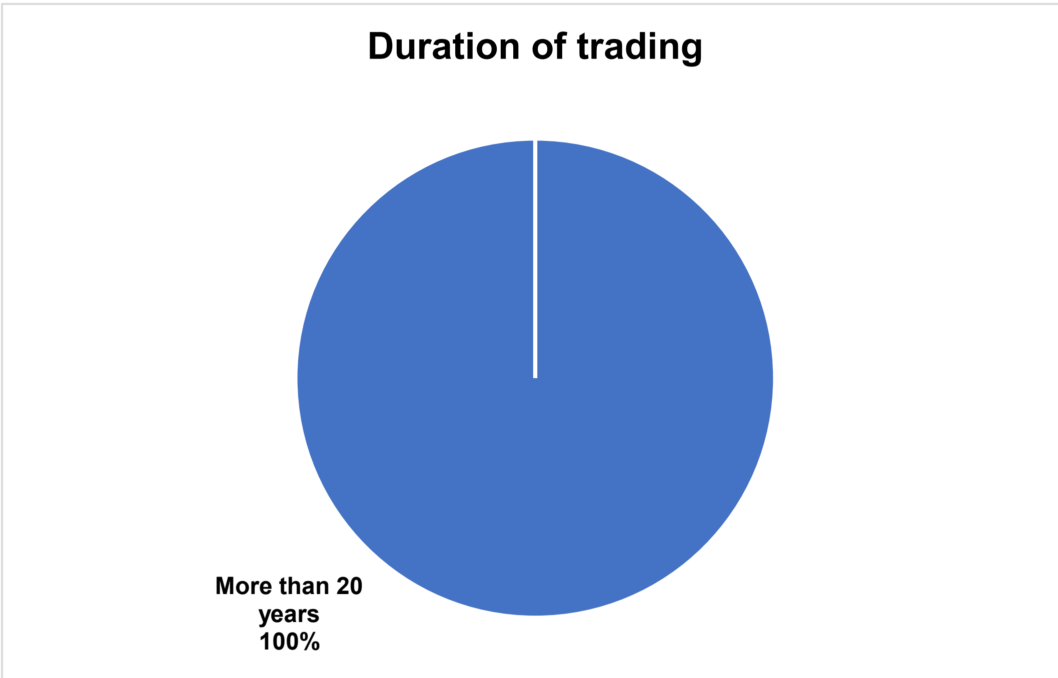
1. **Type of organization**



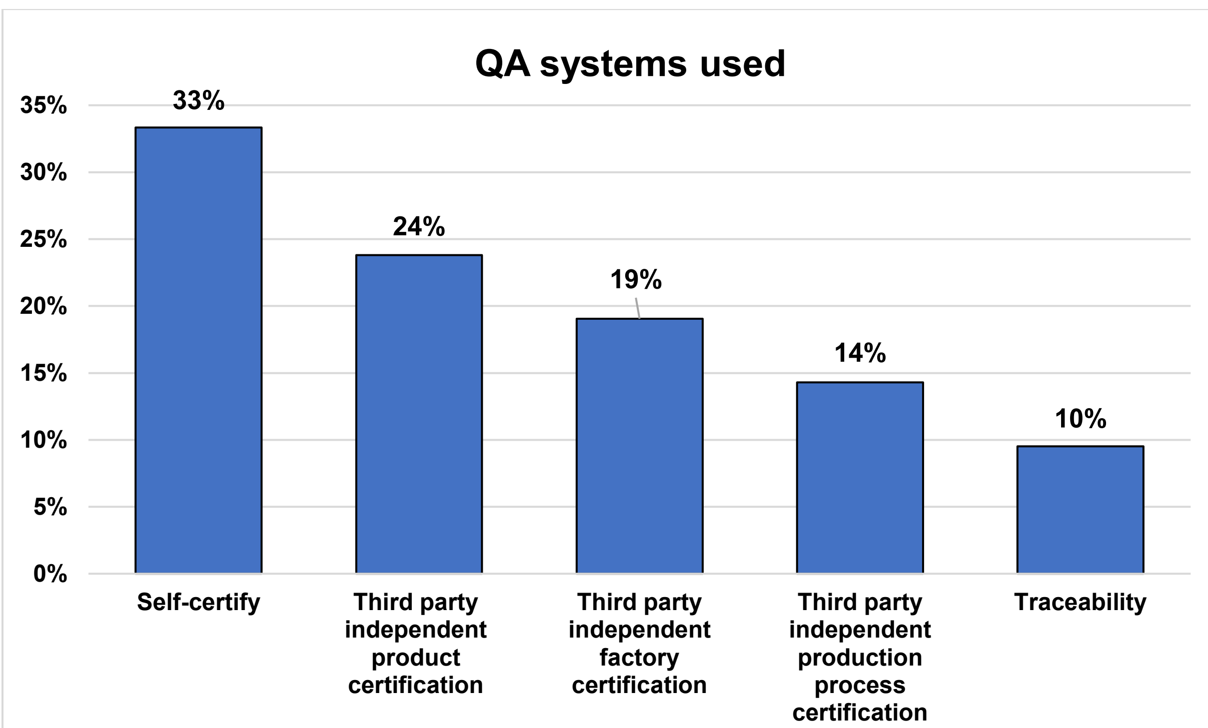
2. **Type of building products**



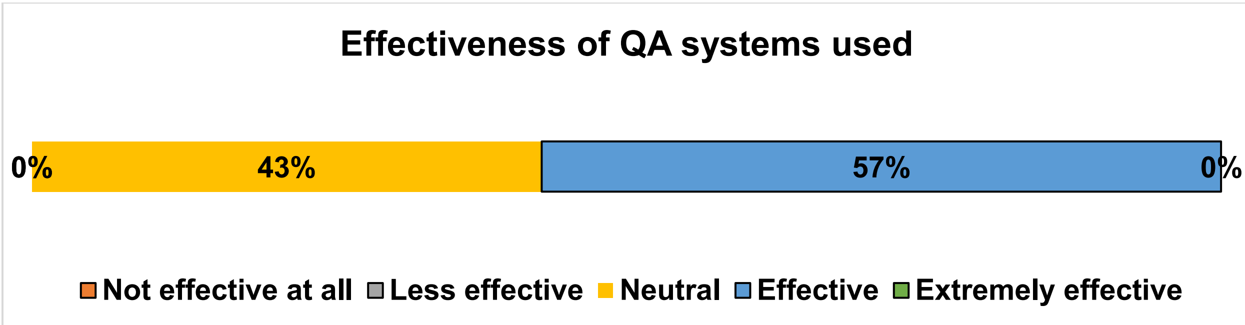
3. Duration of trading



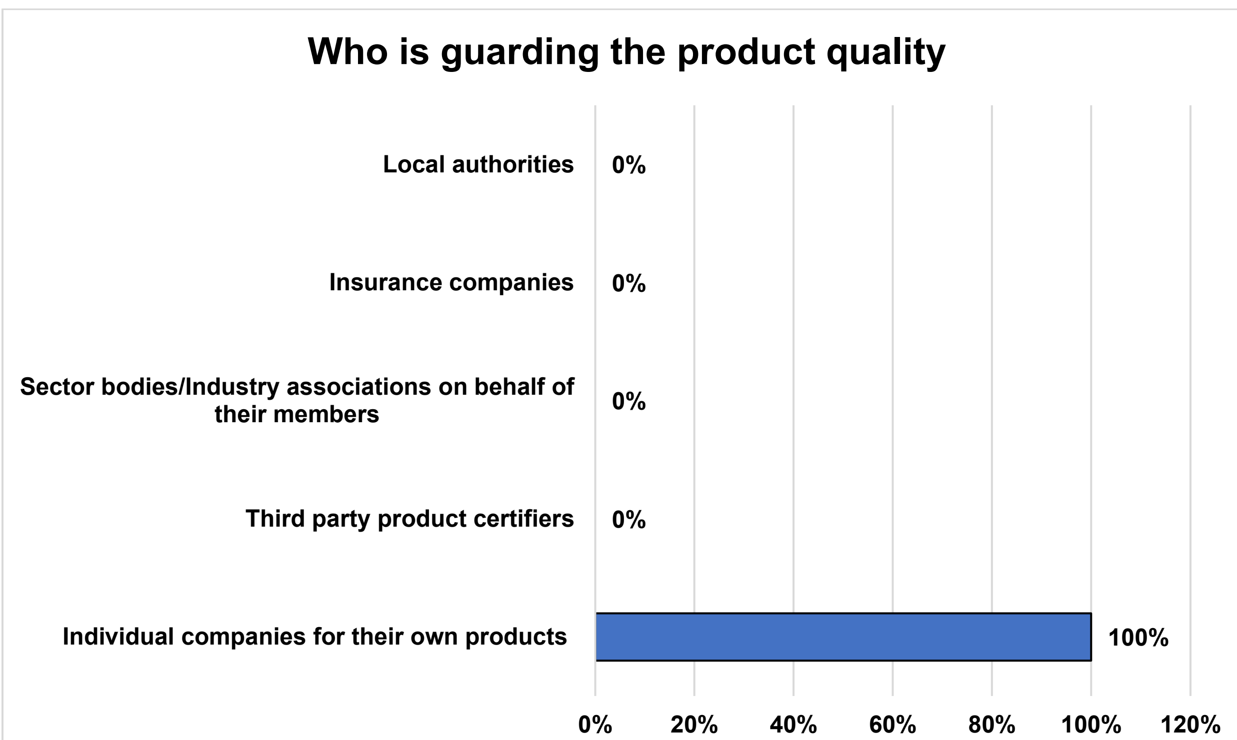
4. QA systems used



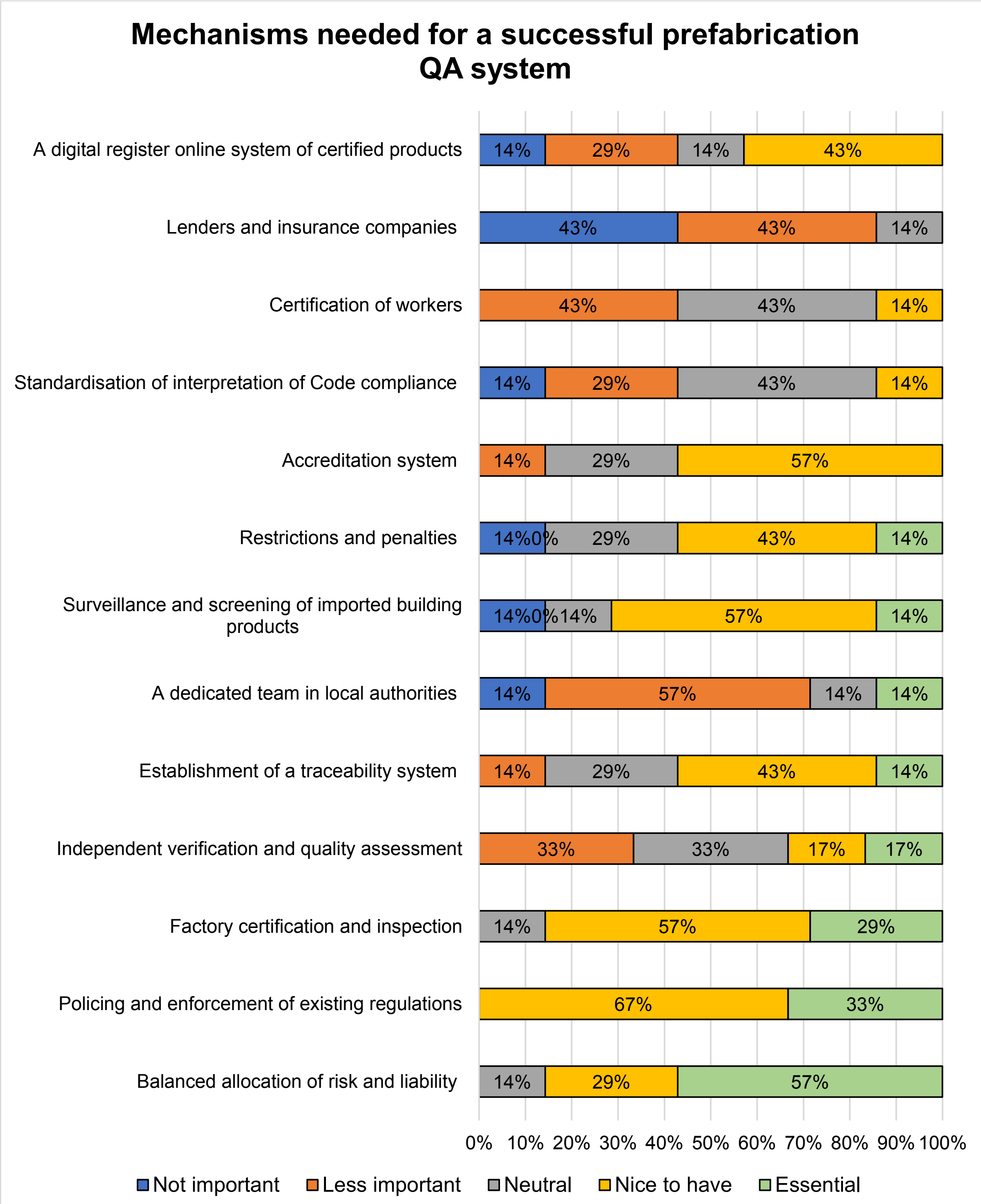
5. **Effectiveness of QA systems used**



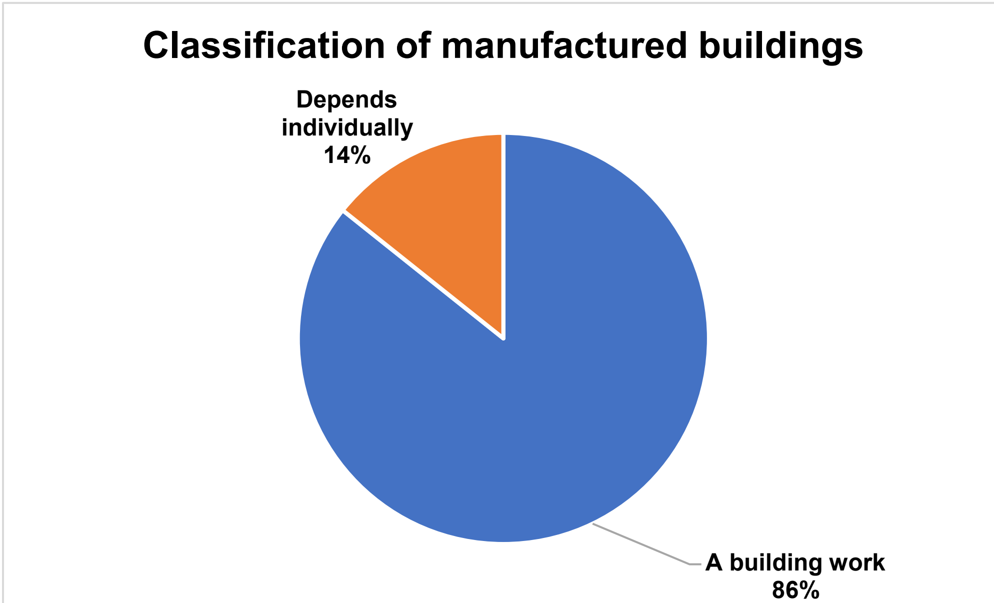
6. **Who is guarding the product quality?**



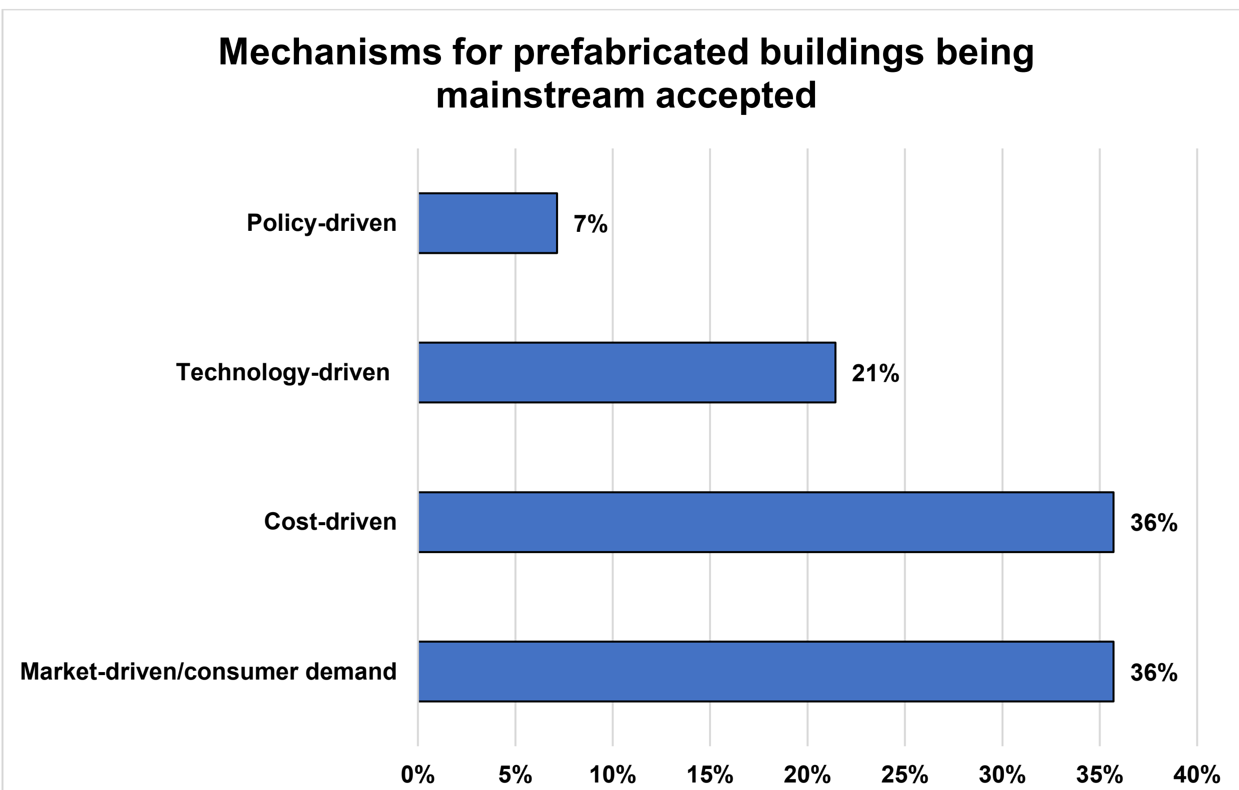
7. Mechanisms needed for a successful prefabrication QA system



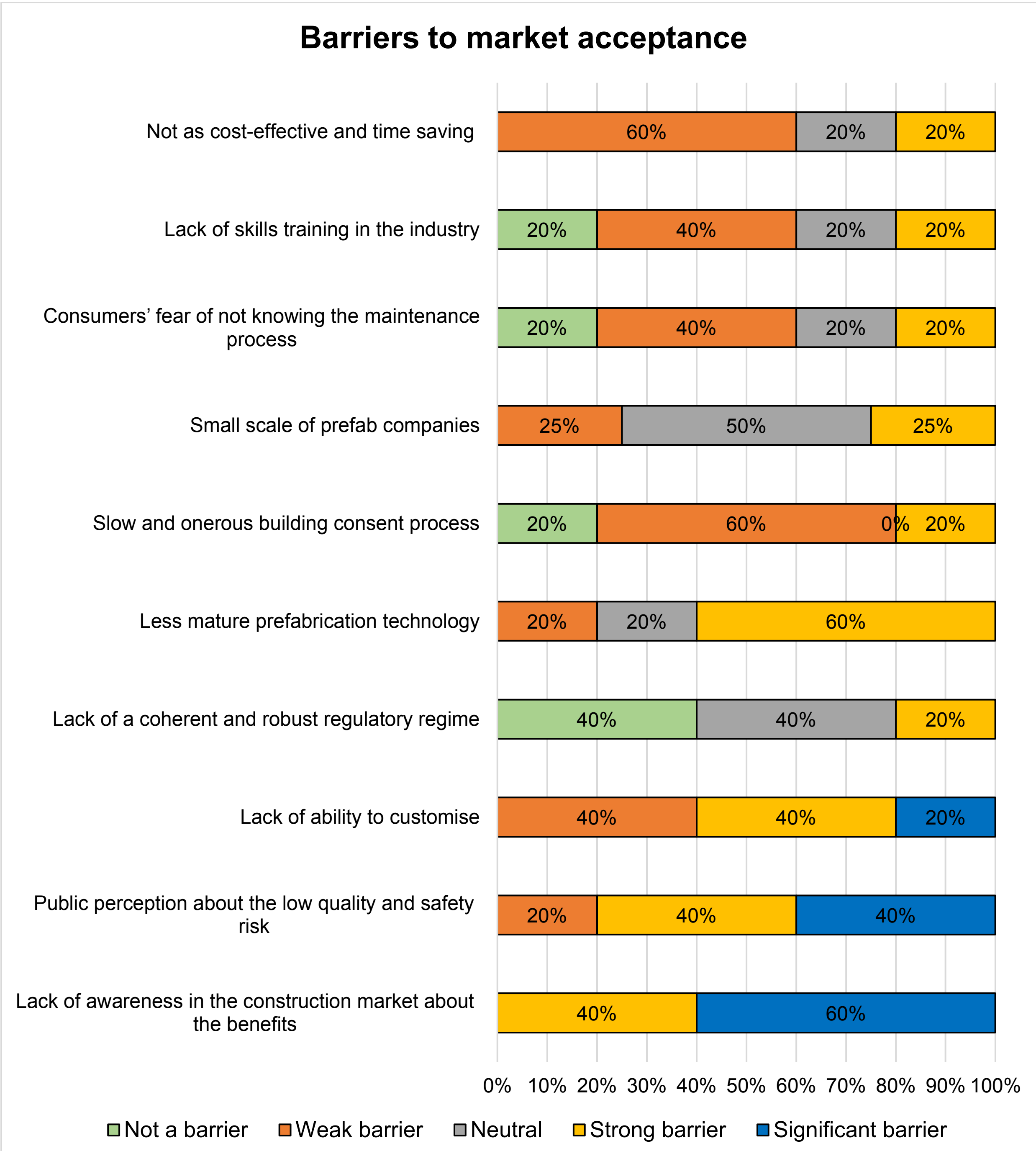
8. Classification of manufactured buildings



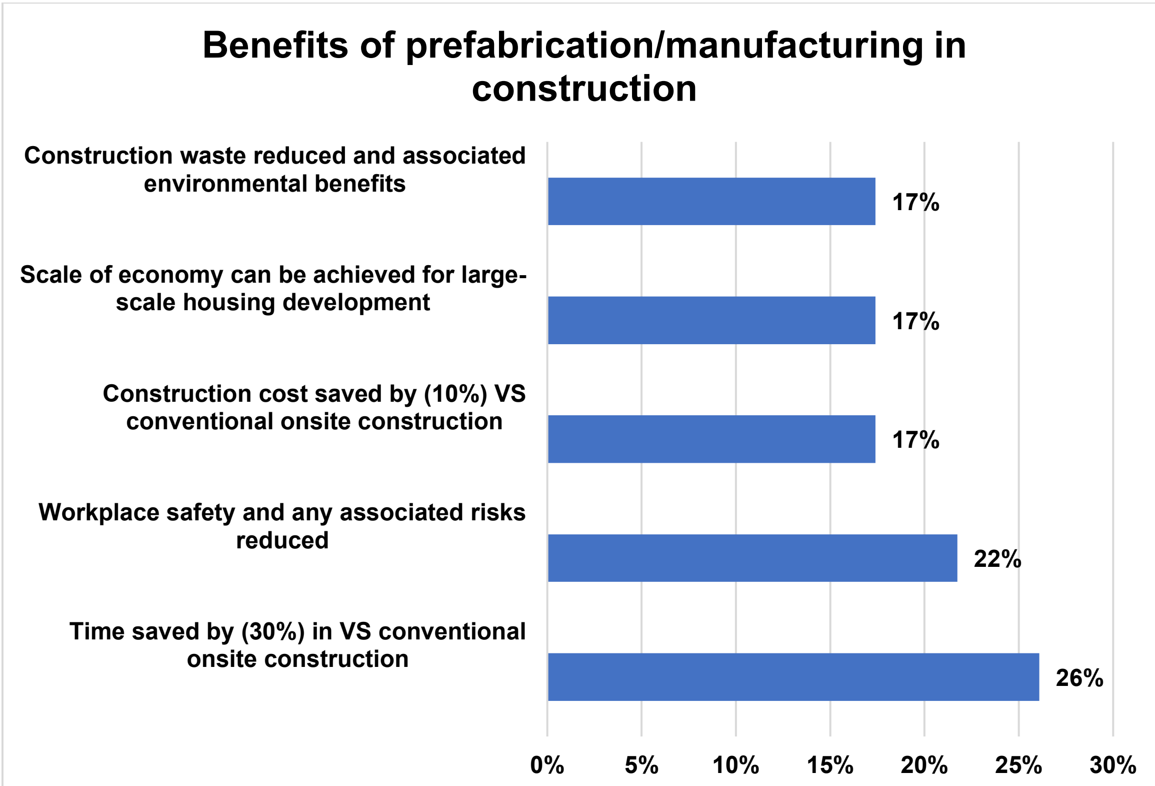
9. Mechanisms for prefabricated buildings being mainstream accepted



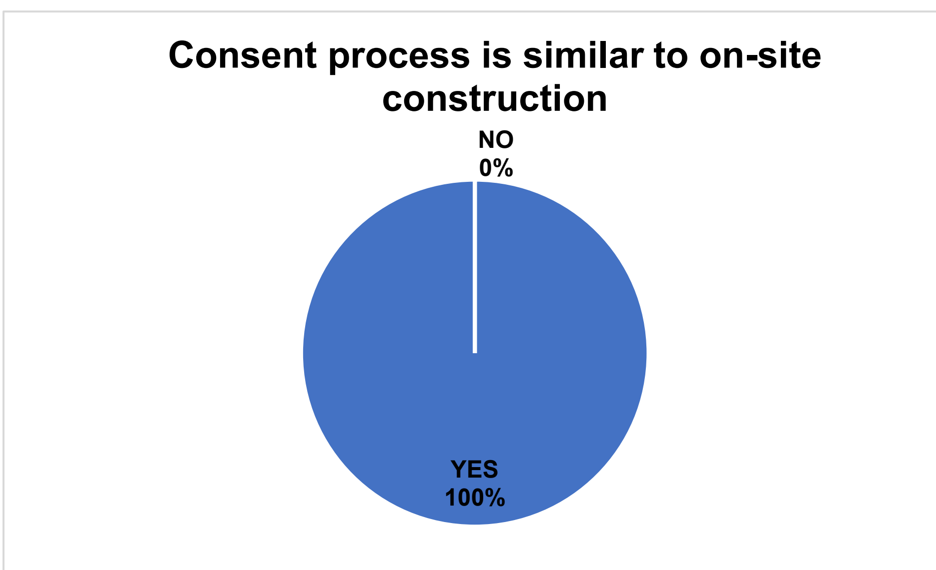
10. Barriers to market acceptance



11. Benefits of prefabrication/manufacturing in construction



12. Consent process is similar to on-site construction



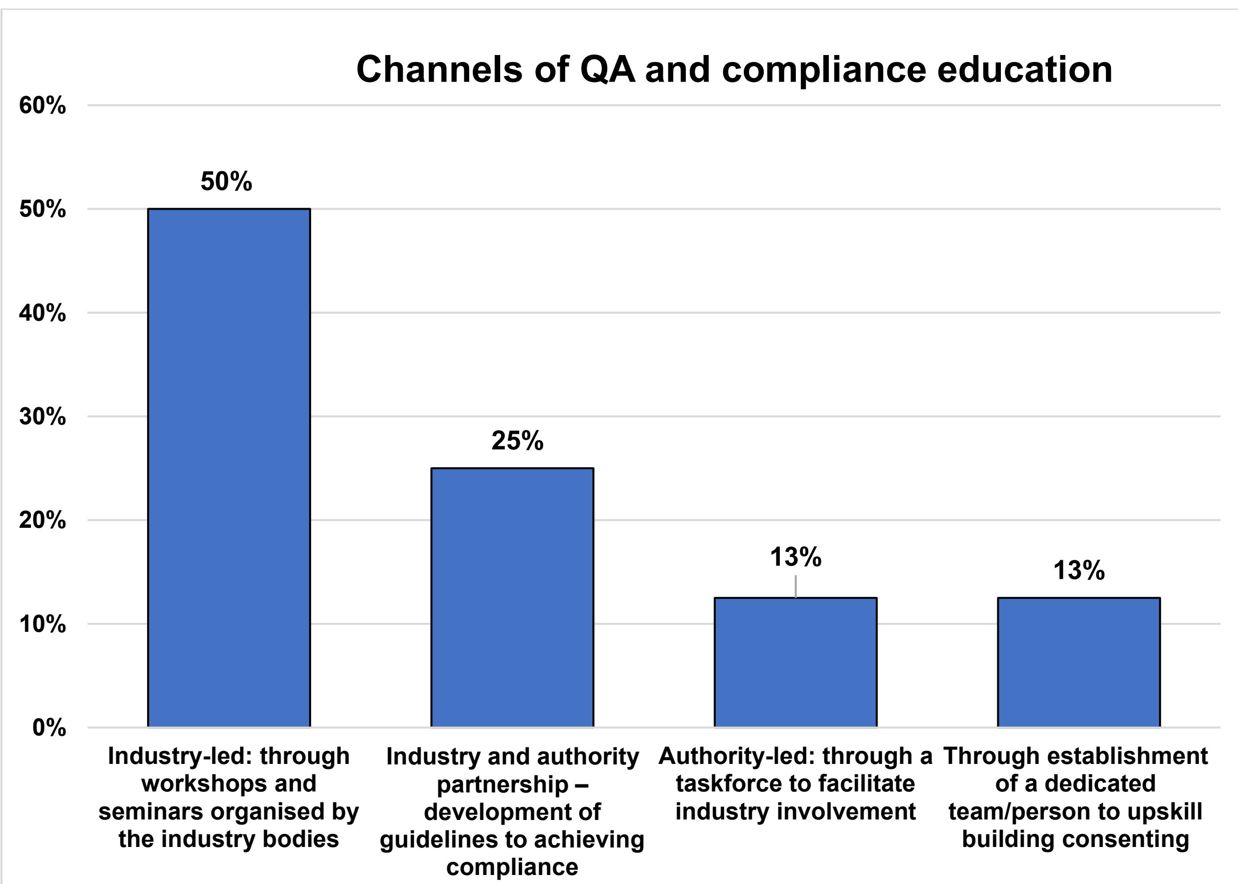
13. Duration of consenting process

Minimum
20 days

Average
50 days

Mximum
100 days

14. Channels of QA and compliance education



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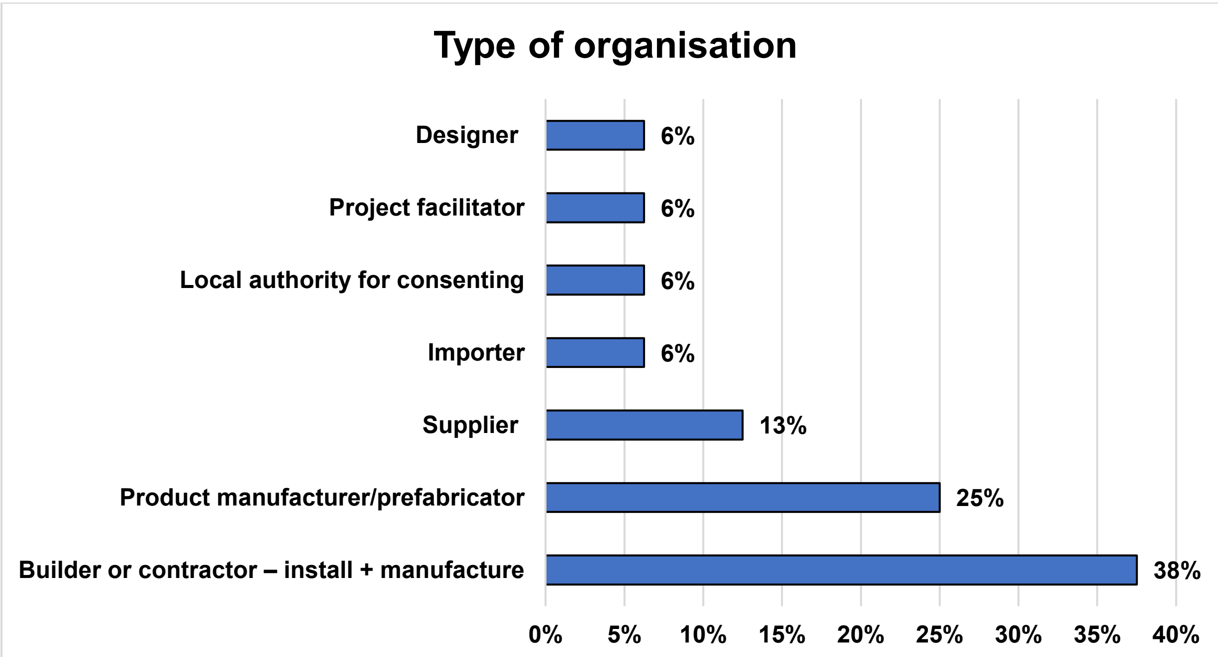
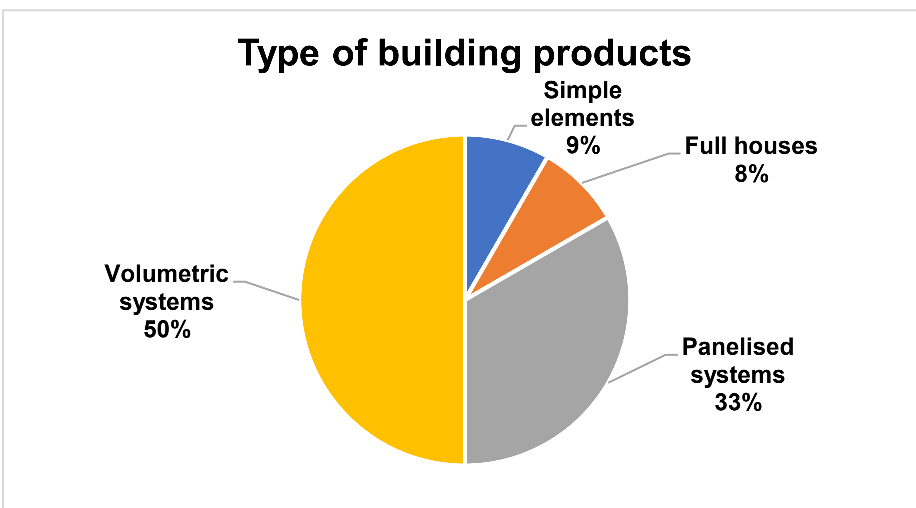
Compliance and assurance prototypes for manufactured buildings research project

QUESTIONNAIRE SURVEY RESULTS: UNITED KINGDOM

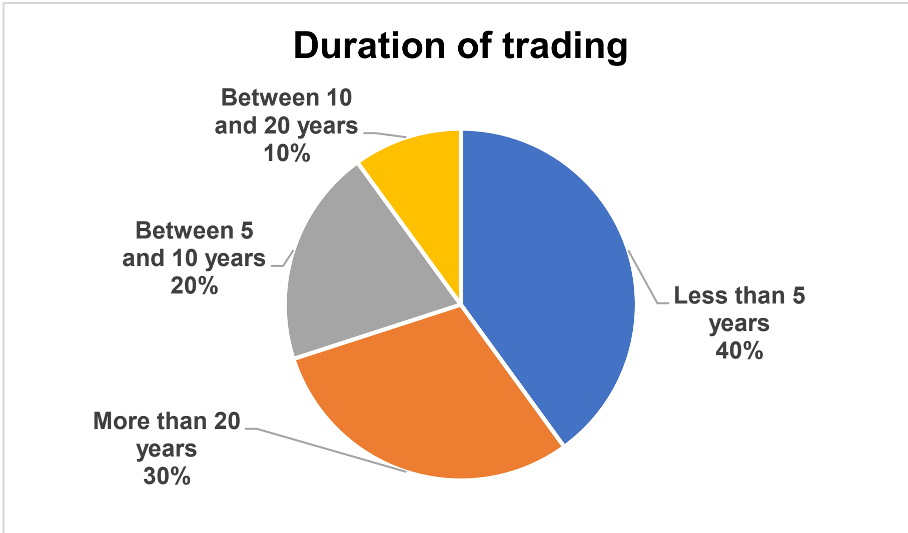
1. **Type of organization**



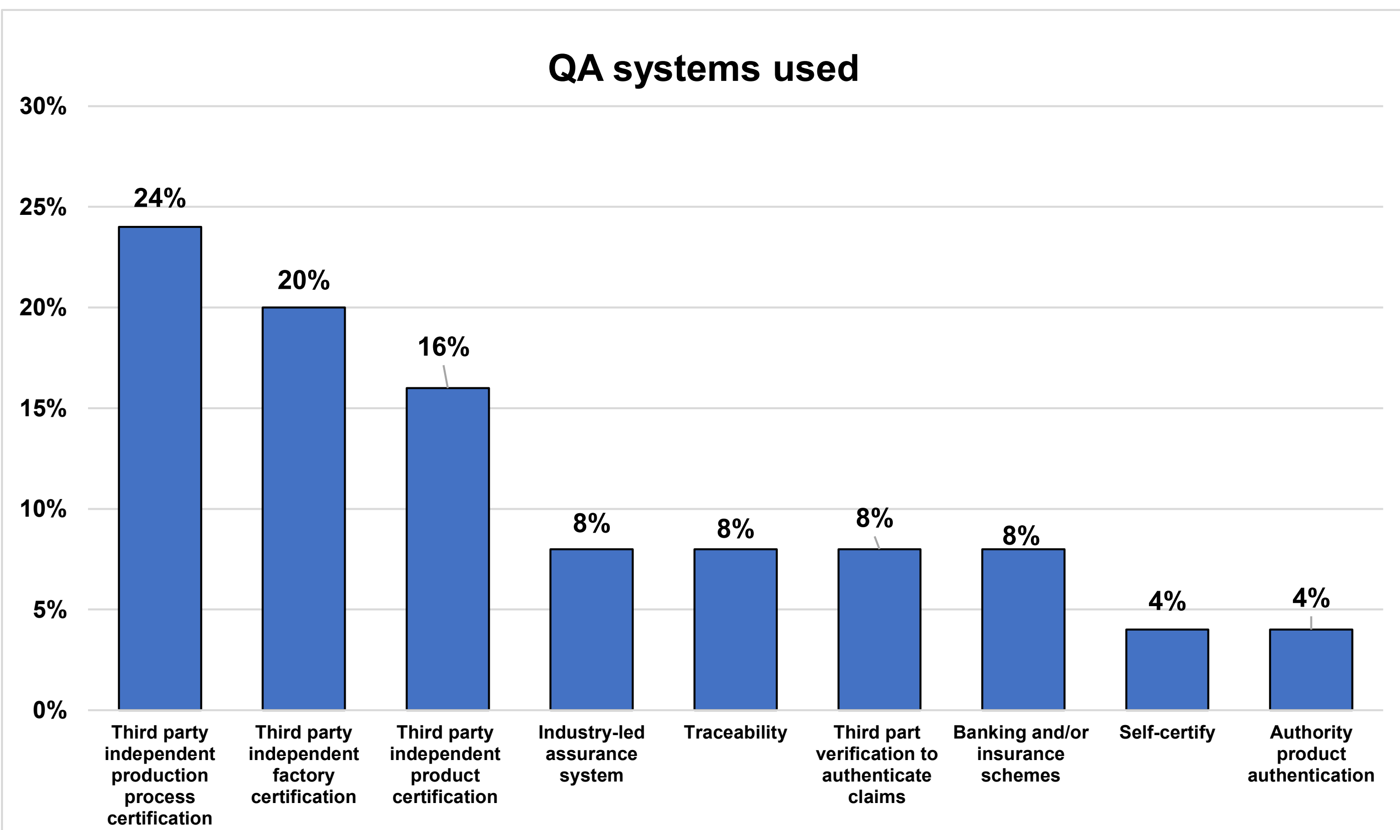
2. **Type of building products**



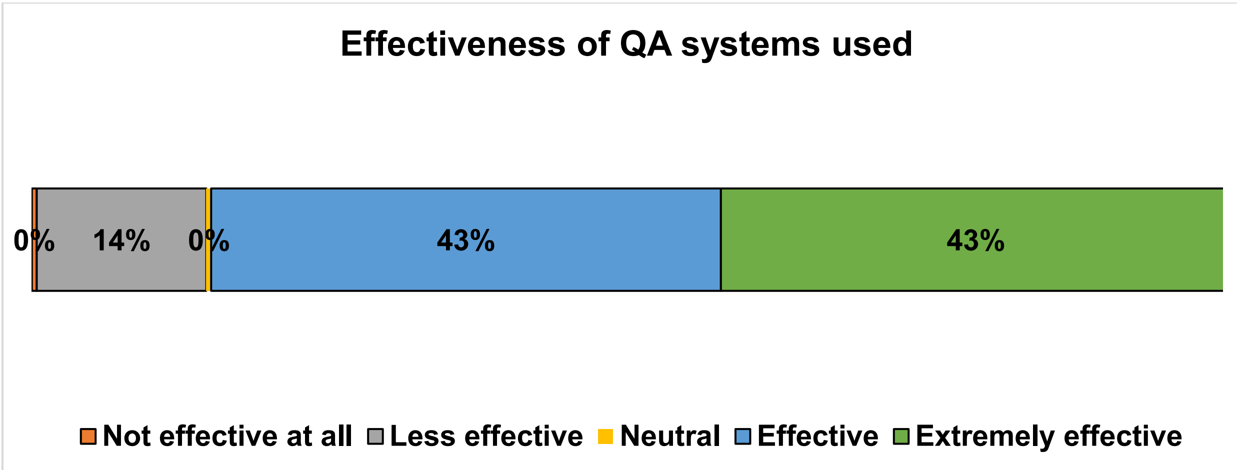
3. Duration of trading



4. QA systems used



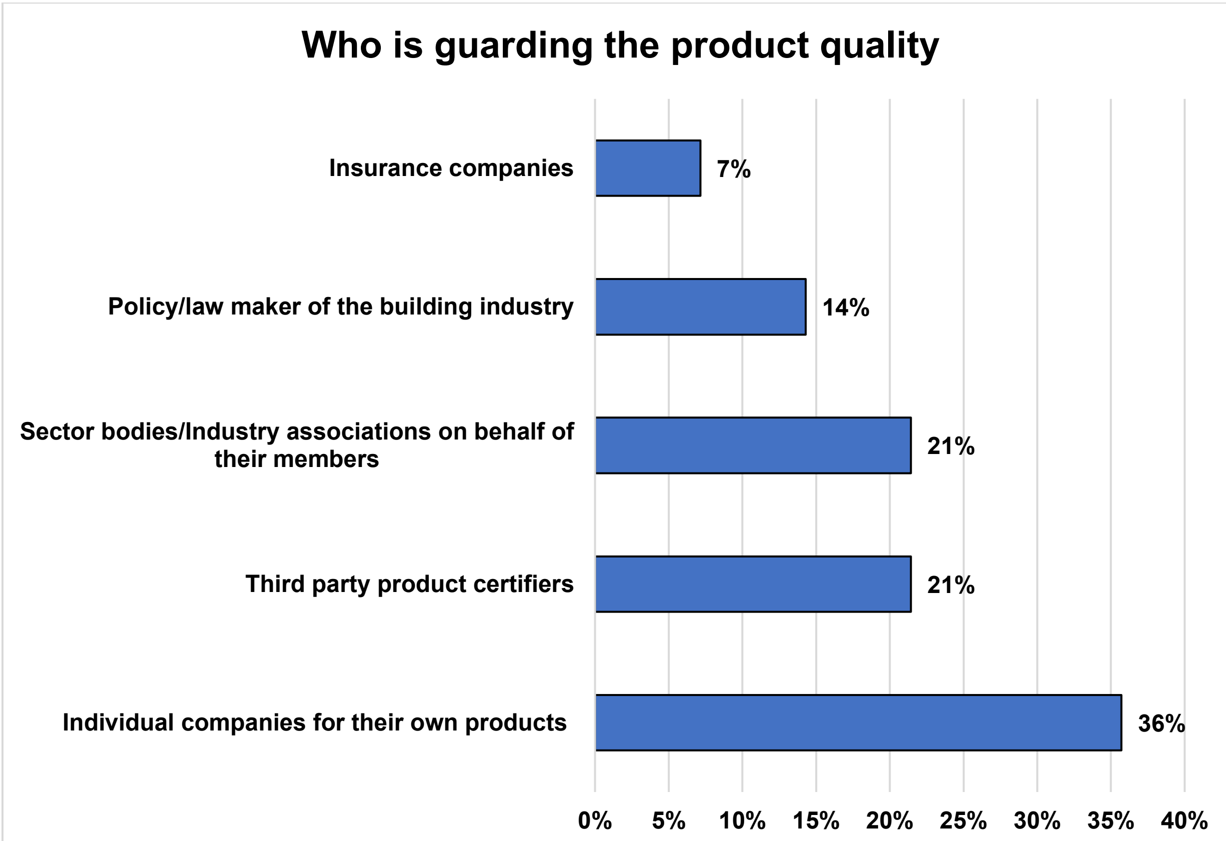
5. **Effectiveness of QA systems used**



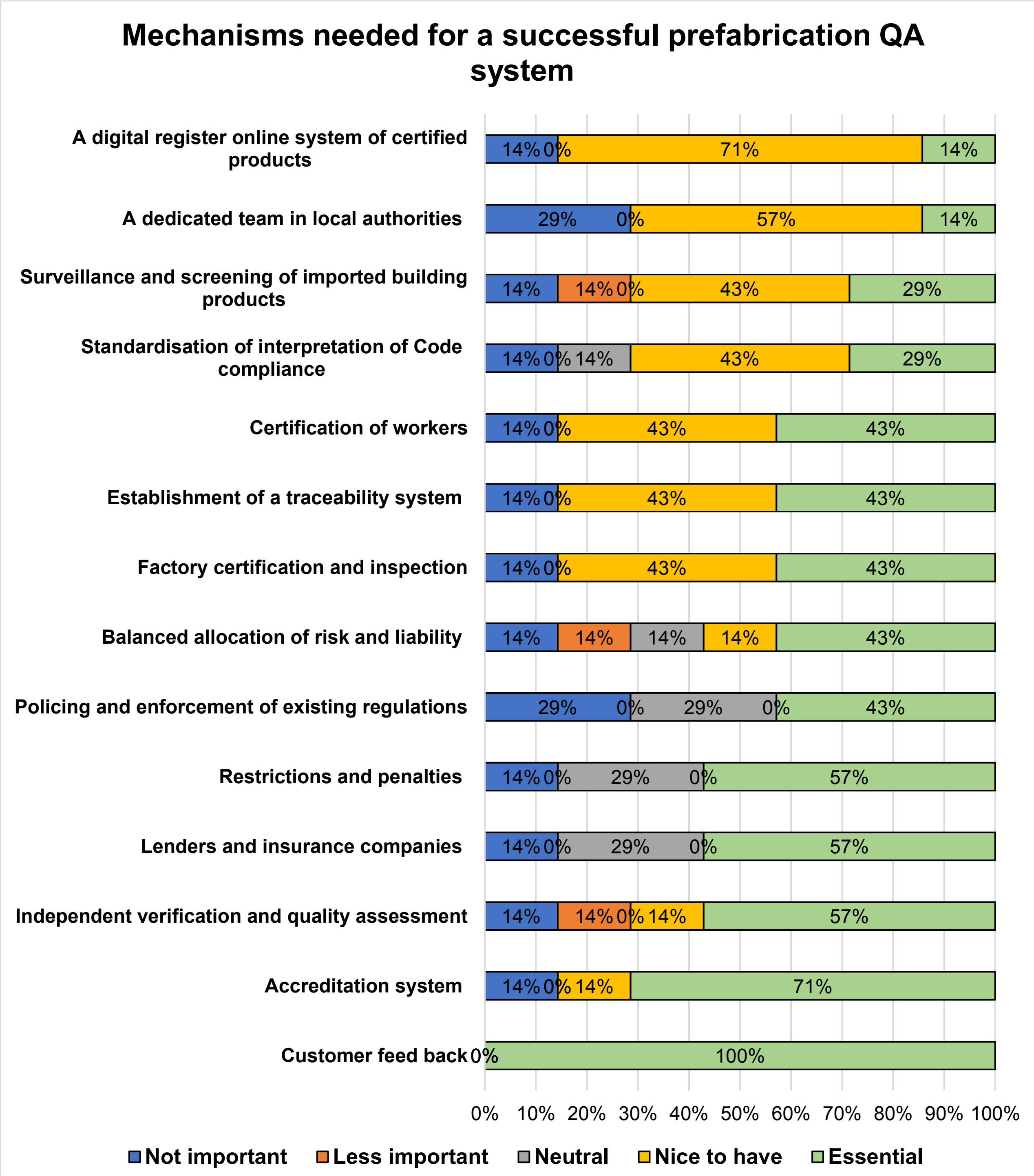
6. **What worked well and what have not?**

1. Industry supported standards such as BOPAS **2. Electronic QA system integrated with ERP** **3. Shop floor metrics for quality** **4. Close monitoring of labour**	**1. Regulations**

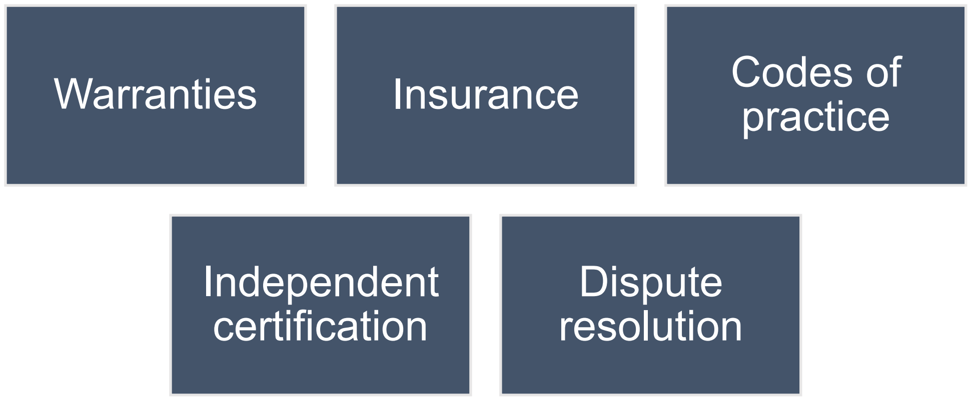
7. **Who is guarding the product quality?**



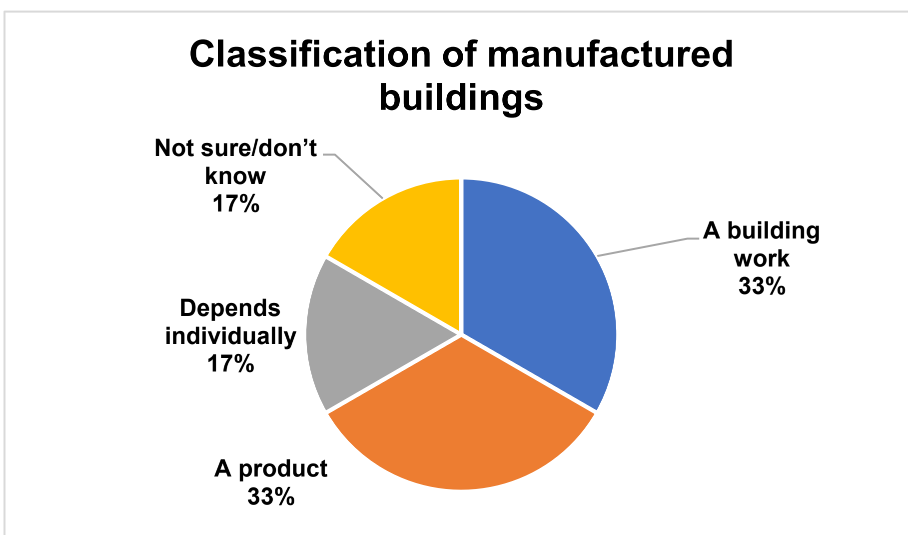
8. **Mechanisms needed for a successful prefabrication QA system**



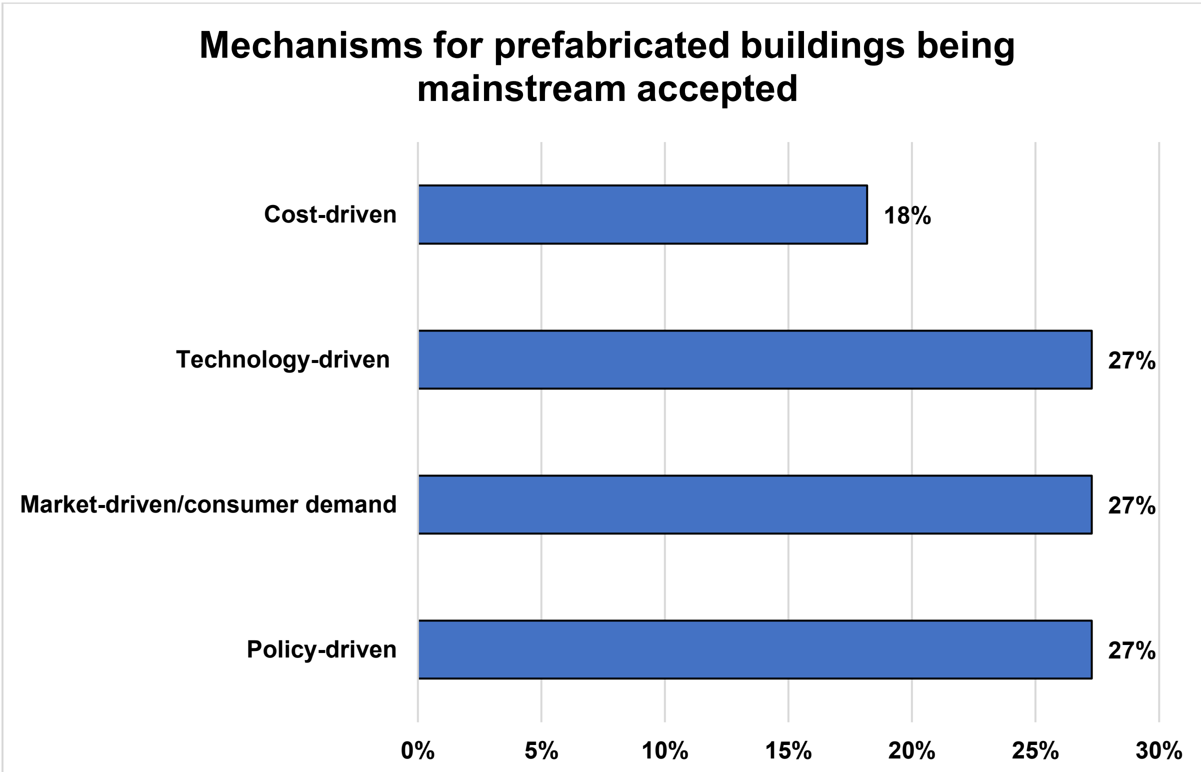
9. Legal remedies for non-compliant products



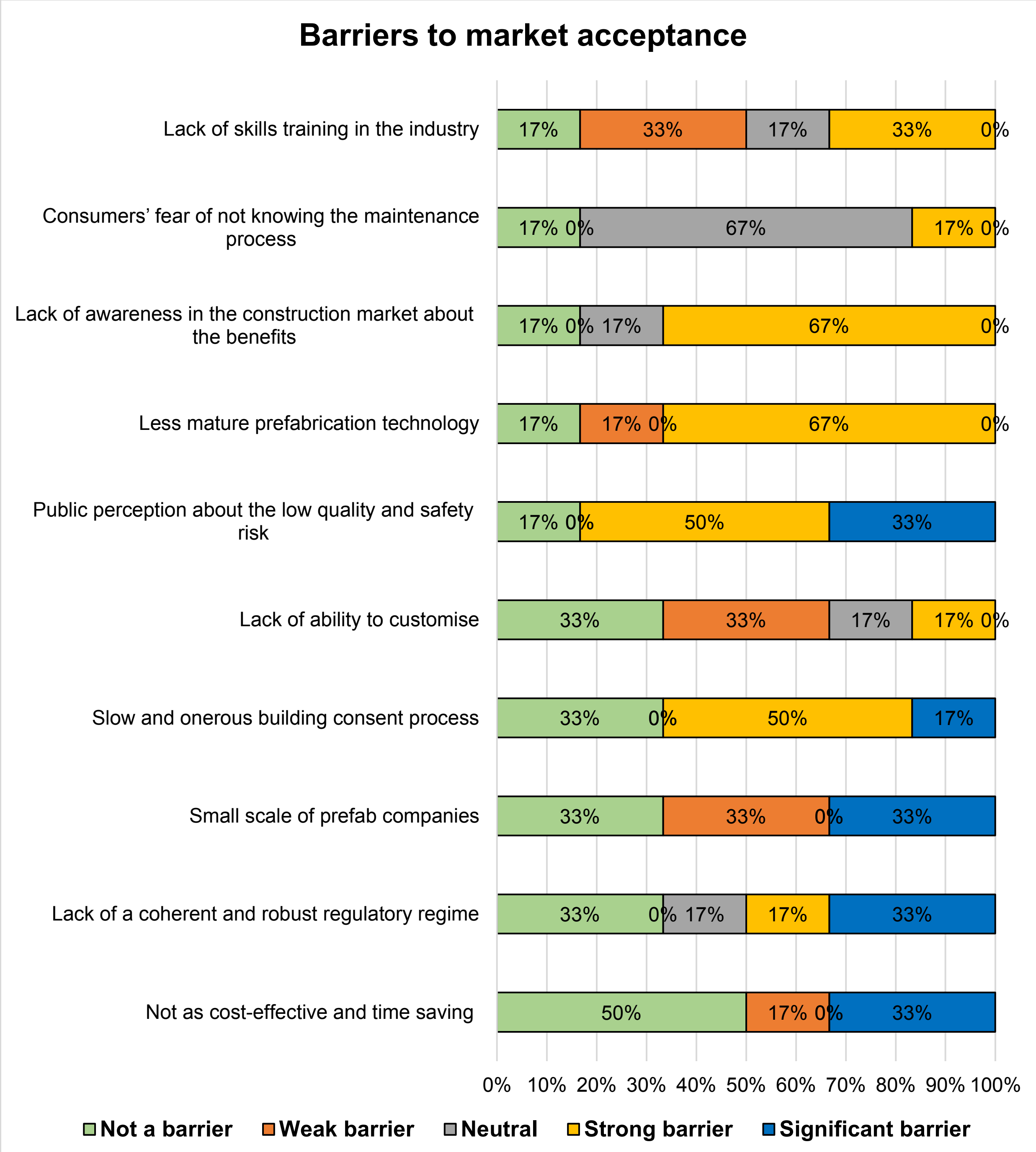
10. Classification of manufactured buildings



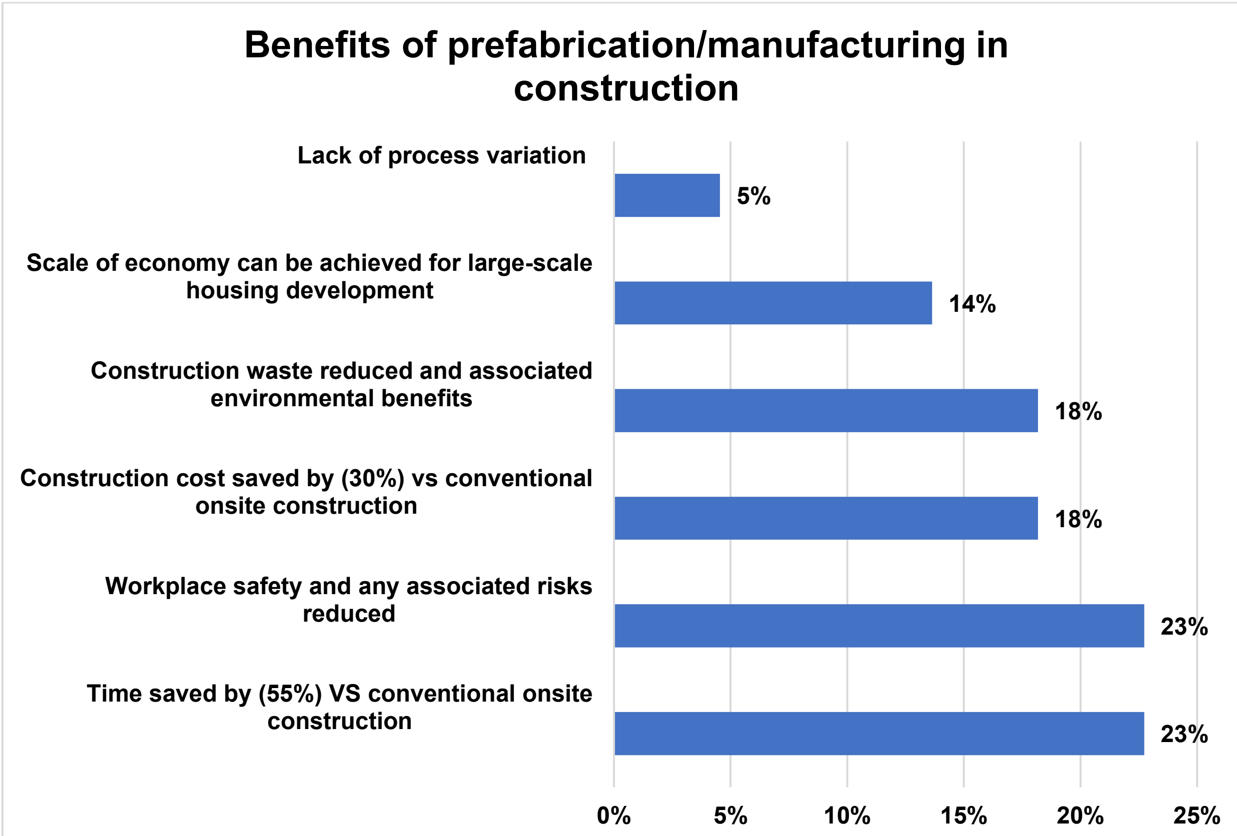
11. Mechanisms for prefabricated buildings being mainstream accepted



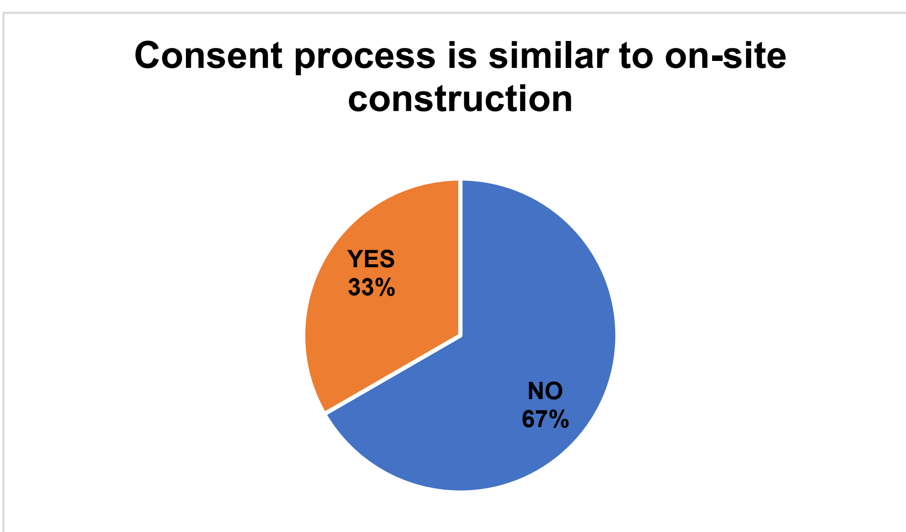
12. Barriers to market acceptance



13. Benefits of prefabrication/manufacturing in construction



14. Consent process is similar to on-site construction



15. Duration of consenting process

Minimum
28 days

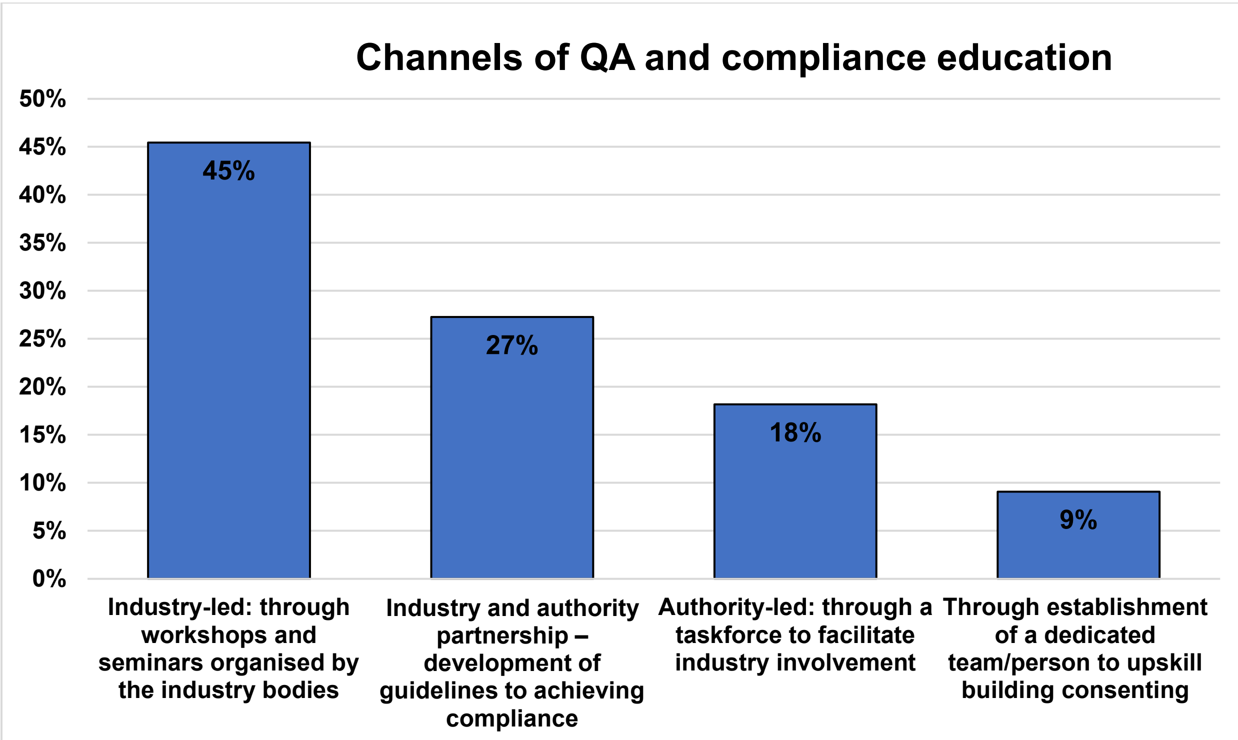
Average
74 days

Mximum
120 days

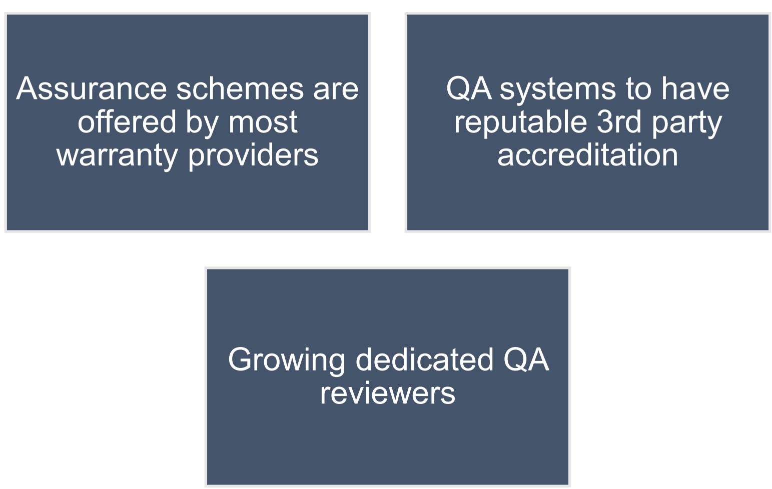
16. Comments on how to improve consent process

- Education
- Adopt a manufacturing mindset and not tweak designs
- Rapid approval by adopting QA processes
- Technologies

17. Channels of QA and compliance education



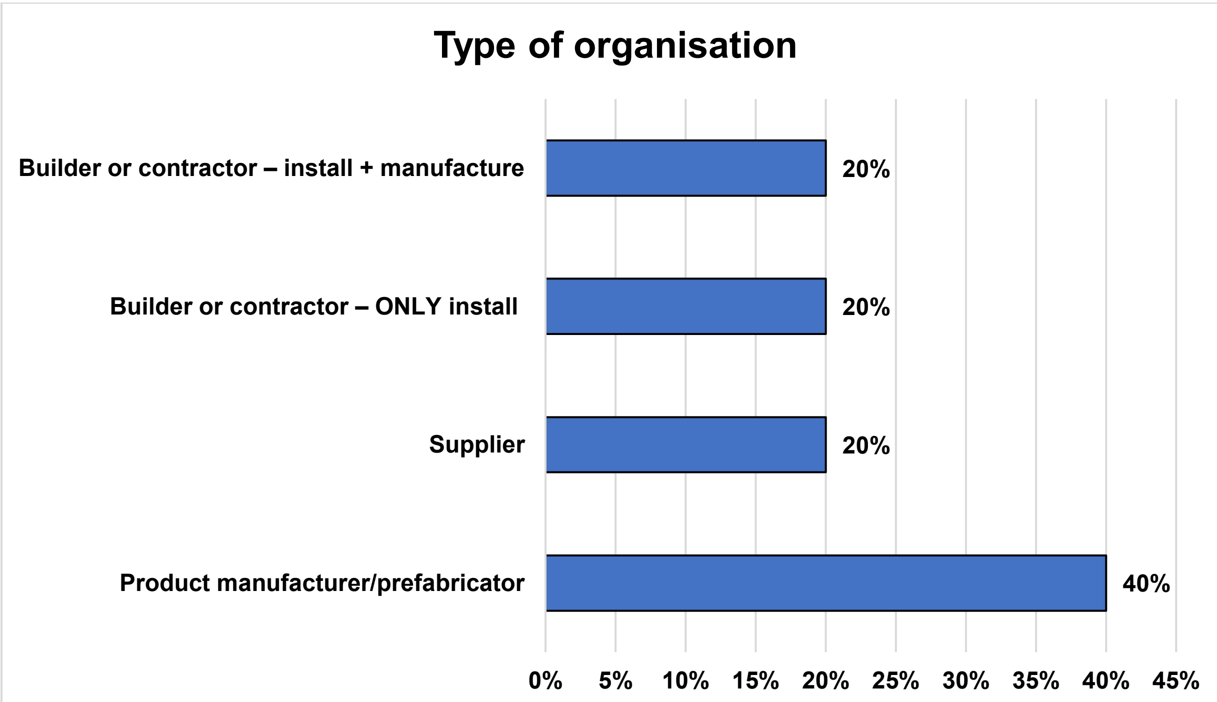
18. Other levers to support QA and compliance of manufactured buildings



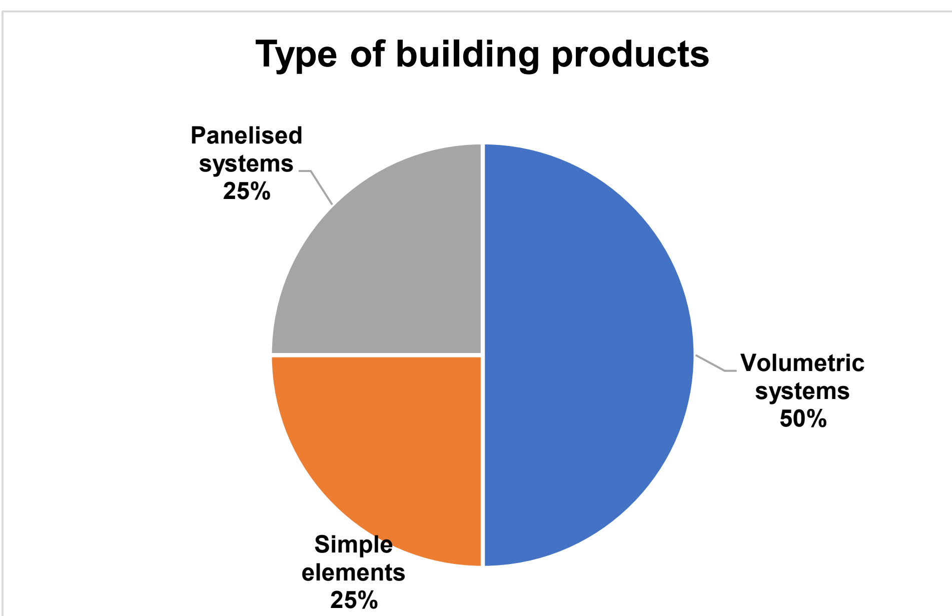
Compliance and assurance prototypes for manufactured buildings research project

QUESTIONNAIRE SURVEY RESULTS: AUSTRALIA

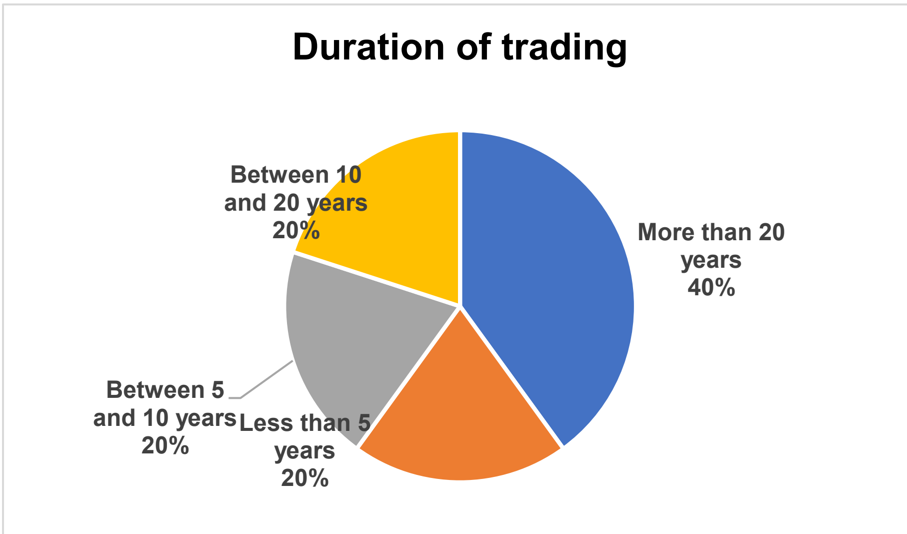
1. Type of organization



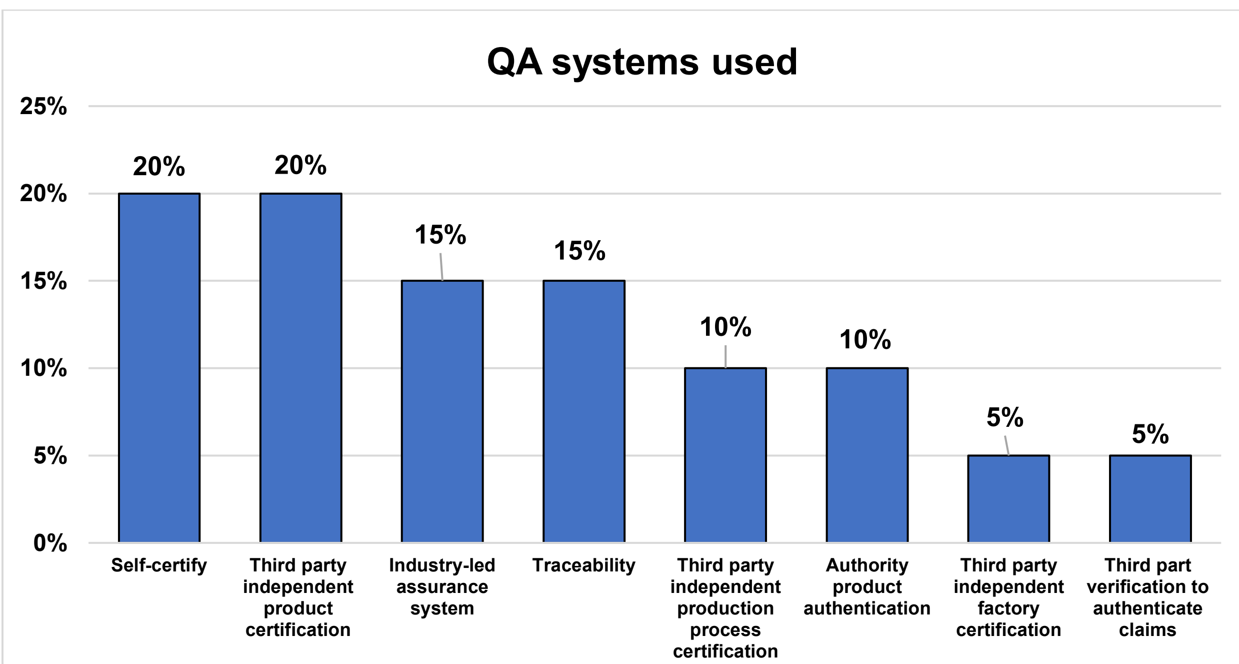
2. Type of building products



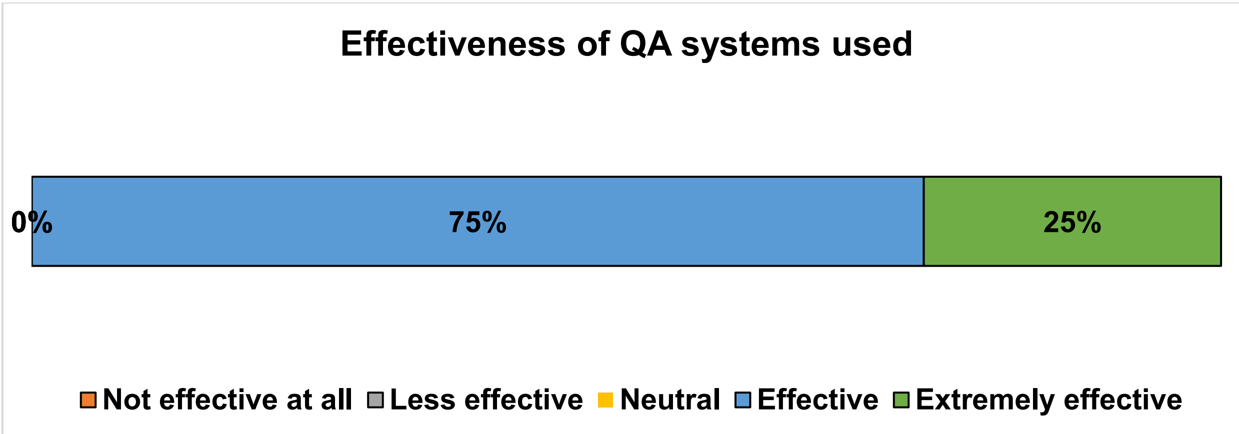
3. Duration of trading



4. QA systems used



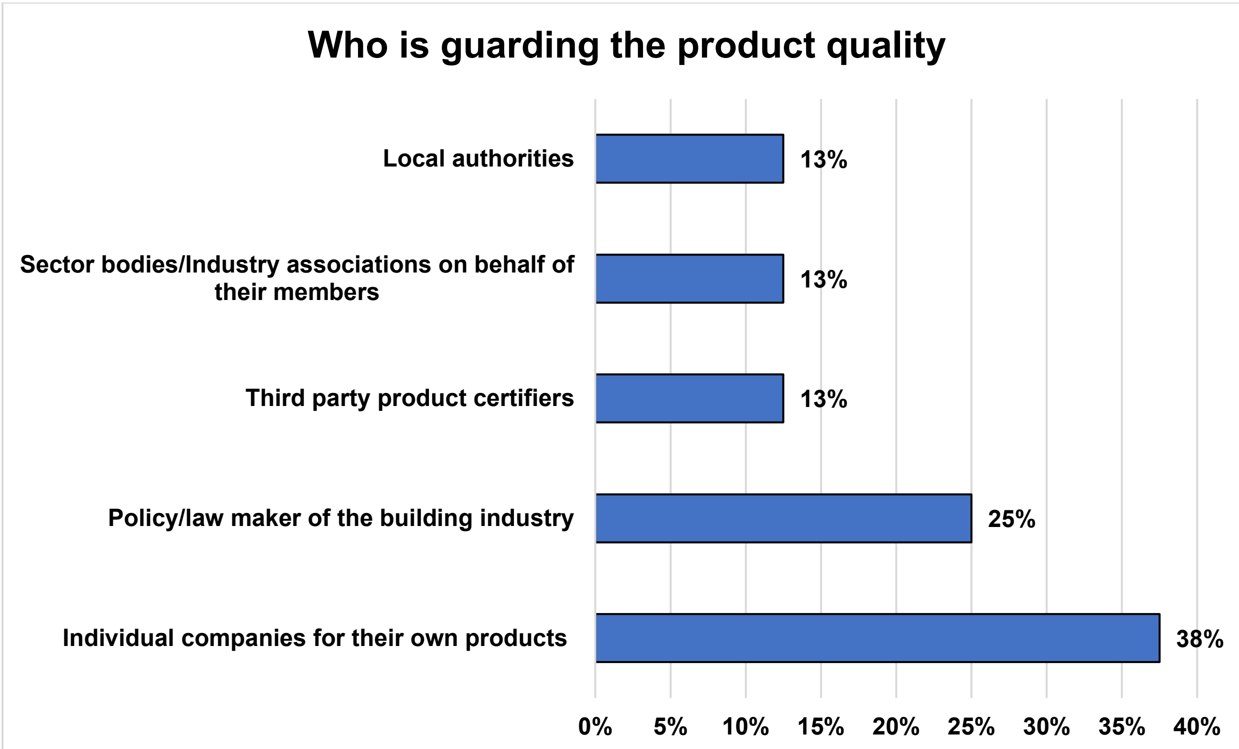
5. **Effectiveness of QA systems used**



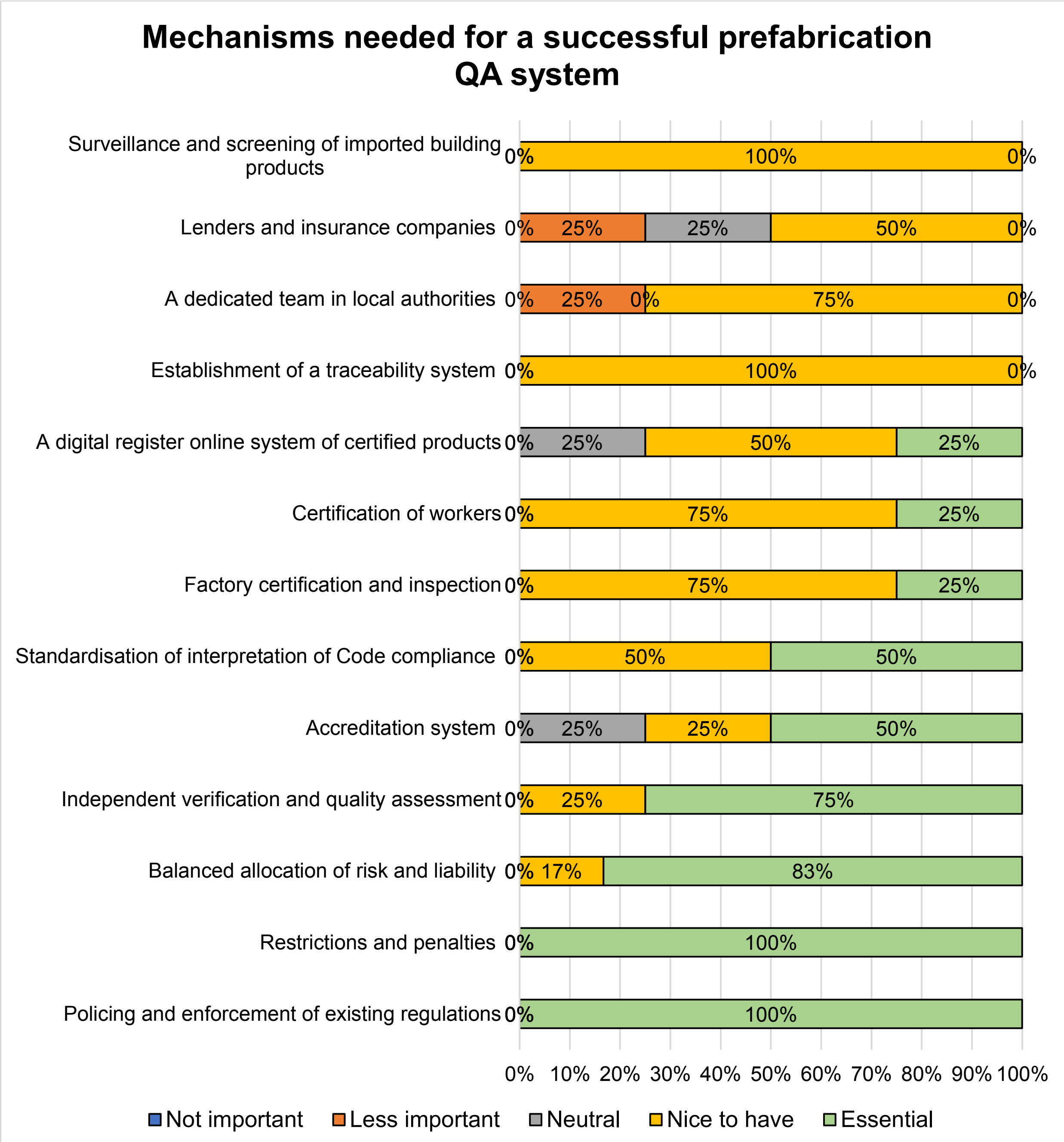
6. **What worked well and what have not?**

+	−
1. Law and regulations **2. Third party certification** **3. Supply chain quality assurance system.**	**1. Regulations**

7. Who is guarding the product quality?

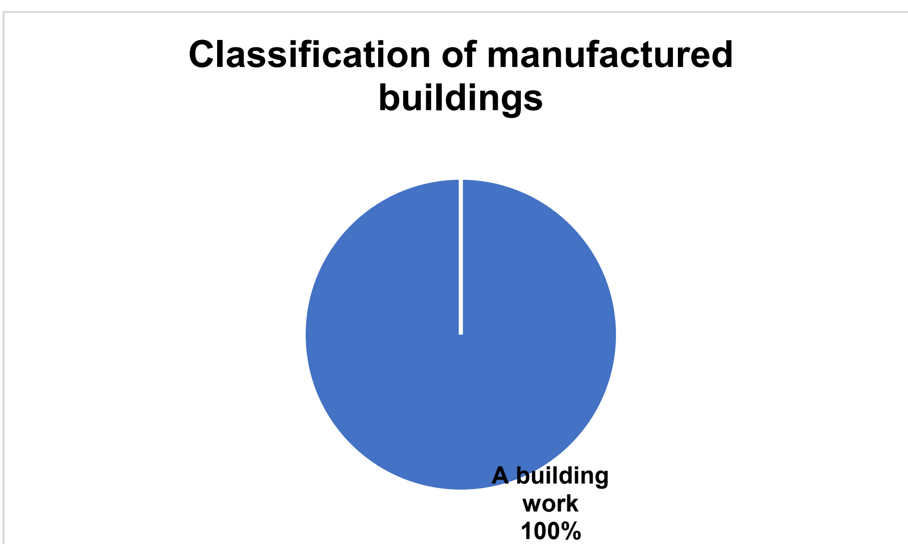


8. Mechanisms needed for a successful prefabrication QA system

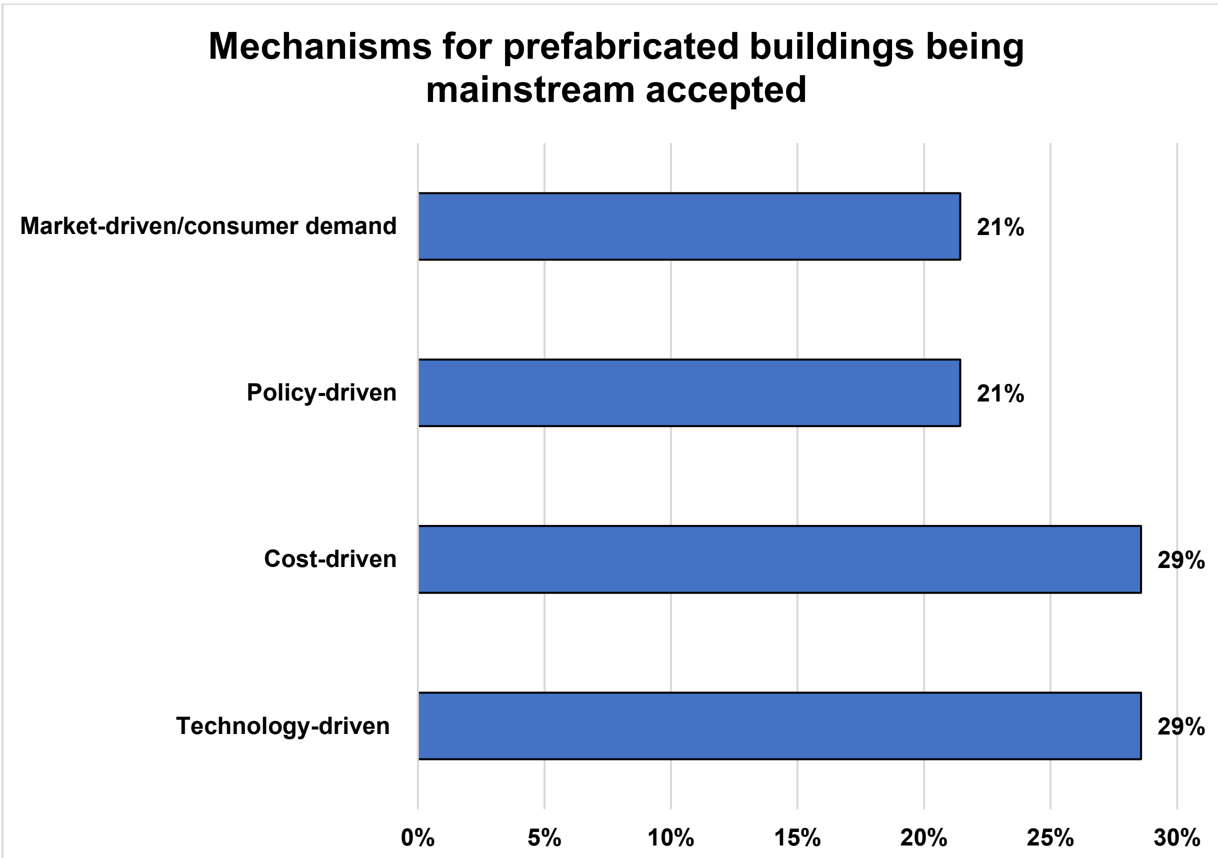


9. Legal remedies for non-compliant products

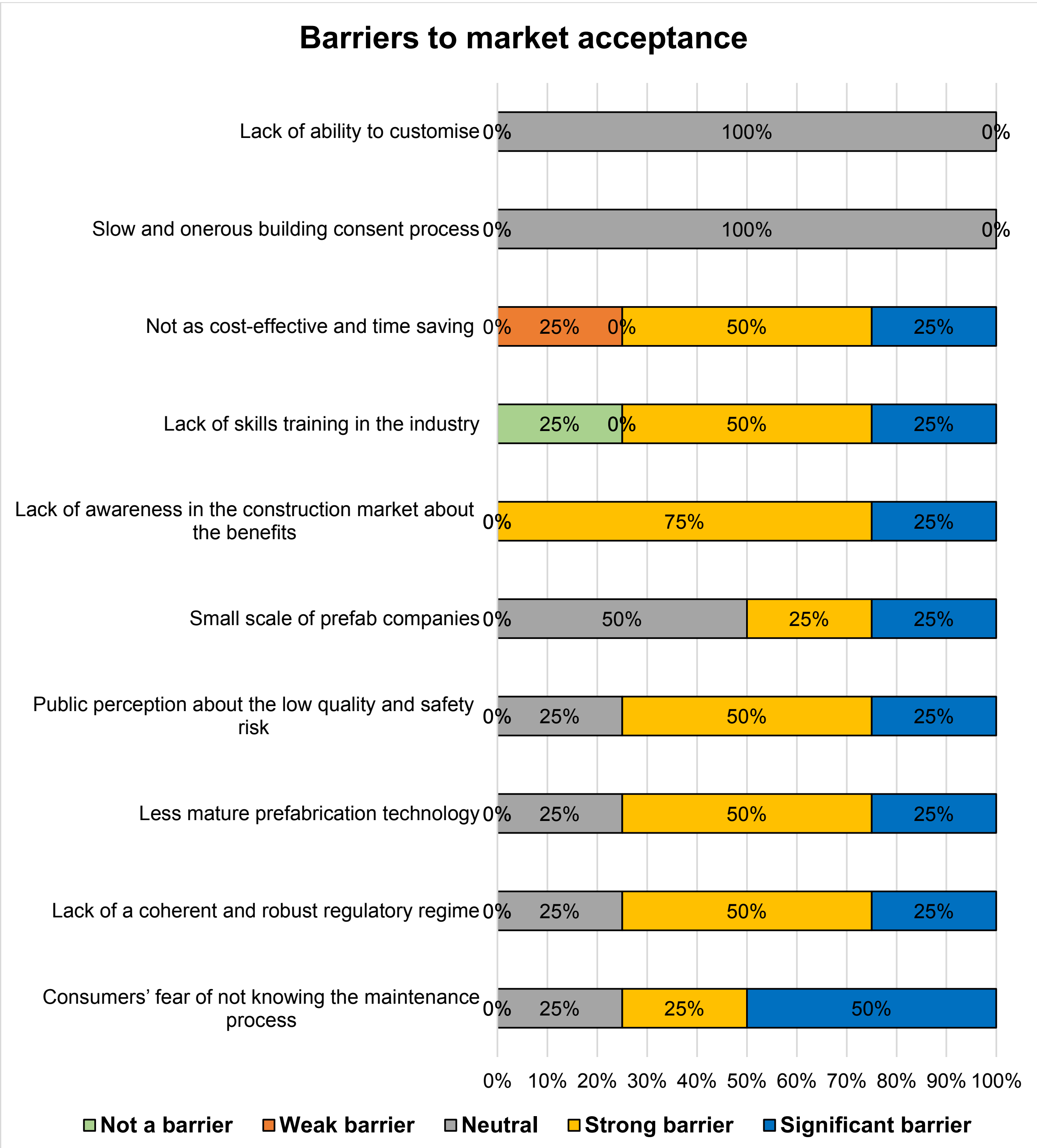
10. Classification of manufactured buildings



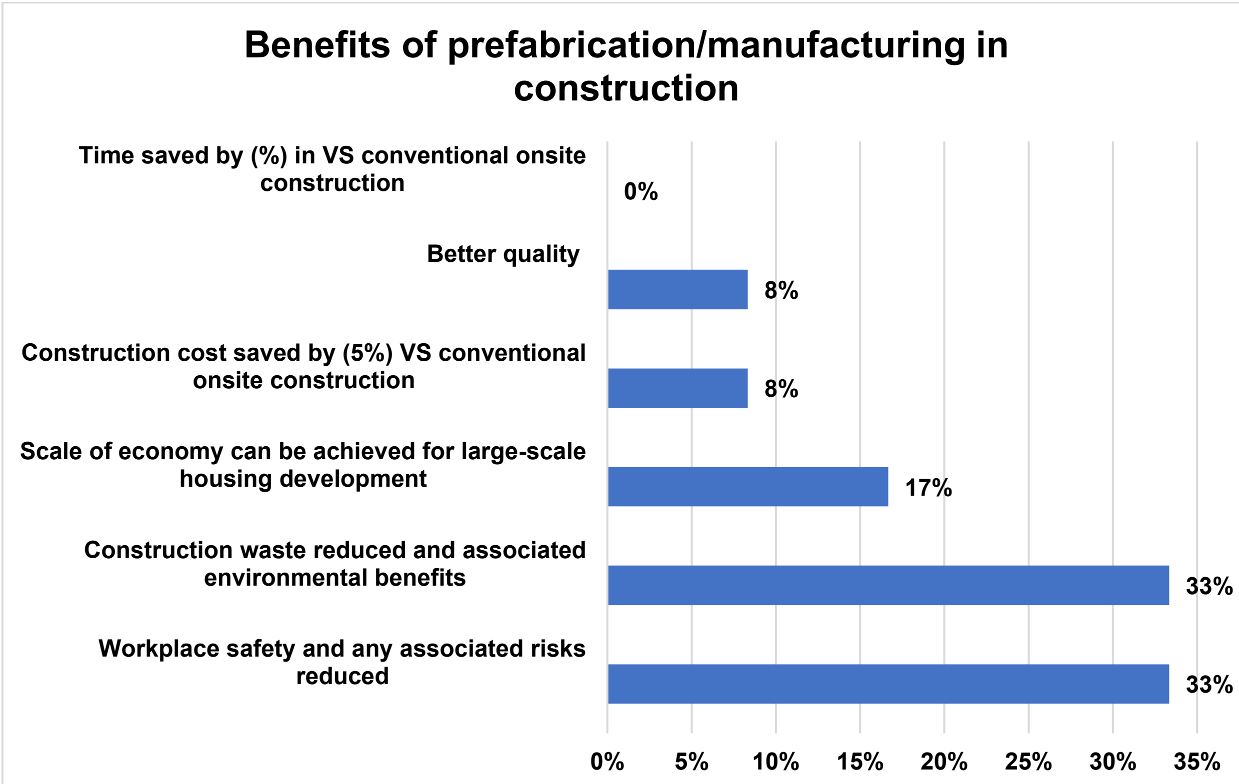
11. Mechanisms for prefabricated buildings being mainstream accepted



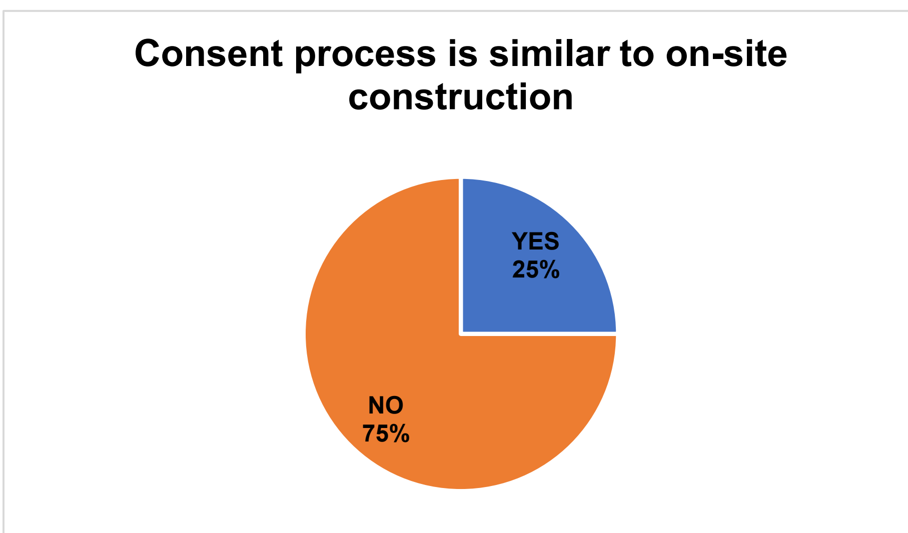
12. Barriers to market acceptance



13. Benefits of prefabrication/manufacturing in construction

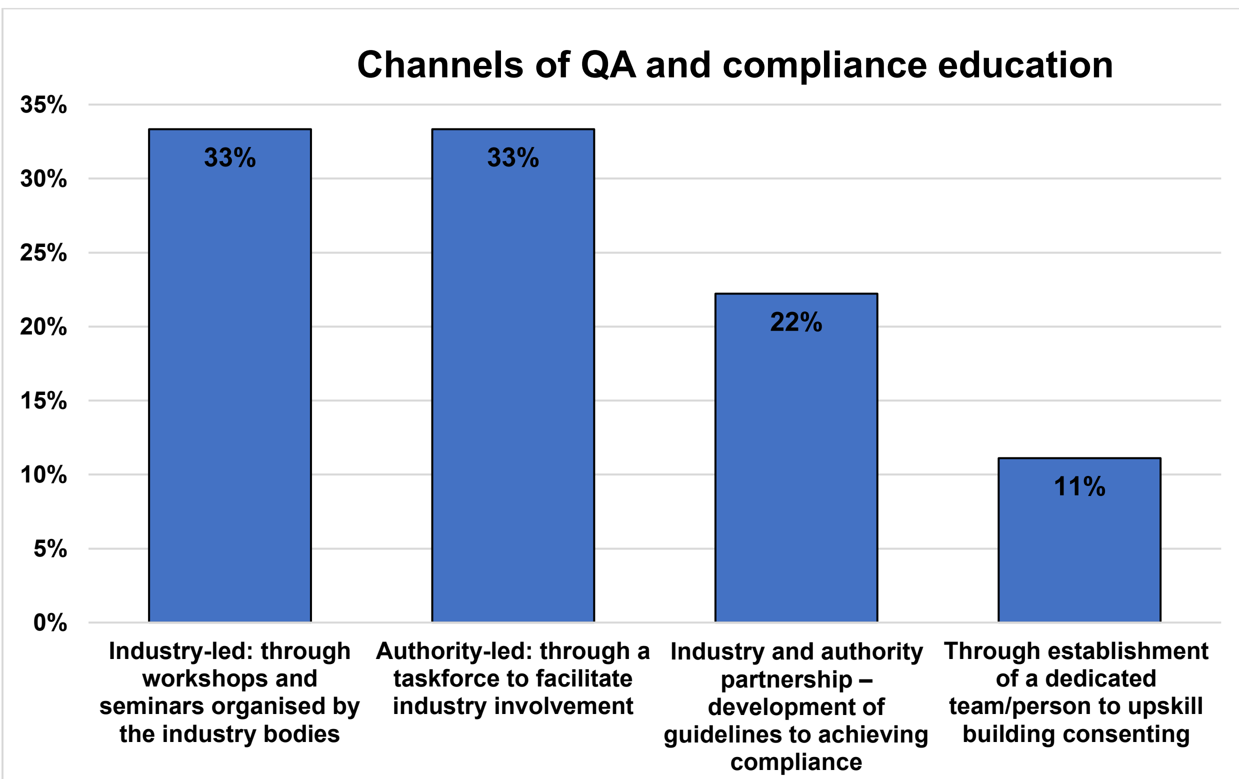


14. Consent process is similar to on-site construction



15. **Duration of consenting process**

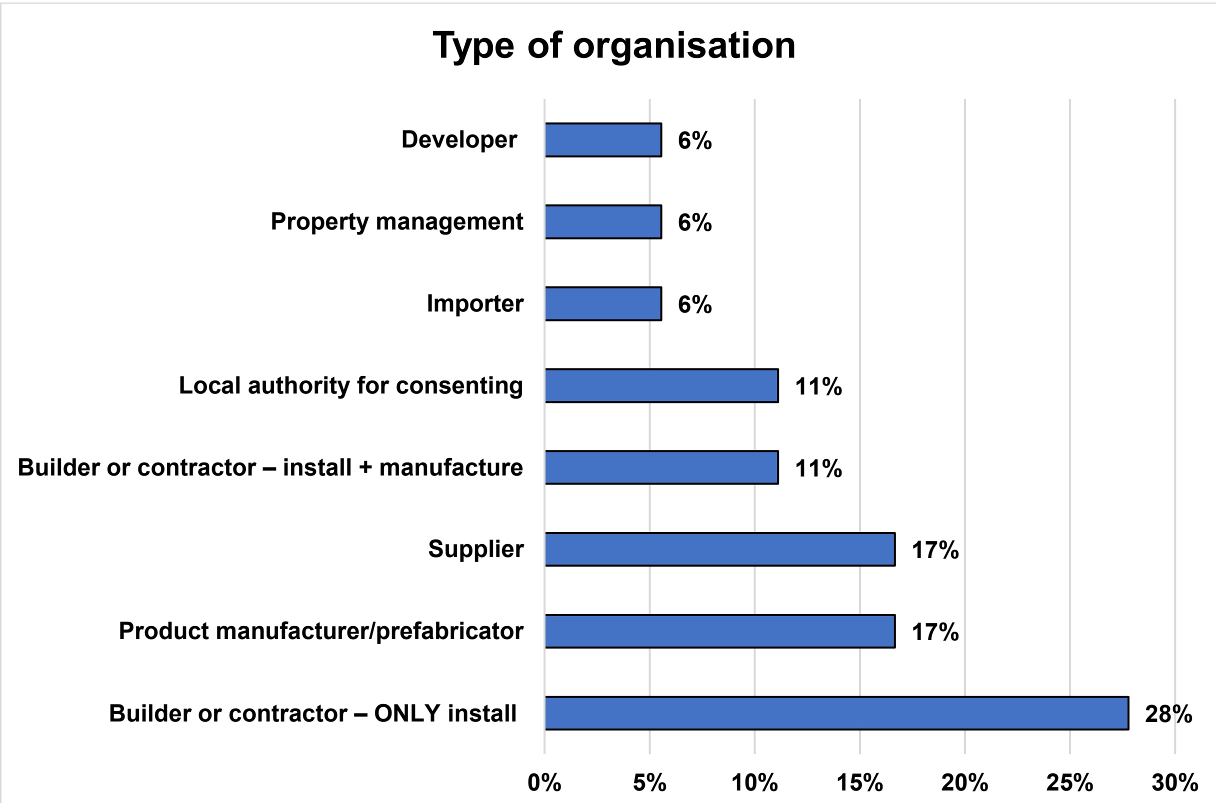
16. **Channels of QA and compliance education**



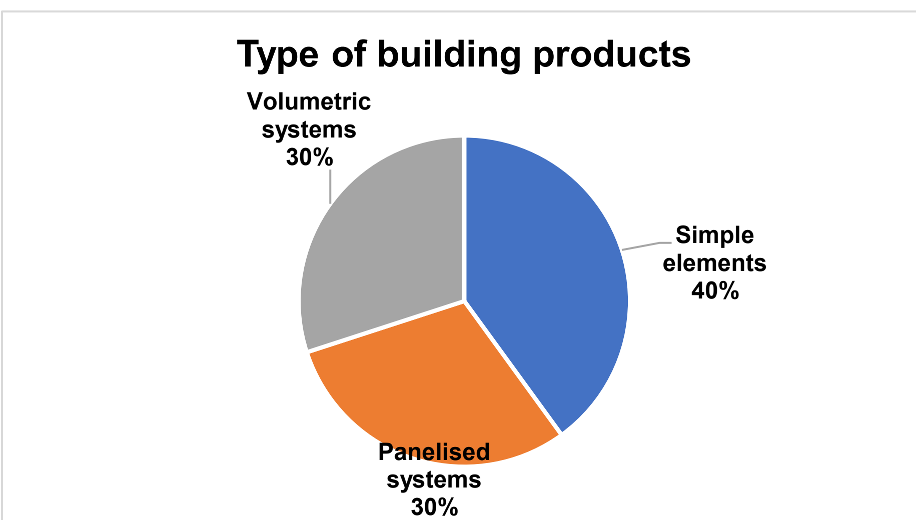
Compliance and assurance prototypes for manufactured buildings research project

QUESTIONNAIRE SURVEY RESULTS: SINGAPORE

1. Type of organization

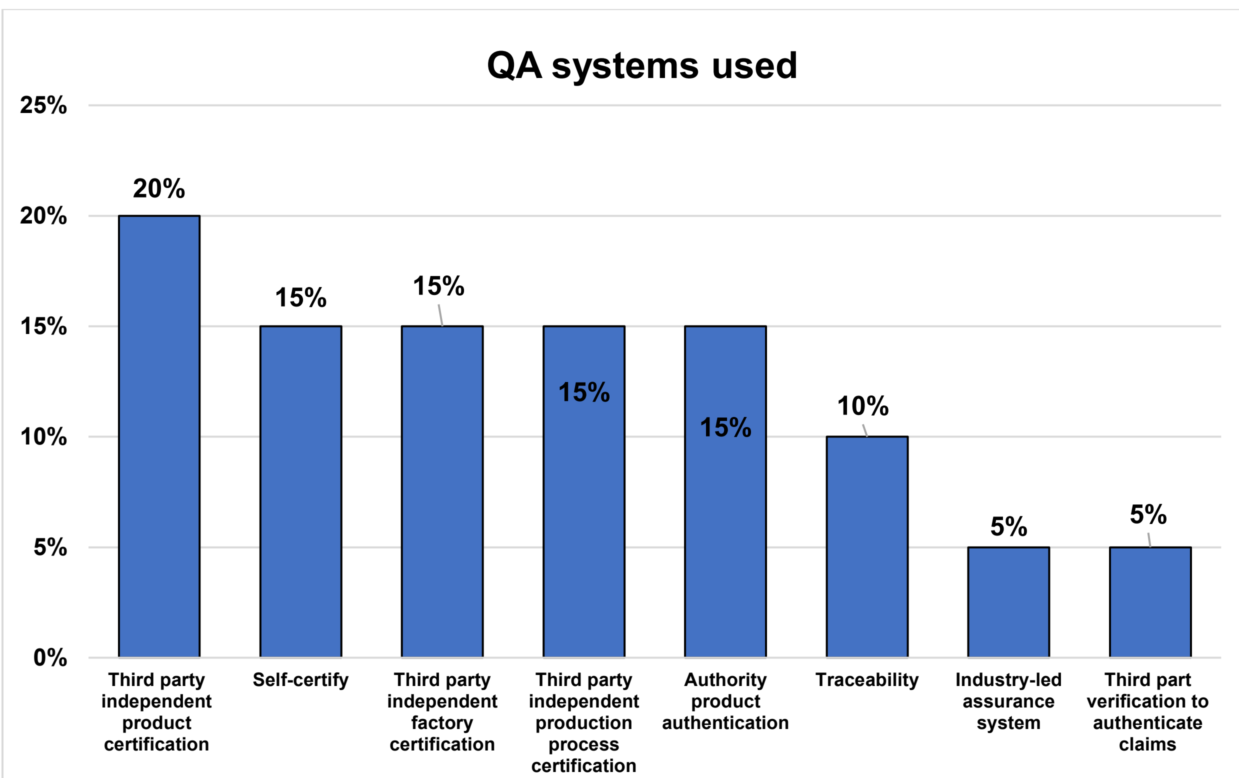


2. Type of building products

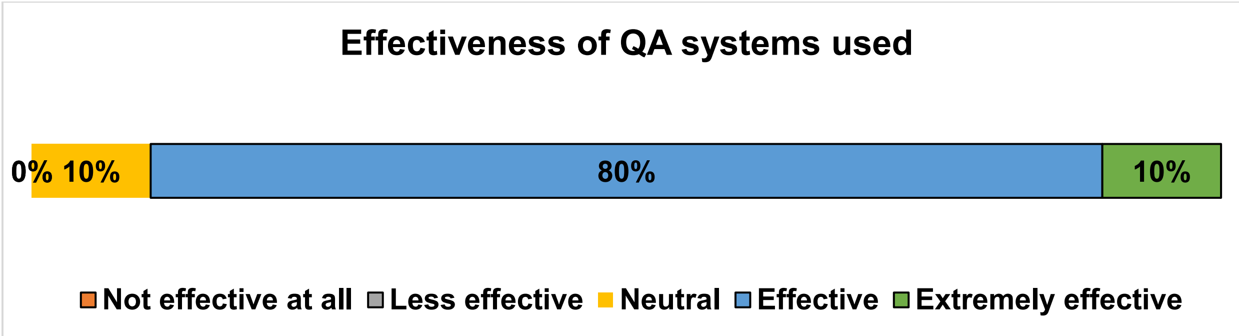


3. Duration of trading

4. QA systems used



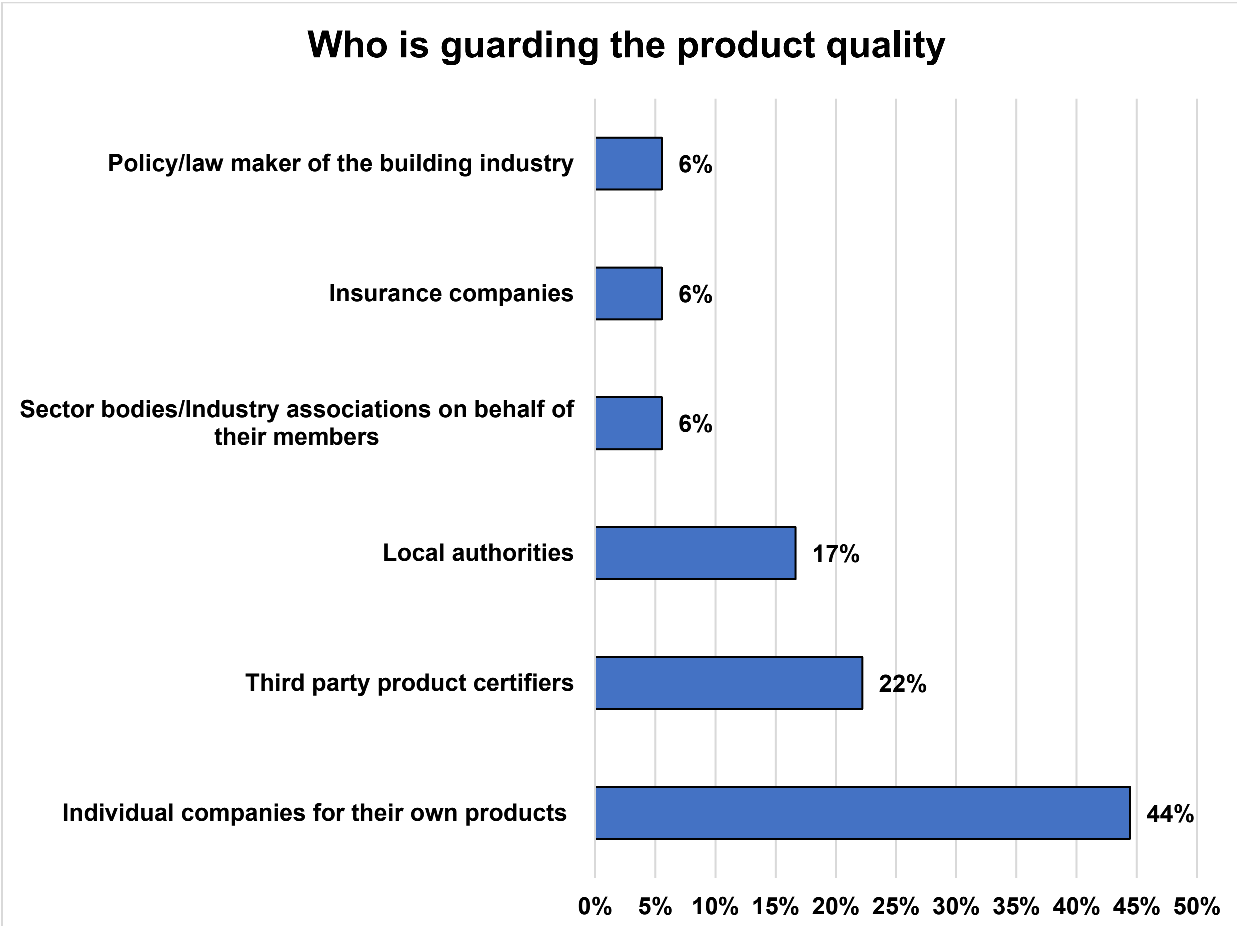
5. Effectiveness of QA systems used



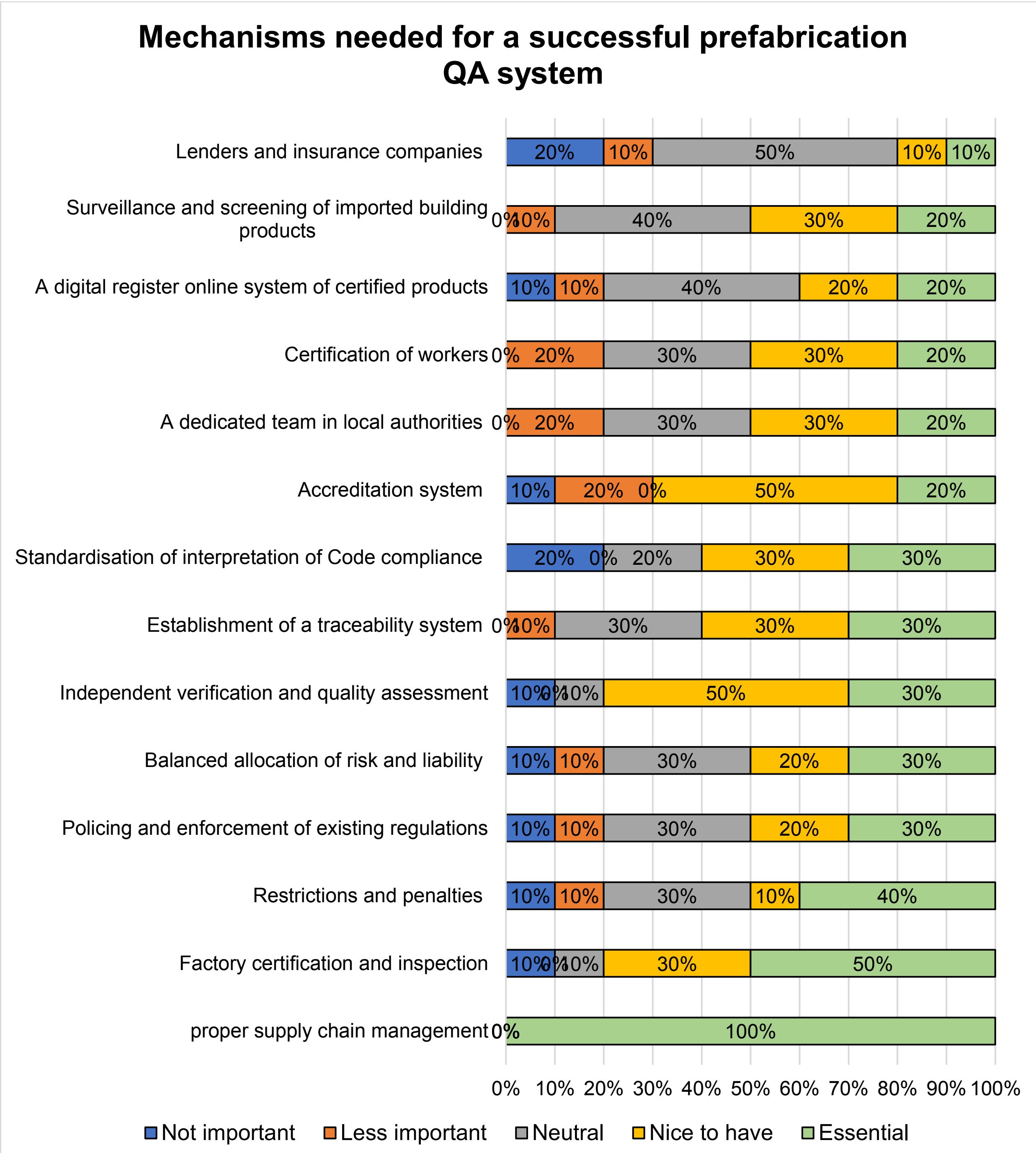
6. **What worked well and what have not?**

+	−
1. Technology **2. International QA like ISO** **3. Certification** **4. Strict quality control** **5. Internal audits with 3rd party** **6. 3rd party independent factory certification** **7. Factory production control** **8. QA upon delivery of products**	**1. Perform QA after fabrication as any amendments will be costly**

7. Who is guarding the product quality?



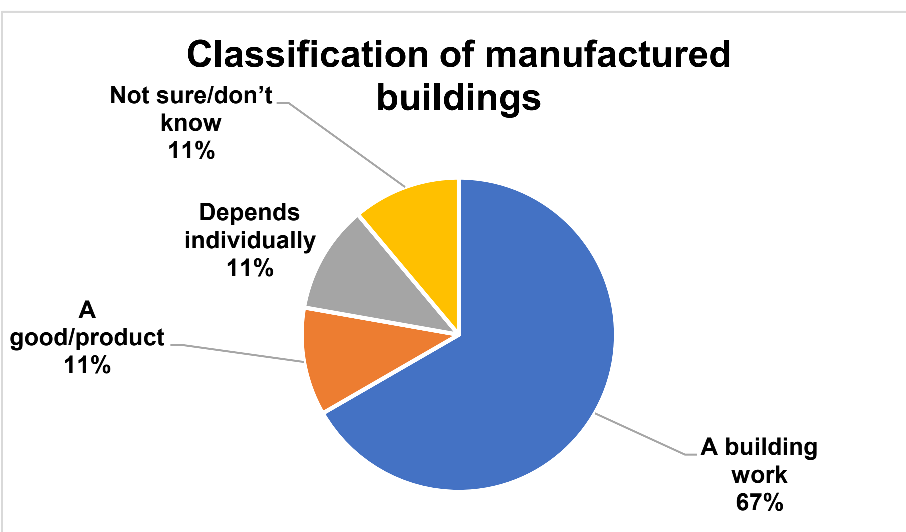
8. Mechanisms needed for a successful prefabrication QA system



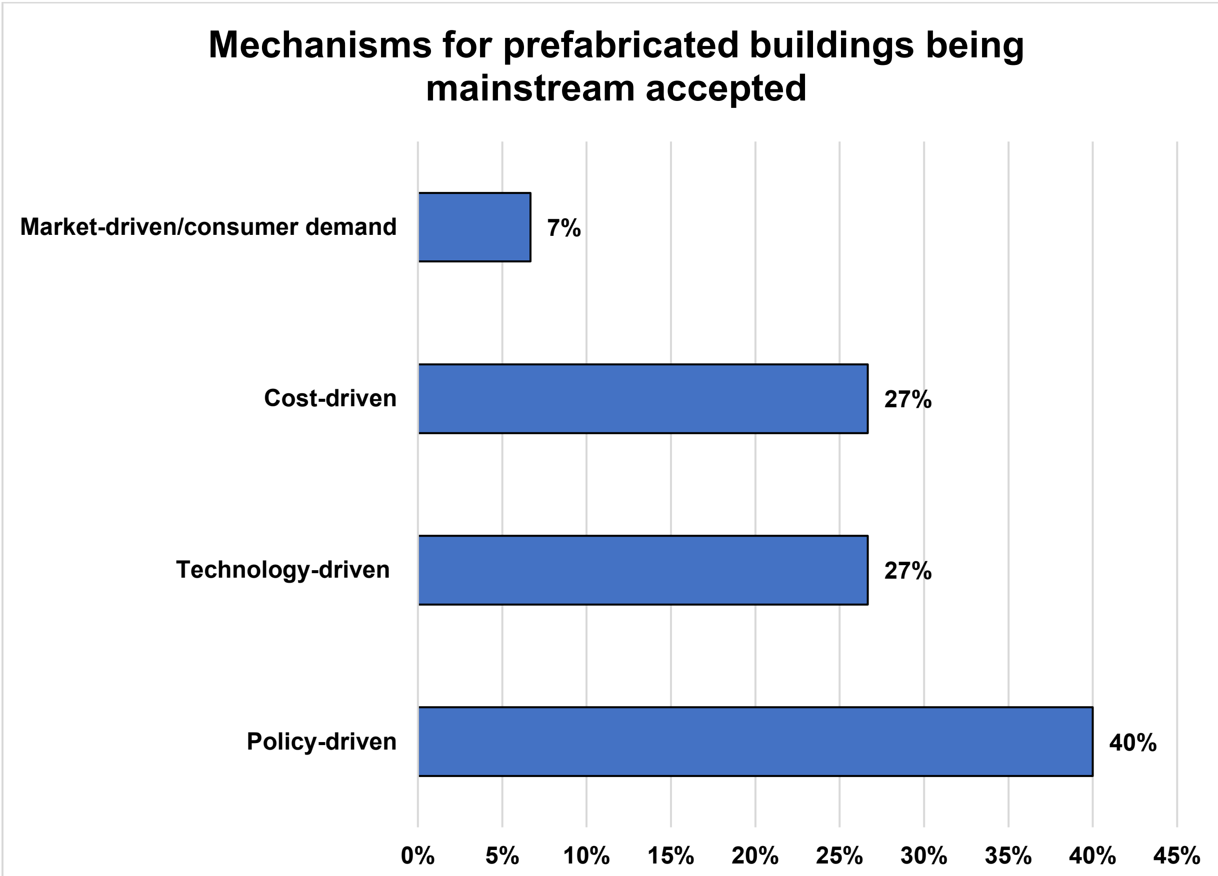
9. Legal remedies for non-compliant products

- Warranties
- Suspension
- Dispute resolutions
- regulation
- Rebuilding
- Structure will be hacked off at supplier's cost.
- SOP Act
- Liquidated damages
- Internal agreement
- Performance bond
- Contract mechanisms

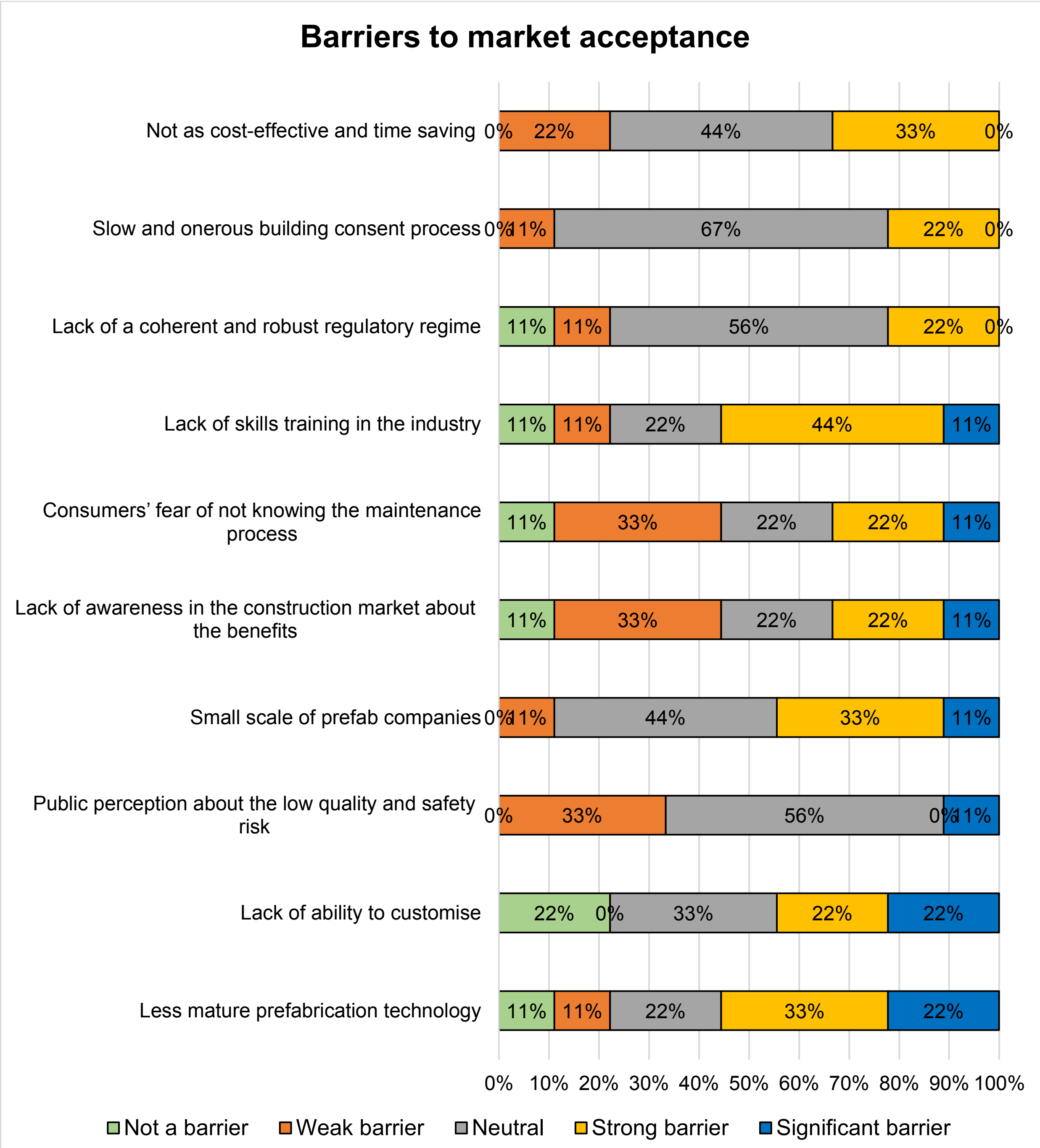
10. Classification of manufactured buildings



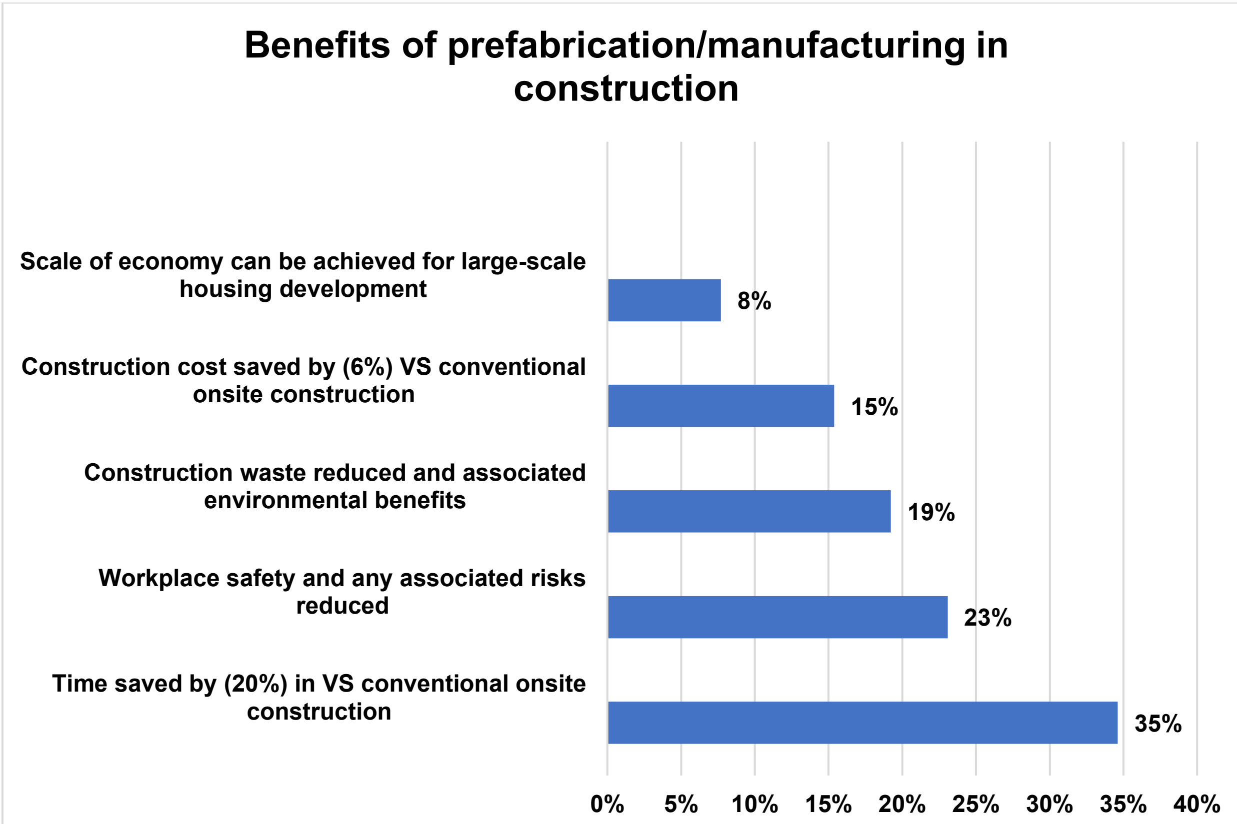
11. Mechanisms for prefabricated buildings being mainstream accepted



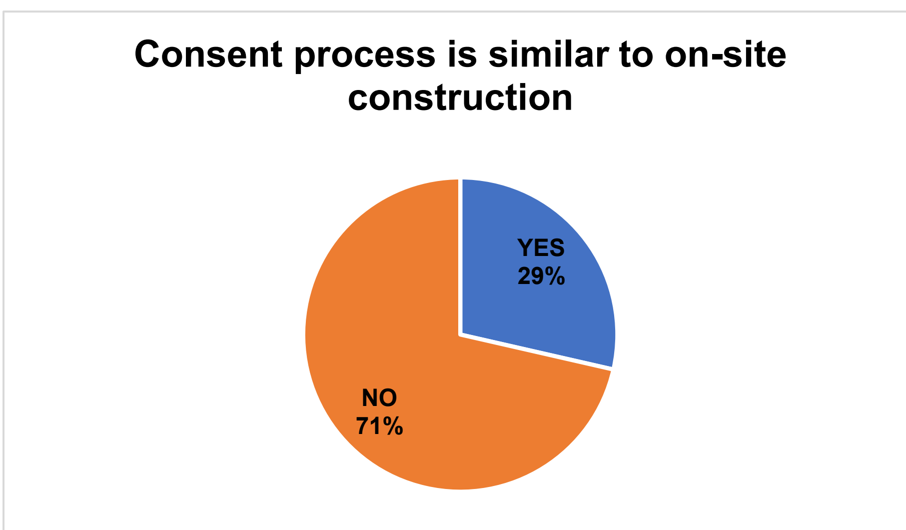
12. Barriers to market acceptance



13. Benefits of prefabrication/manufacturing in construction



14. Consent process is similar to on-site construction



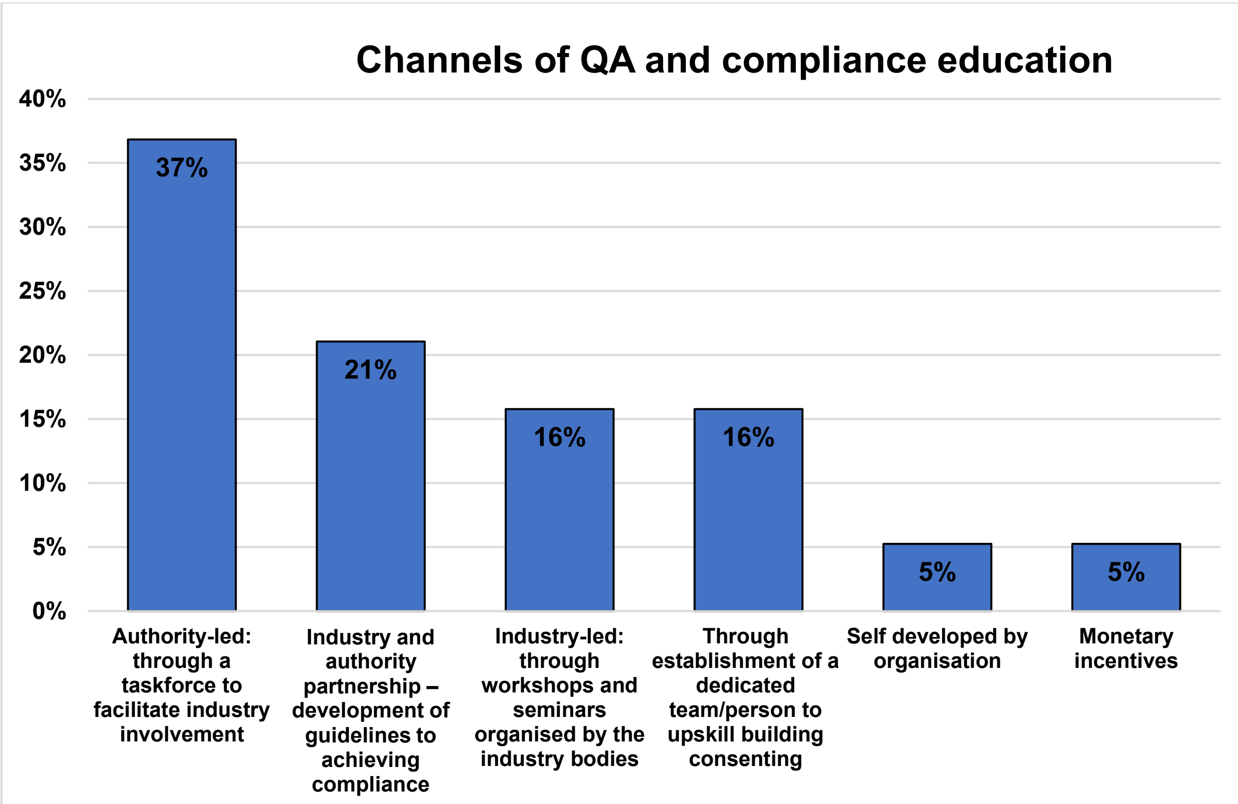
15. Duration of consenting process

Minimum	Average	Mximum
15 days	37 days	60 days

16. Comments on how to improve consent process

- Use BIM (technology)
- Save time and labour
- Change regulations
- Skip detail inspection: certification for the fabrication by specifc govermnet Authority
- Eliminate consent process: by ensuring quality certification that meets or exceed requirements.
- Use digital process

17. Channels of QA and compliance education



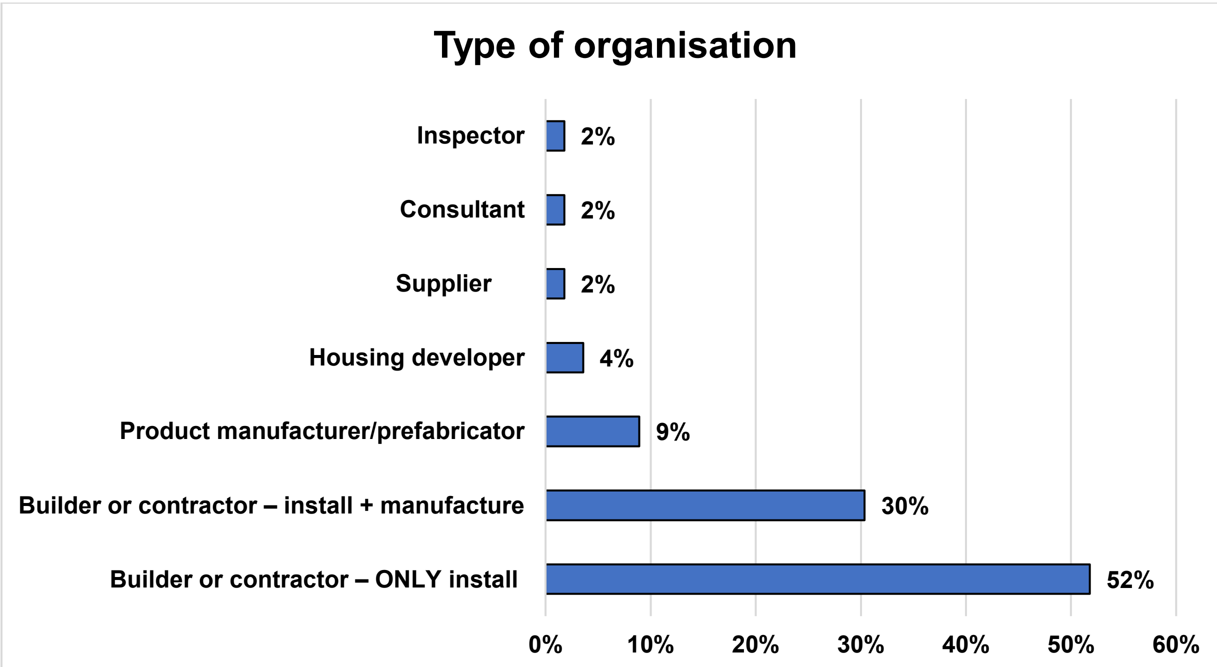
18. Other levers to support QA and compliance of manufactured buildings

- Audits
- 3rd party accreditor
- Government funding/ incentives
- Support from Government

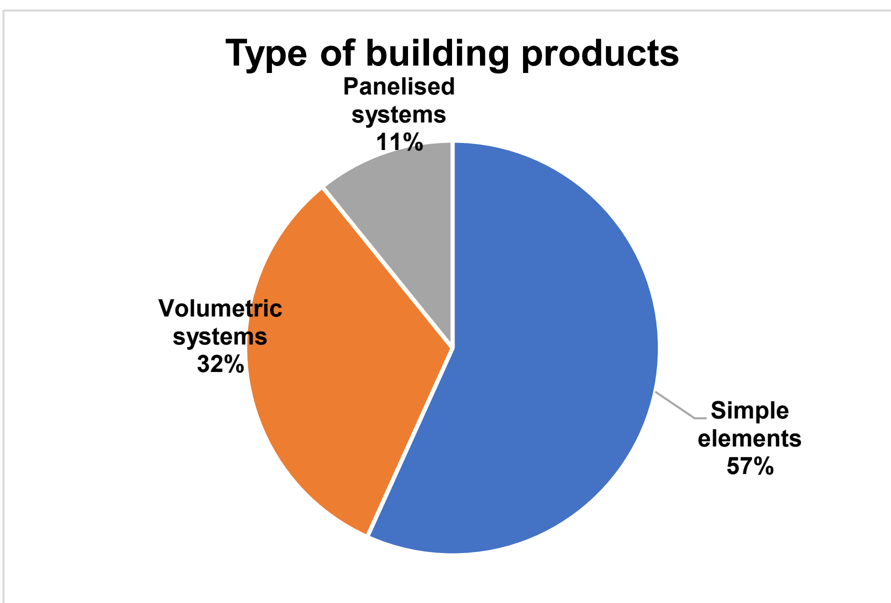
Compliance and assurance prototypes for manufactured buildings research project

QUESTIONNAIRE SURVEY RESULTS: CHINA

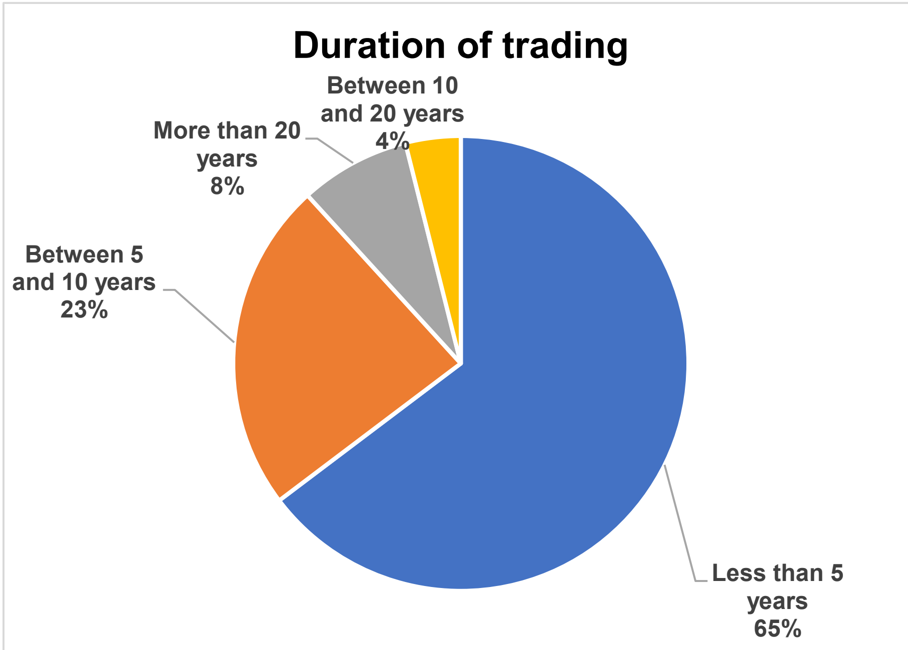
1. Type of organization



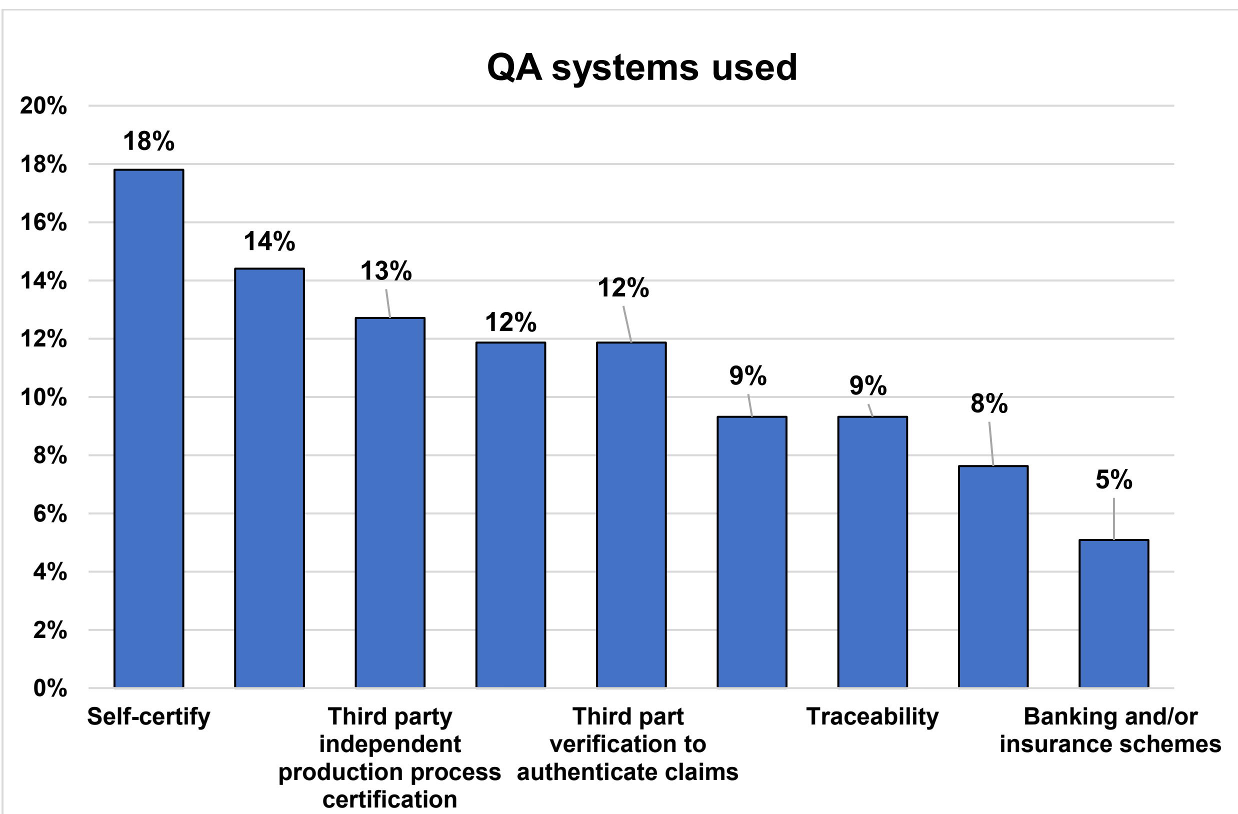
2. Type of building products



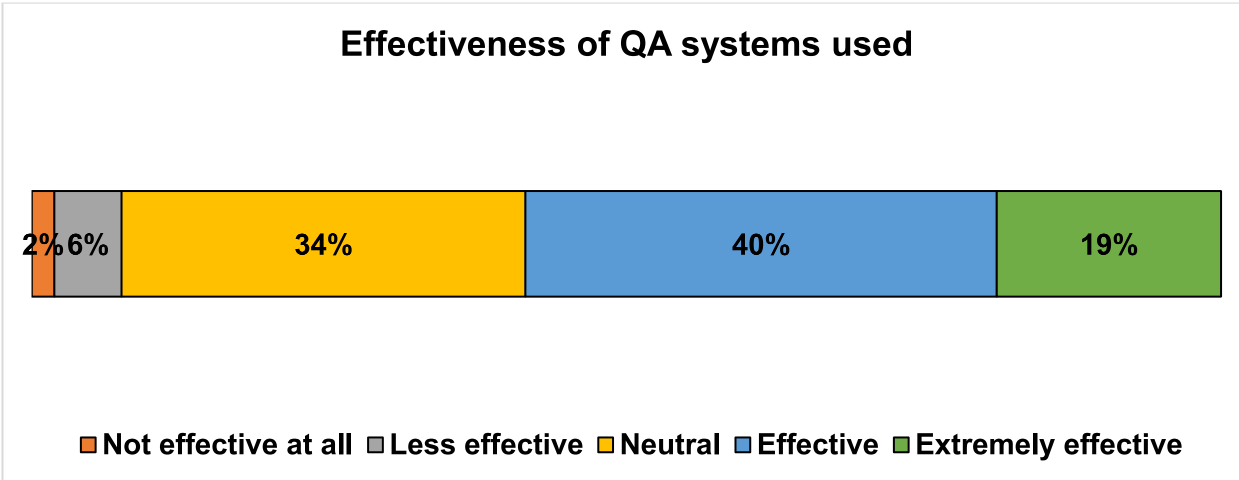
3. **Duration of trading**



4. **QA systems used**



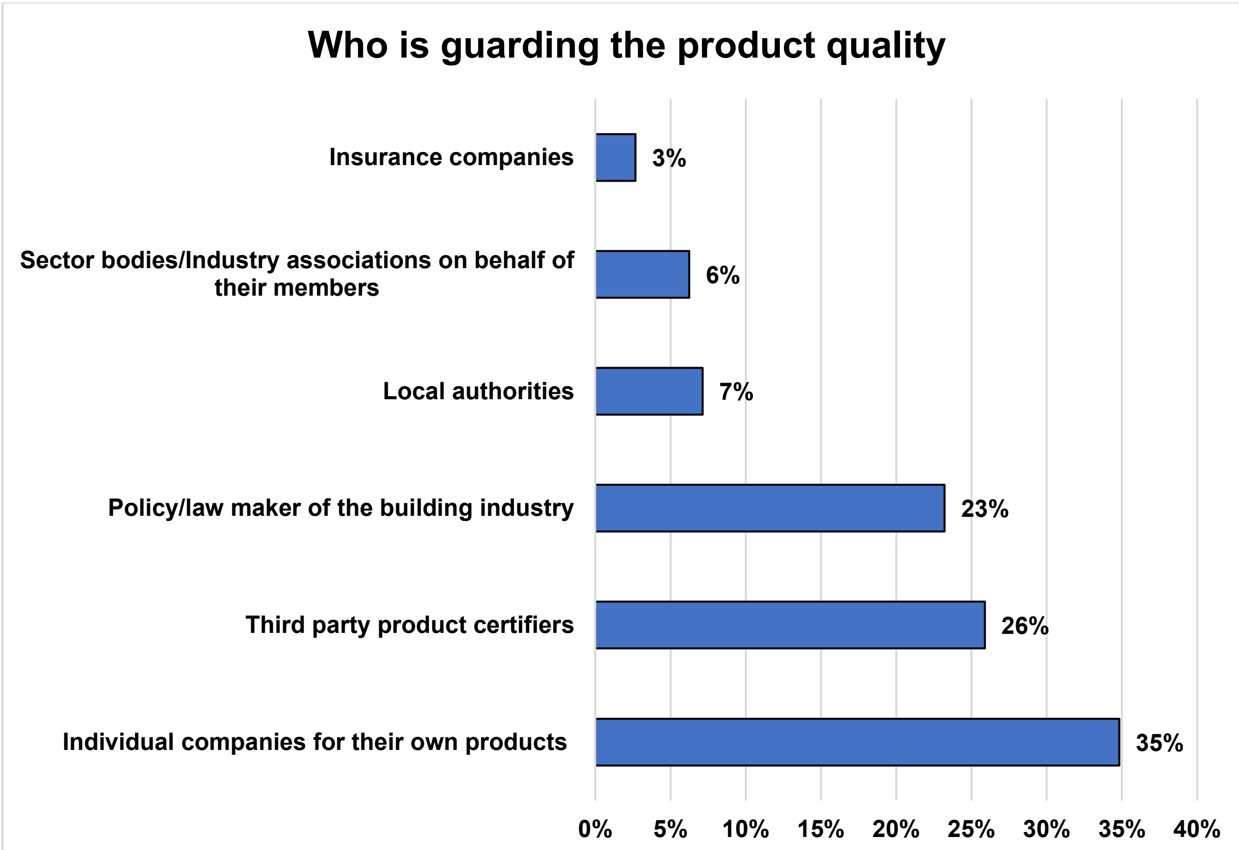
5. **Effectiveness of QA systems used**



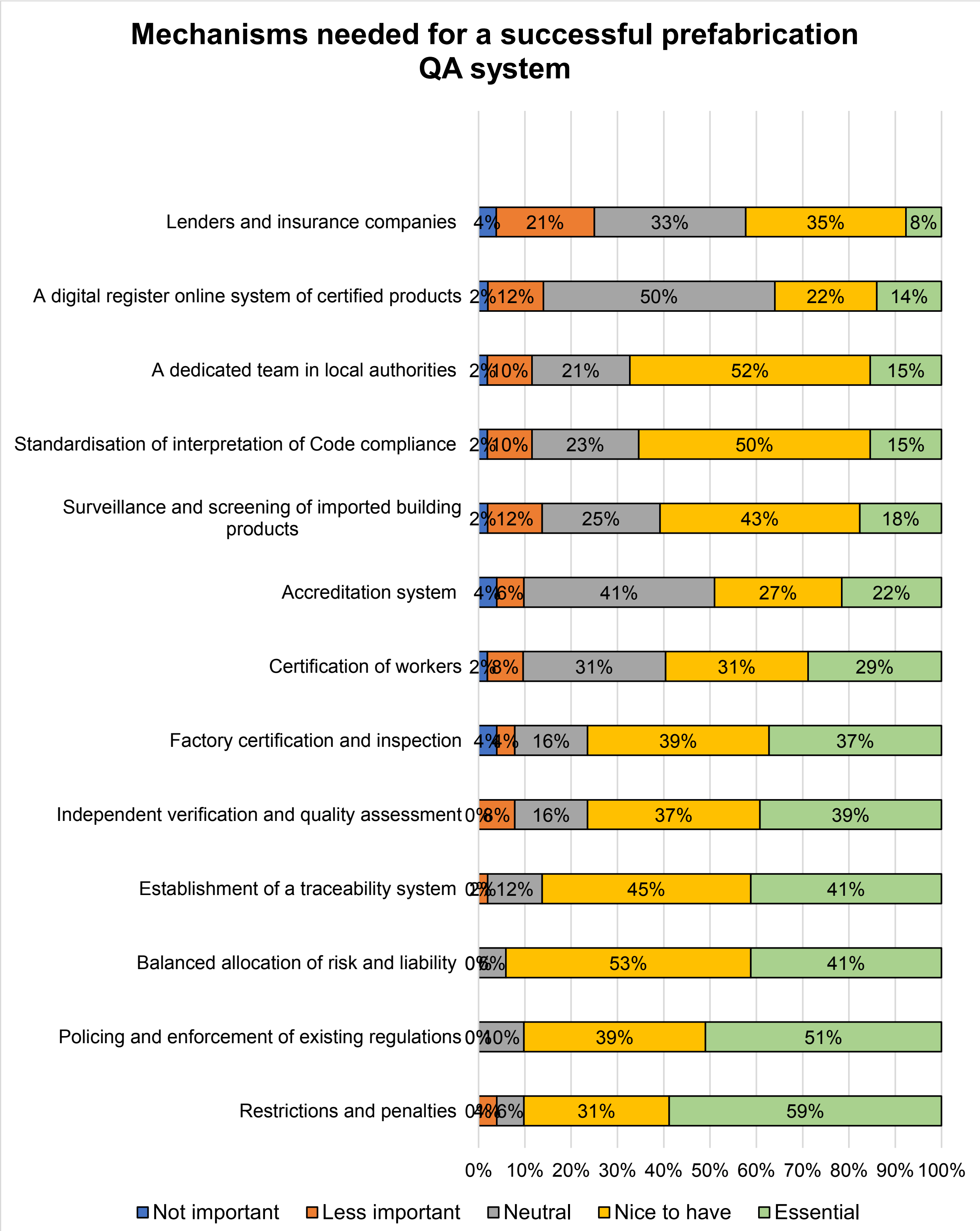
6. **What worked well and what have not?**

1. In-house quality assurance	1. Regulations implementation
2. ISO certification	2. Workmanship quality assurance
3. Traceability	3. Reliability of the QA/QC system
4. Certifying workers	4. Third party certification
5. Law and enforcement 5. 3rd party approvals	

7. **Who is guarding the product quality?**



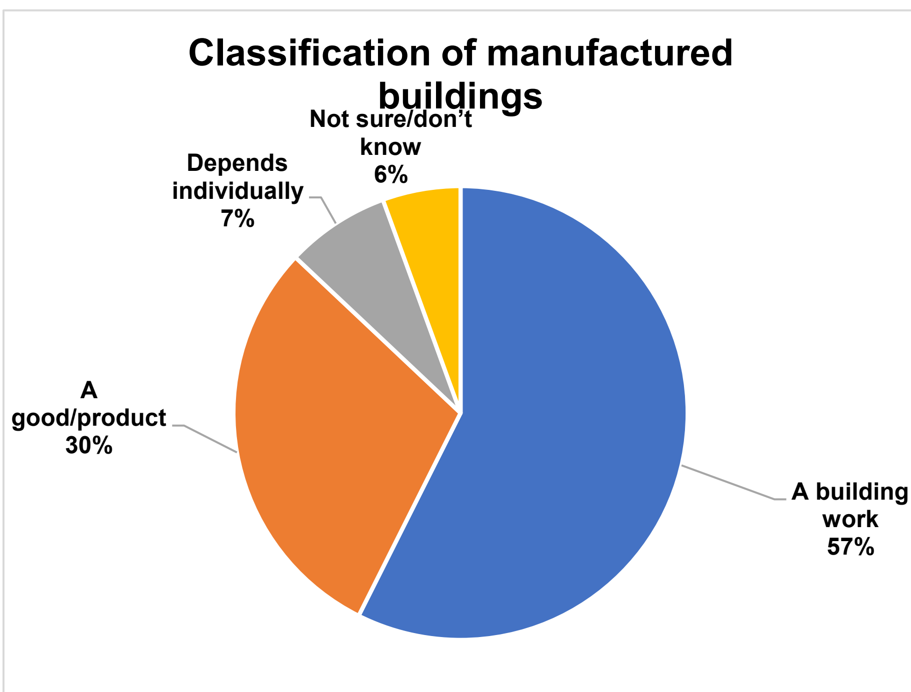
8. Mechanisms needed for a successful prefabrication QA system



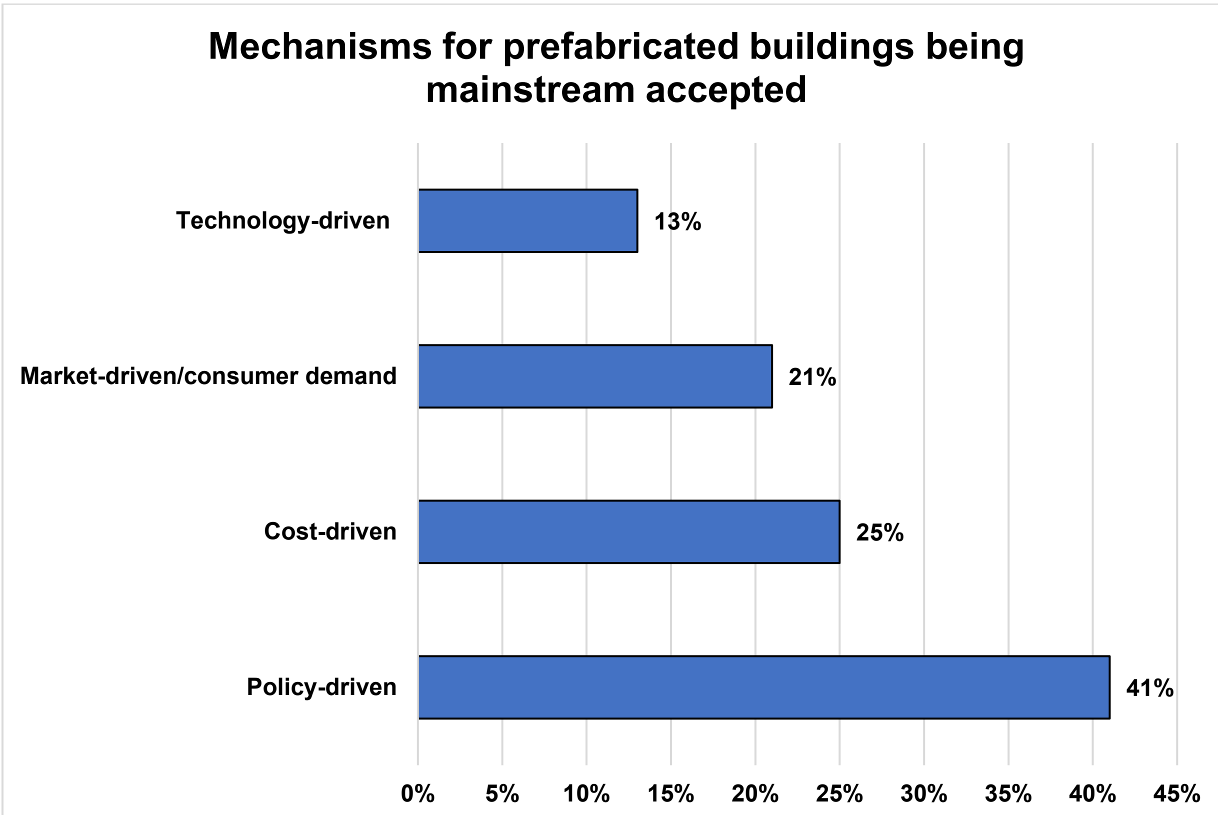
9. Legal remedies for non-compliant products

- Contract clauses (Product recall)
- Building Act
- Bond
- Performance system of manufacturers (recored and track quality issues)
- Third party guarantee
- Third party assessment
- Consumer law

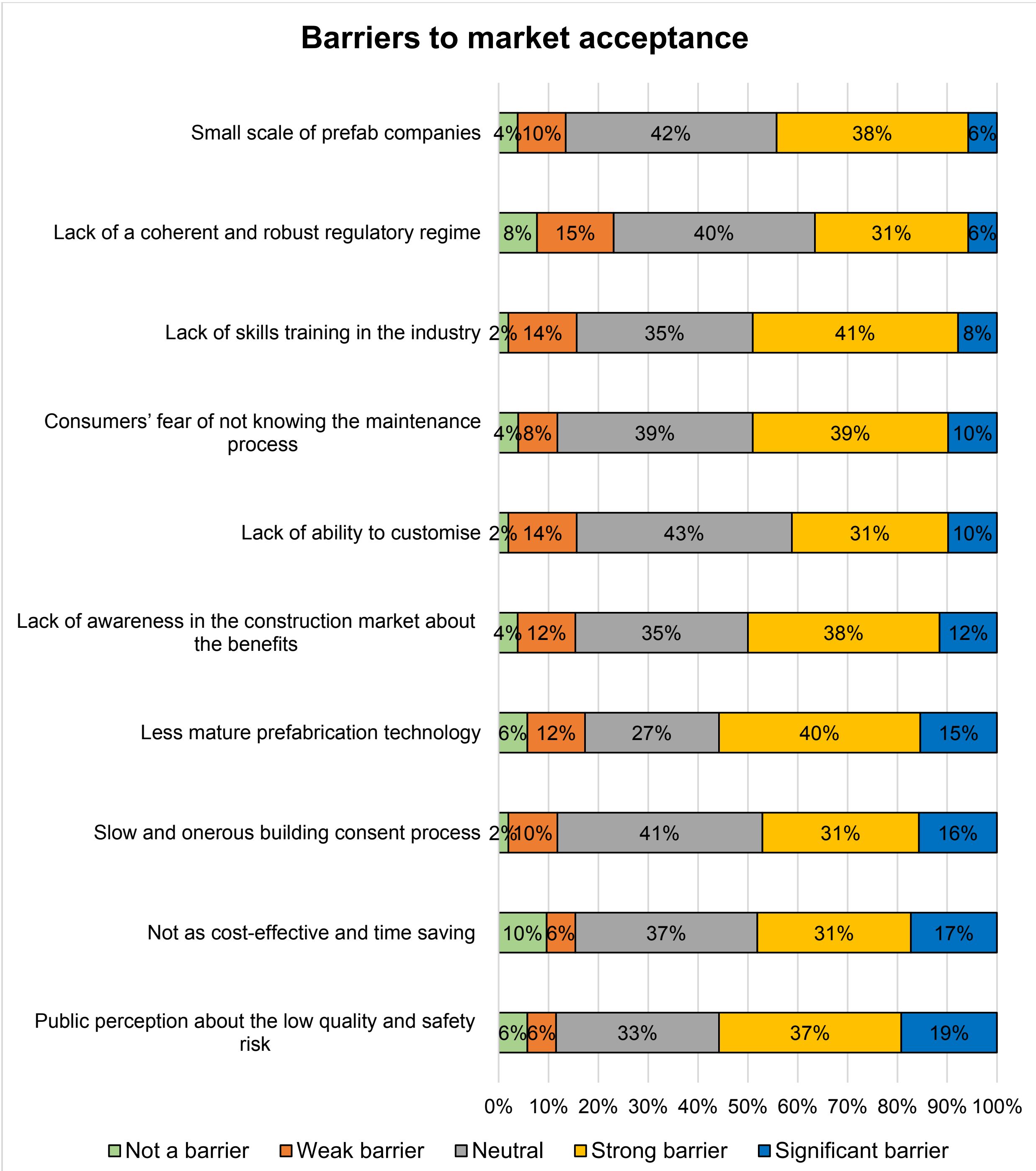
10. Classification of manufactured buildings



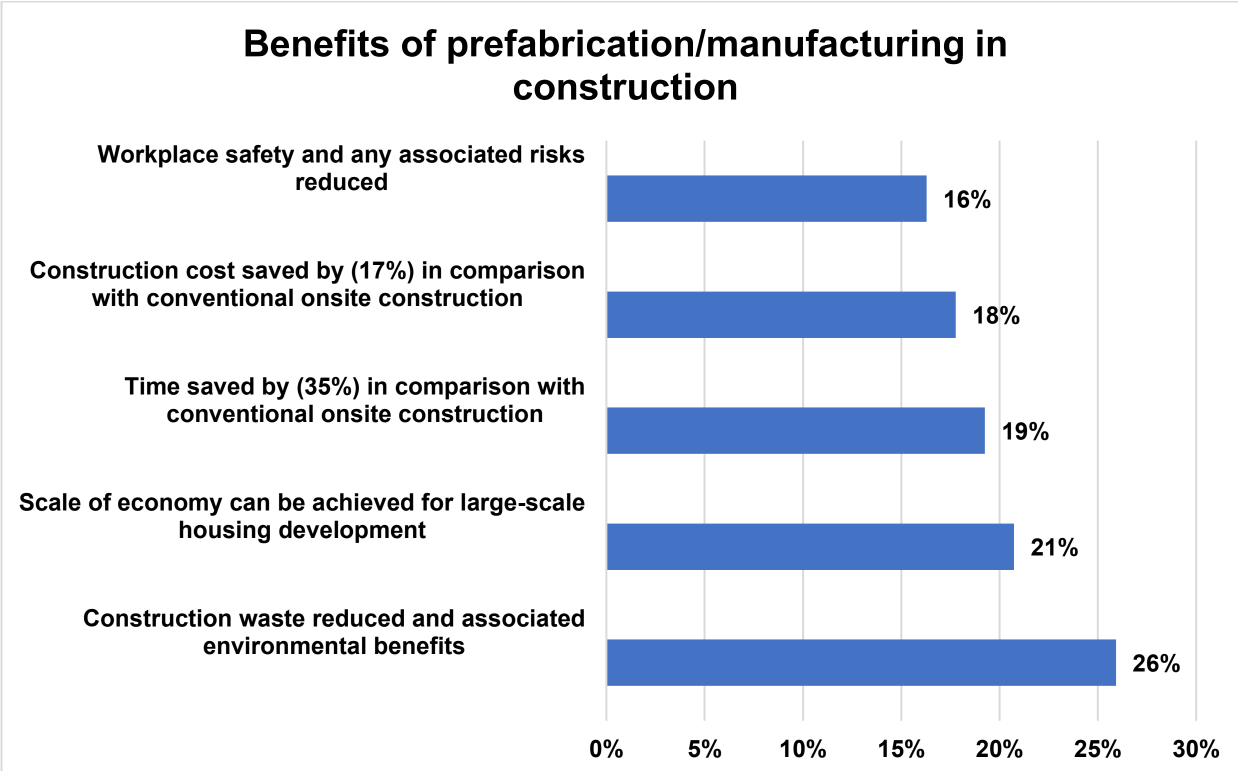
11. Mechanisms for prefabricated buildings being mainstream accepted



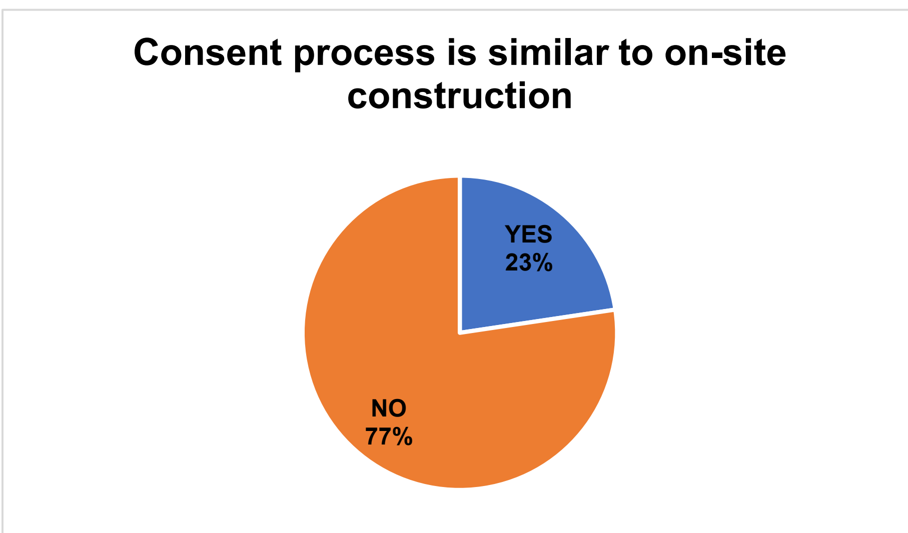
12. Barriers to market acceptance



13. Benefits of prefabrication/manufacturing in construction



14. Consent process is similar to on-site construction



15. Duration of consenting process

Minimum
28 days

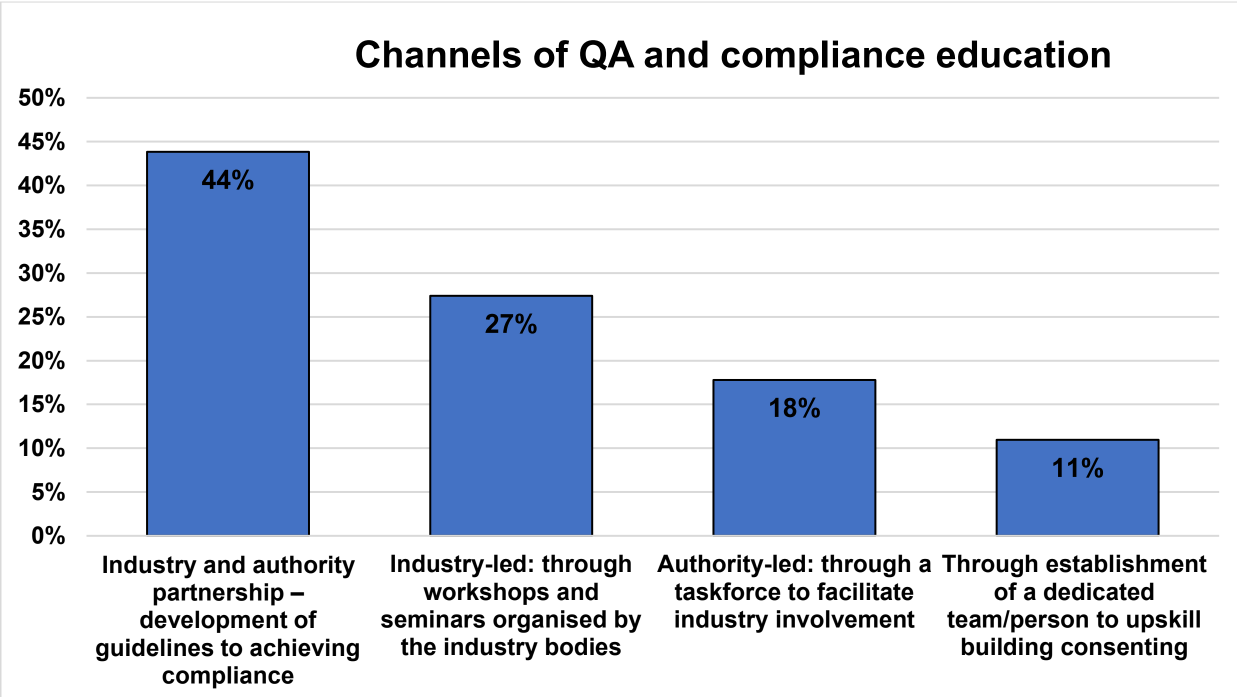
Average
50 days

Mximum
80 days

16. Comments on how to improve consent process

- Design specifications to be more detailed
- Industry associations to issue consenting
- Standardisation to steamline the consenting process
- Digital or online consenting

17. Channels of QA and compliance education



18. Other levers to support QA and compliance of manufactured buildings

- Inspections can be carried out from the design stage to completion stage.
- Issuing QA standards for the manufactured buildings
- Enforce using prefabrication for projects funded by government agencies
- Government advocacy
- Government regulations and policies
- Periodical inspections from the local authorities
- Set up specialist prefabrication industry associations
- Training and certification for those who work on site

From lessons to practice: Compliance and assurance prototype for manufactured buildings UK Offsite Construction Case Study

2019. 1.

*Note: Please be advised that this report is summarised from the various exiting reports and literature in order to understand the UK offsite construction and its cerfication/assurance scheme.

List of Contents

1.!UK Offsite Construction

1.1.! UK Offsite Construction Market

The construction industry currently makes up 6.5% of the UK economy and forecasts suggested a healthy growth rate of 3.6% in 2016 and 4.3% in 2017, returning output to pre-recession levels in Figure 1 (Experian, 2018). Growth is being driven by demand for infrastructure, public and private housing and commercial buildings. However, the value of project starts is estimated to have declined in by 6% in 2018 and a small recovery in project starts anticipated in 2019 and 2020 (Glenigan, 2018).

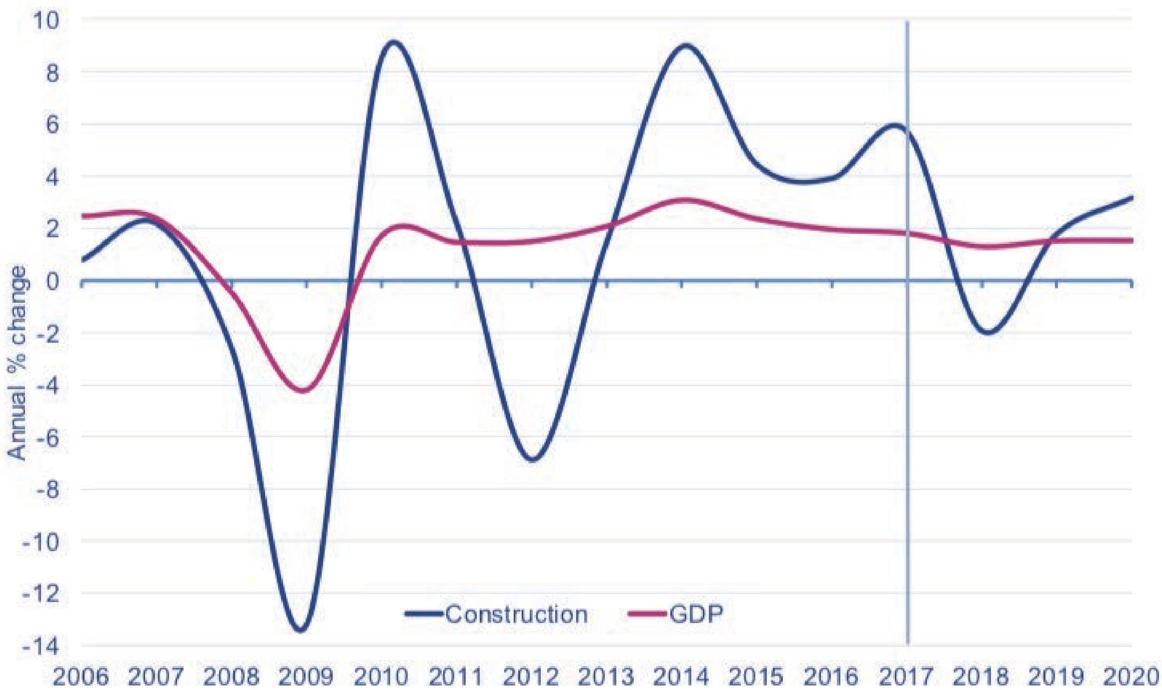


Figure 1 Growth in UK Construction Output and GDP
Source: Office for National Statistics, Experian

The UK construction industry has long been criticized for its poor productivity, uncertainty in delivery, skill shortage, poor image and data transparency. Offsite production (OSP) under the overarching umbrella of modern methods of construction (MMC) was sought by the UK Government to ameliorate the UK construction industry, meet market demands, overcome manual skill shortages and improve productivity (Nadim and Goulding, 2010). Off-site production is not a new concept and alternative forms or modern methods of construction (MMC) have a long history in the UK. In the post-war period much use was made of a variety of innovative house-building systems and from time-to-time since then, there have been surges in interest (NHBC, 2016) and it been used increasingly in construction, as a means of improving quality and increasing efficiency (Construction Excellence, 2004).

Almost all construction projects today contain some degree of offsite manufacturing, but in aggregate it remains a very small part of the industry as shown in Table 1. According to the UK Commission for Employment and Skills (2013), the most recent estimates put the value of offsite construction at around £1.5bn, with a potential to achieve as much as £6bn. Projections for 2013 (developed in 2009) suggest the current value of the sector as likely to be 7 per cent of total construction output. In total, the construction sector currently contributes nearly £90bn to the UK economy (BIS, 2013). A share of 7 per cent would equate to over £6bn.

Table 1. Offsite Construction and Prefabrication Usage of the Housing Market

Items	Contents
Offsite Use	2% of the value of the entire construction sector (including civil works) has been attributed to offsite work, Optimistic estimates as high as 7%, though little housing-specific construction, <5% use of 'non-traditional 'methods for new housing
Annual Production	143,580 (2012)
New Housing vs. Renovations	47% of housing construction output value is for maintenance, extensions and improvements
Housing Types	Detached houses a minority of existing stock 60–70% of new builds are 'houses' as opposed to 'flats'
New Housing Funding Model	UK Permanent house builds: 75–80% of completions by private, for-profit enterprise historically 20–25% non-profit social housing authorities England only: 65% build-for-sale, 23% build for social rental, 5% build for private rental, 7% self-build
Regulations	Building code 'Part L' targets energy efficiency, New construction products / systems need to be certified
Key Events	Sharp decline in house construction since 2007 Prefab use in post-war rebuilding
Contextual Factors	High proportion of speculative land acquisition and building, Comparatively low skill workforce

Source: Office for National Statistics, Steinhardt, & Manley. (2016).

At the end of the spectrum is traditional construction where prefabricated manufactured components such as brick, steel components and other mechanical and electrical equipment are extensively used and have been for many years. At the other end is a fully integrated design and construction strategy producing fully offsite manufactured components and modules. The opportunity for greater utilisation of offsite manufactured components across the industry is significant (KPMG, 2016).

The NHBC Foundation report (2016) ‘Modern Methods of Construction: views from the industry’ surveys 135 housebuilders and housing associations and explores attitudes towards MMC. The natural progression for the industry appears to be more mainstream use of panelised systems followed by modular construction. However, unless these properties are accepted as suitable security for mortgage purposes then the potential solutions that the Government and industry believes MMC can deliver cannot be realised.

1.2.! Relevant Certification and Assurance Scheme

As seen in Figure 2, there is no specific regulations applied for offsite construction in the UK. Buildings constructed offsite and assembled onsite are designed and erected to comply with all applicable building regulations and are generally indistinguishable from traditional site-built construction (CITB, 2017). The UK building regulations do not specify building materials or construction method, but instead set minimum performance standards for all buildings.

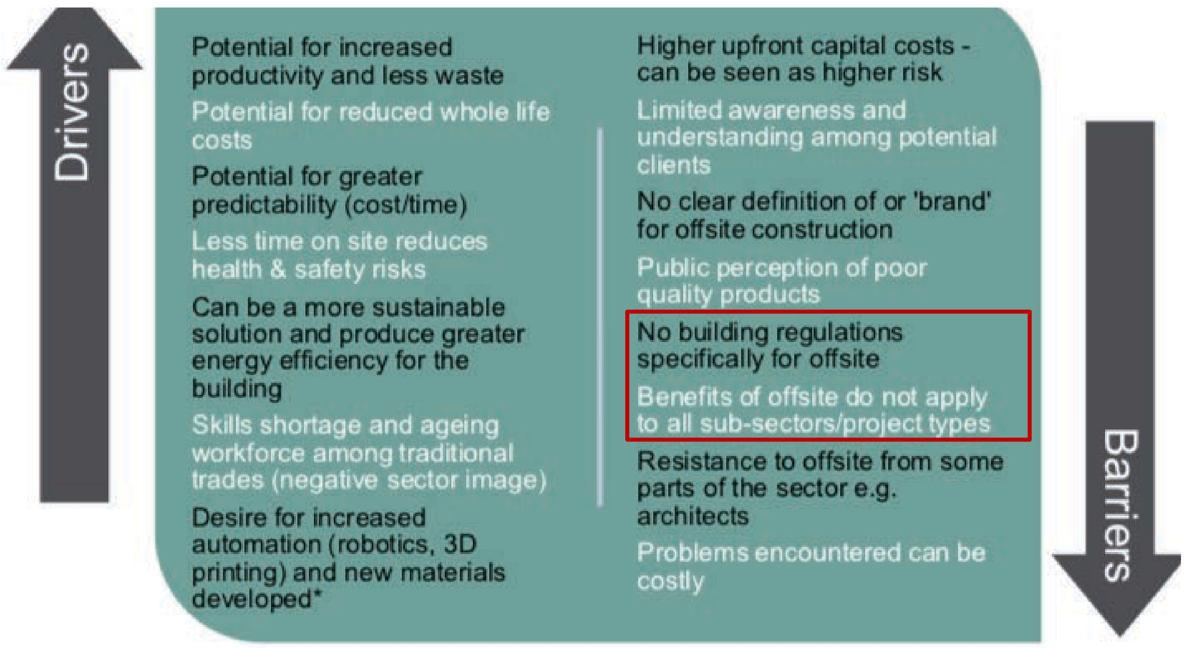


Figure 2. General Drivers and Barriers for Growth in Offsite Construction
Source: CITB (2017)

Therefore, if building work includes any components of offsite products, the Building ACT 1984 and Building Regulations 2010 are applied like the traditional building construction as the Building Act 1984 is the primary, enabling legislation under which secondary legislation such as the building regulations are made. The Building Act

1984 empowers and obliges local authorities to enforce the building regulations in their areas. These powers include a right of entry into buildings and powers of prosecution and enforcement in relation to non-compliant building work, dangerous structures and demolitions.

The "building regulations" made under this Act prescribe notification procedures that must be followed when starting, carrying out and completing building work and set out minimum requirements for specific aspects of building design and construction. A series of the following approved documents provide general guidance on how specific aspects of building design and construction can comply with the Building Regulations.

1. Part A: Structure
2. Part B: Fire safety - volume 1: dwelling houses
   Part B: Fire safety - volume 2: buildings other than dwelling houses
3. Part C: Site preparation and resistance to contaminants and moisture
4. Part D: Toxic substances
5. Part E: Resistance to the passage of sound
6. Part F: Ventilation
7. Part G: Sanitation, hot water safety and water efficiency
8. Part H: Drainage and waste disposal
9. Part J: Heat producing appliances and Fuel storage system
10. Part K: Protection from falling, collision and impact
11. Part L: Conservation of fuel and power
12. Part M: Access to and use of buildings
13. Part N: Glazing — safety in relation to impact, opening and cleaning
14. Part P: Electrical safety
15. Part Q: Security — Dwellings
16. Part R: Physical infrastructure for high-speed electronic communication networks
17. Regulation 7: Materials and Workmanship

Ongoing reviews of Building Regulations for offsite construction - particularly the requirements for thermal and acoustic performance - are setting more onerous criteria for performance requirements and the testing regimes of the finished dwelling (HSE, 2009).

In the UK the number of defects in traditional built homes is considerable, with house builders allocating up to £2,000 per house to rectify problems. Increasing use of offsite construction and manufacturing can reduce these defects as there is less risk of weather damage during construction, and materials can more easily be standardised and their quality can be tested and assured. However, if there is belatedly found to be a problem and issue with a particular MMC then this would have been replicated in many houses, because they are mass produced. Housing is built to last no less than 60 years, so problems and issues could go unnoticed for a certain time. For this reason, mortgage lenders, building insurers and surveyors are very cautious about greater use of offsite construction and manufacturing. For example, some insurers are worried about the resilience of MMC to flooding. In contrast, the risks of traditional site-based masonry construction are well known because the method has been used for a long time (Parliamentary Office of Science and Technology, 2003).

In general, accreditation systems to test the performance of housing products are operated by the British Board of Agrément and British Research Establishment (BRE) Certification as they test construction products and provide independent certification. However, the cost up to £100,000 and the process can take over a year, which means that not all construction companies and manufacturers can apply. According to the 2003 statistics, only six housing MMC have been granted accreditation so far, with three more in the pipeline. It is clear that it can be difficult to gain buildings insurance as well as mortgage if houses are built using unaccredited methods. Hence, some construction companies and manufacturers urge that Government should offer grants to assist with accreditation.

In 2003, the Council of Mortgage Lenders suggests that the Housing Corporation (In 2009, it was transferred to two new organisations, the Homes and Communities Agency and the Tenant Services Authority) should make it mandatory to use accredited methods when building social housing, in particular. The Housing Corporation is not willing to do so as it believes the directions about which MMC to use should be taken by individual Housing Associations. Besides, with the 25% MMC target commencing in 2004, there are concerns that there would be insufficient industry capacity if Housing Associations were limited to using accredited manufacturers.

1.2.1. British Board of Agrément (BBA) certification

According to BBA (2017), the British Board of Agrément (BBA) is an independent UK organisation that offers an approval service for construction products, systems and installers. They are the UK's major authority for providing reassurance to consumers, and achieve this through Agrément Certificates with the following services.

Agrément certificates

An agrément certificate is issued for a successful product or system following a detailed assessment including both laboratory testing and inspections. In addition, the manufacturer is audited to ensure they have an adequate quality management system. Repeated testing is undertaken for the duration of the certificate's validity period.

Test reports

A test report is issued by the BBA following the successful sampling of a product on a particular day.

Assessment reports

An assessment report is issued by the BBA following the successful assessment of specific properties of a product or system.

Product certification

To receive product certification, a product is tested against certain standards or other documentation.

Management systems certification

A management system can be assessed and certified to confirm that the product is manufactured in a controlled environment.

CE Marking

A product with CE (Communauté Européenne, although it is sometimes taken to stand for Conformité Européenne) marking demonstrates that the manufacturer meets appropriate European legislation.

Production control

Production control ensures that manufacturers continue to produce products that conform to a technical specification.

Prototype assessment

A prototype assessment report confirms the likely performance of a prototype product at the validation stage.

Additionally, the British Board of Agrément(BBA) provides 'product approval', 'Test bodies', 'Site inspections', 'ISO 9001 (Quality Management System)' and 'ISO 14001 (Environmental management systems)' services as parts of United Kingdom Accreditation Service (UKAS).

Offsite Product Certificate Case – Factory Production Control (FPC)
Certificate – BS EN 1090 (Structural Steel) – Execution of Steel and Aluminium Structures
The Construction Products Regulation places a legally binding obligation on all companies involved in the fabrication of steel and aluminium structures to CE mark their products on 1st July 2014. An FPC Certificate, issued by a Notified Body, is an essential part of the CE marking process which allows products to be placed on the European market. As a UKAS accredited certification body, the BBA has developed the required expertise to issue FPC Certificates to compliant companies across the UK. This certified fabrication of steel and aluminium structures can be applied to offsite construction as part of housing construction. Recently, Atspeed which is the UK provider of Schöck Ltd. get a BBA certificate of steel structure produces and plan to get a BBA certificate of a modular balcony system.

1.2.2. Build Offsite Property Assurance Scheme (BOPAS)

The BuildOffsite Property Assurance Scheme (BOPAS) was launched in 2013. The Property Assurance Scheme has been jointly developed by Buildoffsite, The Royal Institute of Chartered Surveyors, Lloyds' Register, BLP and the Council of Mortgage Lenders (CML), to provide assurance to the lending community that non-traditional constructed properties against which they may be lending, will be sufficiently durable as to be readily saleable throughout the duration of two mortgage terms, which may equate to 60 years. Further that the structural integrity will not intrinsically have a negative impact on the mortgage security during that term (BLP, 2015).

BOPAS has been developed to address the perceived risks associated with innovative construction and is recognised by the principal mortgage lenders as providing the necessary assurance underpinned by a warranty provision. As seen in Figure 3, the Assurance Scheme comprises (BOPAS, 2018):

- Assessment and accreditation against best practice by Lloyd's Register EMEA.
- A 60-year durability assessment by BLP Insurance.

- A web-based database comprising properties constructed under the BOPAS scheme with details of construction.

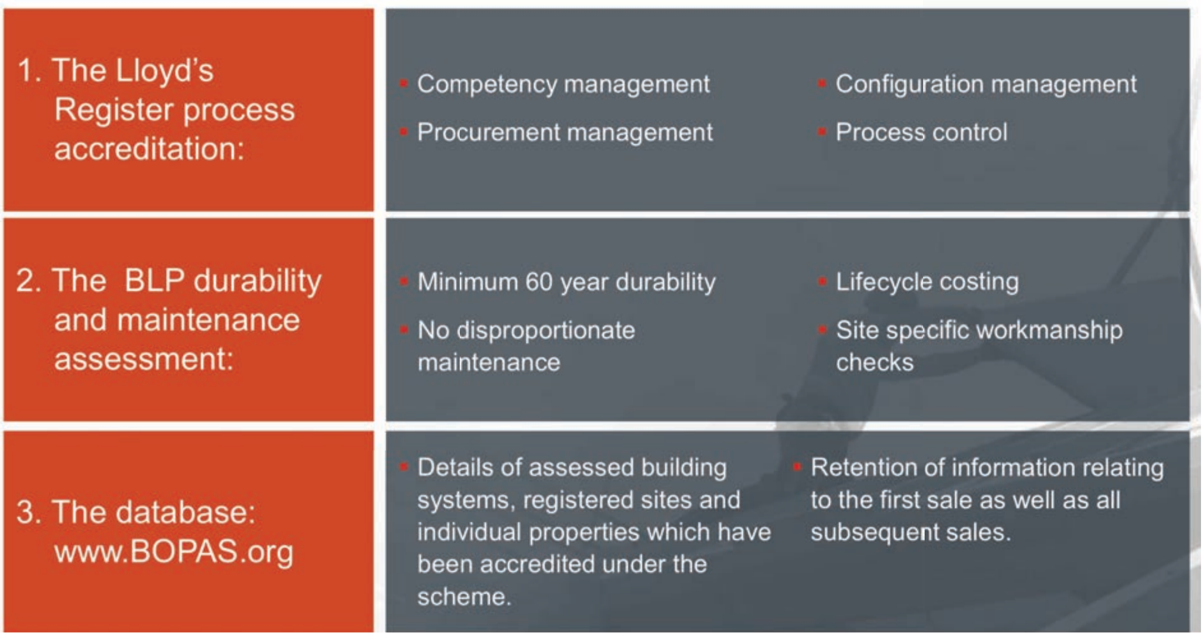


Figure 3. BOPAS Assurance Scheme – Three components

1. The Lloyd's Register accreditation process:

The process accreditation which is carried out solely by Lloyd's Register, evaluates and facilitates the adoption of best practice by manufacturers and constructors in key performance areas such as risk management, competency management, configuration management, procurement management and process control at each stage of project development, through concept, design, manufacture and construction.

A structured and systematic approach at each phase of the project life cycle will ensure consistency and repeatability and the accreditation scheme requires this discipline to be adopted by organisations and their suppliers/subcontractors seeking accreditation under the scheme.

The assurance of repeatability, delivered through the accreditation process in Figure 4, will provide assurance to:

- Asset valuers, mortgage valuers and surveyors providing for a more consistent through-life performance of the innovative systems/ products and therefore reduced variability in asset value
- The provision of latent defect insurance, as any form of variability in the system or product warranted, introduces greater risk for the warrantor.

Figure 4. Factory Visit and Process Evaluation

2.! The Durability and Maintenance Assessment:

The BLP durability assessment is a rigorous and structured process following the principles of service life planning of constructed assets as defined in the international standard ISO 15686. The durability assessment is based on a standard time frame of 60 years. This would be the minimum expectation for structural components unless intended specifically for more temporary applications. Where shorter life components are identified, expected service lives are stated including relevant maintenance requirements.

The purpose of the BLP durability assessment is to provide assurance on the probable service life of a building based on its component parts and assemblies in typical environmental and use conditions:

- The BLP durability assessment is confirmed as a recognised technical assessment of innovative design and construction
- Issues relating to repairability, maintainability and suitability for the intended environment are covered
- The assessment gives confidence regarding the performance over time of the system to potential users, purchasers and funders.

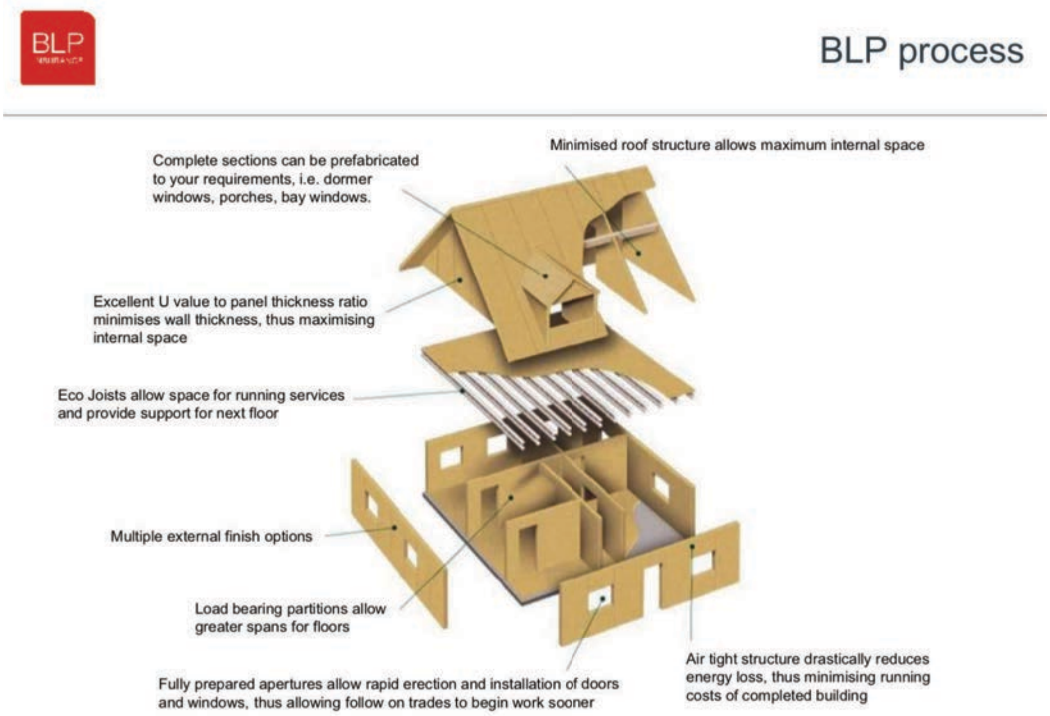


Figure 5. BLP Durability Evaluation

3.! The BOPAS web-based database:

In Figure 6, a web enabled database has been created comprising details of assessed building methodologies, registered sites and registered/warranted properties. Access to information, regarding major structural components of an innovative construction, will assist the asset valuers, mortgage valuers and surveyors in the provision of a more definitive valuation/determination of condition.

Figure 6. BOPAS Web-based database (www.bopas.org)

The website operates a traffic light system (See Figure 7) so that the progress of a system through the assessment process can be tracked as shown in Figure 6. Developed schemes using a BOPAS accredited system are uploaded to the database allowing valuers to assess by postcode if a particular property con structed from non-traditional means has been through the BOPAS process.

BOPAS Approved Technologies & Products

The technologies and products involved in offsite manufactured systems and innovative construction techniques will change the construction landscape and BOPAS will ensure that they meet stringent quality criteria.

Technology or Product name	Approval status
AcerMetric™ Panels	Not Assessed
Actavo Steel Framed Modular Solution	Under Assessment
Binderholz Brettsperholz Building System (BBBS)	Approved
Biond Construction System	Approved
BSJ system	Approved
CIDARK P3 System	Approved
Cross laminated timber based	Approved
Design for Manufacture and Assembly (DfMA) methodology	Not Assessed

Figure 7. BOPAS Approved Technologies and Products (www.bopas.org)

The Buildoffsite Property Assurance Scheme offers designers, manufacturers and constructors, as well as lenders and, ultimately, buyer's confidence in Modern Methods of Construction.

In order to get a BOPAS certificate, there are mainly two separate assessments – a durability and maintenance assessment of the building product by BLP Insurance or technology and a process accreditation of the organisation itself by Lloyd's Register EMEA. If designers, manufacturers and constructors who are involved in offsite manufacture of systems and products would like to get a BOPAS certificate, they should submit their applications for both assessments separately. It should be remembered that it is not just for the manufacturers, designers and constructors. The BOPAS scheme also benefits other stakeholders such as property owners and developers, as well as the lending community, valuers and property surveyors as it presents evidence to lenders that their developments will or have been designed, manufactured and constructed by BOPAS-accredited organisations in accordance with an accredited design system.

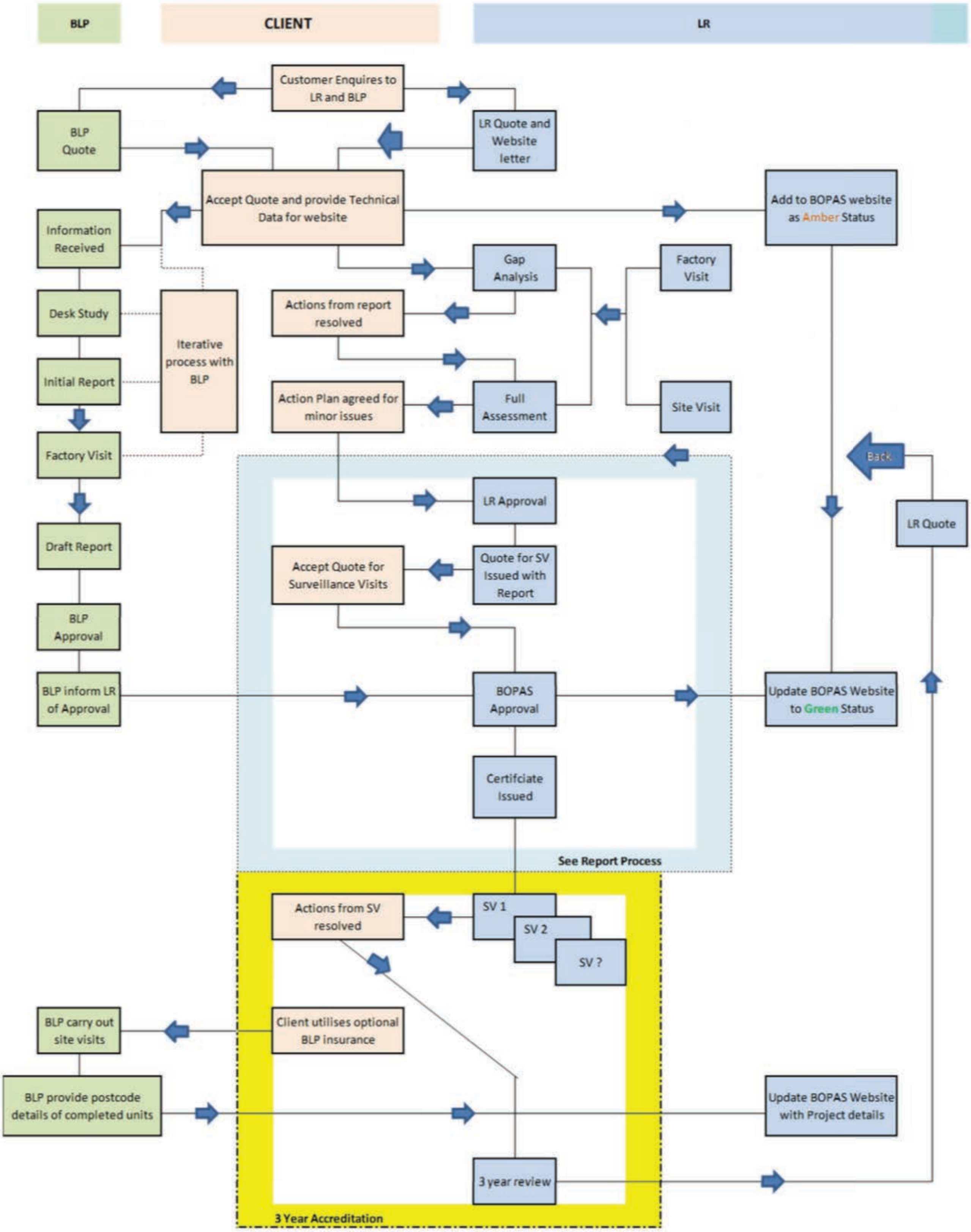


Figure 8. Flowchart of BOPAS Process
Note: BLP - Building Life Plans (www.blpinsurance.com), LR - Lloyd's Register EMEA (www.lr.org/en/)

As the first stage of BOPAS accreditation process, the Lloyd's Register accreditation process includes the Gap Analysis based on 1 to 1 interview with key staff members, verbal feedback, consensus approach, detailed report and findings log as seen in Figure 9. The Gap Analysis is undertaken to examine the overall status of the processes, systems and competencies. The analysis would be carried out over a period of one day at the manufacturer's offices by 1 or 2 Assessors. It is unlikely that site visits will be required at this stage.

Ref	Grade	Status	Requirement	Finding	Current Situation	Date Closed
002	Major NC	Open	Process Control – Project Management, Procurement, Transport and Storage	(At Gap) Major Non-Conformance (Major NC........shall ensure that their audit programme considers all activities undertaken by a service provider or supplier including the design, manufacturing, transport, construction, project management, maintenance, refurbishment and disposal. The audit programme shall be based on the results of a risk evaluation of the service provider and suppliers activities, targeting those at highest risk to ....in compliance with the BuildoffSite scheme. Should an inadequate audit programme be identified by Lloyd's Register particularly for single, sole suppliers or service providers (such as ....), then Lloyd's Register will conduct audits of all such key suppliers		
004	Major NC	New	HR, Training and Competency	At Gap – (Major NC) – ...... need to develop, document and complete a competency process (to include a competency and training matrix) for all management and operational positions (including contracted out consultants and tradespeople where relevant).		
008	Major NC	New	Configuration Management	At Gap – (Major NC) – .... need to develop, draft processes and flowcharts detailing the concept, design, manufacture and construction of standard house designs, one off designs and the typical project process.		
009	Major NC	New	Process Control – Design and Manufacture	At Gap – (Major NC) –..... processes should be able to satisfy BOPAS Project Management (Design and Manufacture) requirements independently and be repeatable with any design consultants and manufacturer.		
015	Major NC	New	Transportation	At Gap – (Major NC) – ...... require a process and formal procedure for the transportation of products between off-site and on-site locations.		
019	Major NC	New	Risk Identification, Assessment and Control.	At Gap – (Major NC) – Lessons learned (risks and opportunities) from completed projects need to be captured and recorded with evidence of communication to relevant depts.		
025	Major NC	New	Process performance monitoring	At Gap – (Major NC) – ..... is required to build and formalise a key performance indicator process for i) the quality of their product and ii) the performance of their business.		
028	Major NC	New	Performance, Monitoring and Improvement	At Gap – (Major NC) – A formalised reporting and logging system with a process for root cause analysis and rectification needs to be included and documented.		

Figure 9. Examples of deficiencies Identified

Factory and site visits will be performed to evaluate risk management, competency management, configuration management, procurement management, competency management, product risk and process control. As shown in Figure 10, the results of full assessment are quantified according to the characteristics of the maturity levels including scope, competency, procurement and so on.

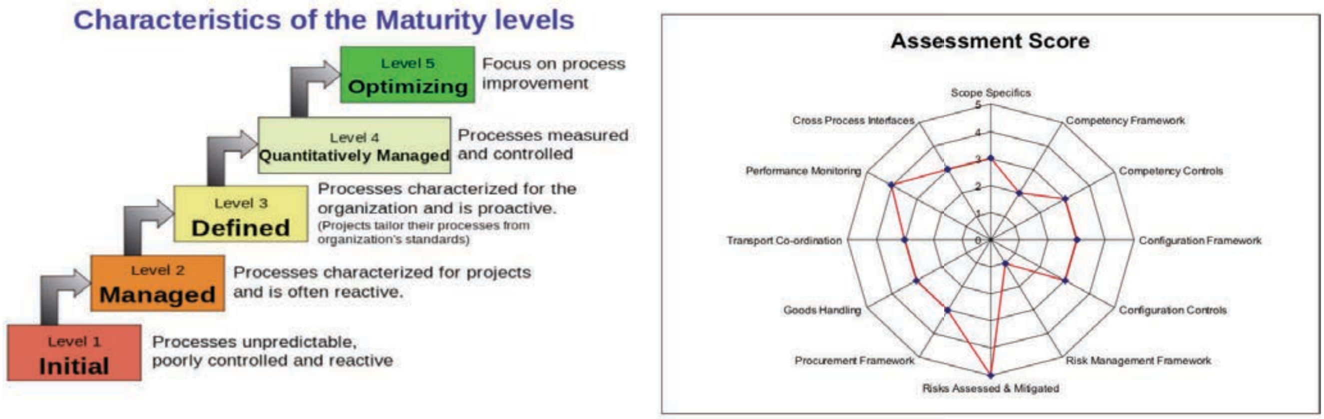


Figure 10. Quantitative Evaluation

The Durability and Maintenance Assessment is a rigorous and structured process following the principles for service life planning of built and constructed assets in the international standard ISO 15686. The durability assessment is based on a standard time frame of 60 years. Where shorter life components are identified, expected service lives are stated including relevant maintenance requirements. The BLP durability assessment qualifies as an independent technical approval for an assessment of suitability for housing as set out in the Housing Corporation requirements in the Scheme Development Standards 5th Edition April 2003 section 1.6.3 (It has been changed to 'Housing Corporation Design and Quality Standards, 2007' (BLP, 2015).

Figure 11 shows a snapshot of the BLP durability and Maintenance Assessment on the screen which evaluate issues relating to repairability, maintainability and suitability for housing are covered and the assessment includes:

- Structural performance
- Interface design and detailing
- Resistance to key agents of degradation (corrosion of metals, decay of
- timber, etc)
- Risk of interstitial and surface condensation
- Resistance to weathering, wind, rain and radiation

- •! Resistance to thermal and moisture movement
- •! Expected durability and maintenance requirements
- •! Quality control processes (e.g. factory controls, transport, storage,
- •! installation, feedback, dealing with faults and change mechanisms)
- •! Installation process: e.g. training, installation manual, qualifications

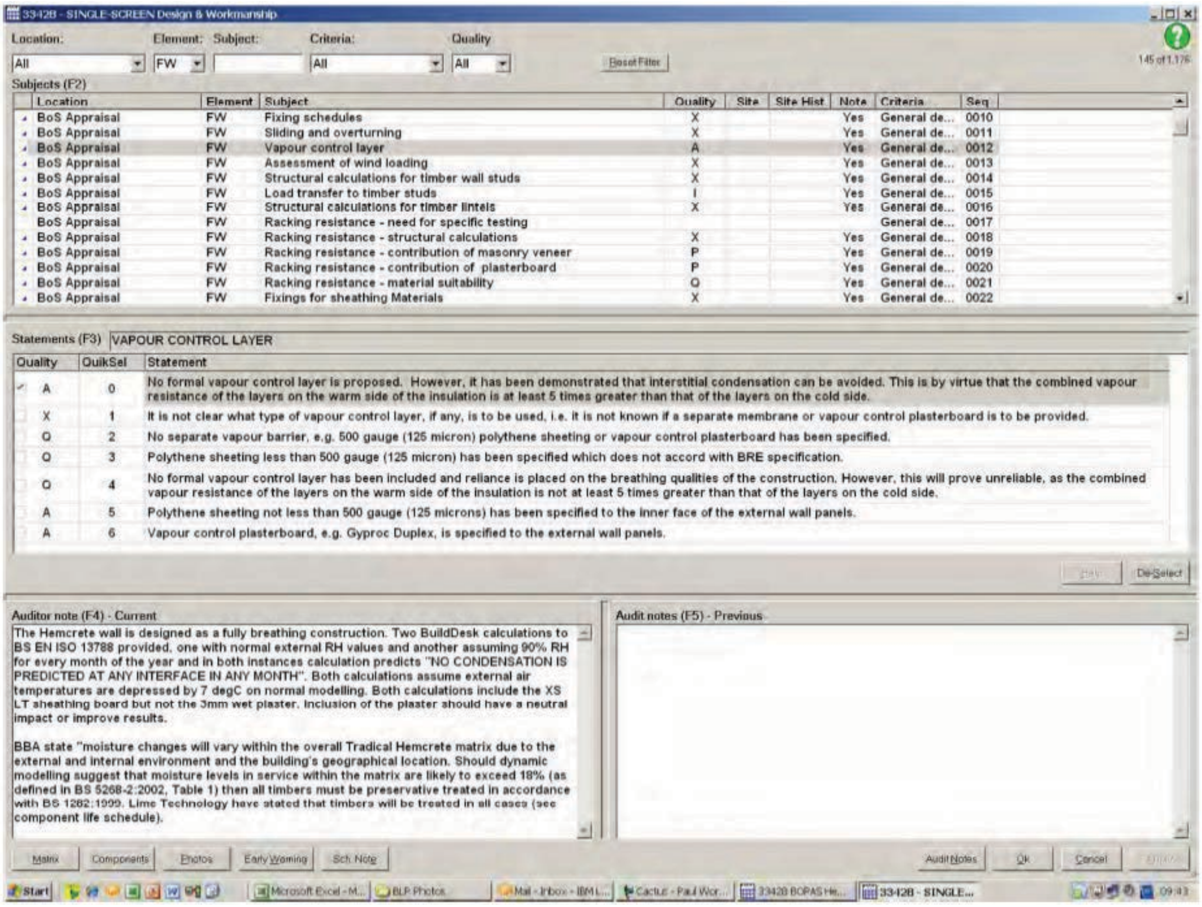


Figure 11. Durability and Maintenance Assessment

BOPAS registrations for accreditation were relatively slow from 2013 through to 2015 but interest in offsite began to rise in 2016 and 2017 as seen in Figure 12. The number of registrations for 2018 has already reached 12, with another 50 currently in discussion. Last year saw 20 BOPAS registrations in total, with 11 registrations achieved in 2016 and five in 2015, signalling that the number of registrations this year is on track to surpass all previous years since the scheme's inception (Offsite HUB, 2018).

The 23 designers, manufacturers, and constructors including Stewart Milne (www.stewartmilne.com) which is one of the biggest housing contractors have been accredited by BOPAS so far and 30 companies are in progress for being accredited (see Figure 13). More than 50 companies including AECOM, Laing O'Rouke are in discussion for being accredited by BOPAS.

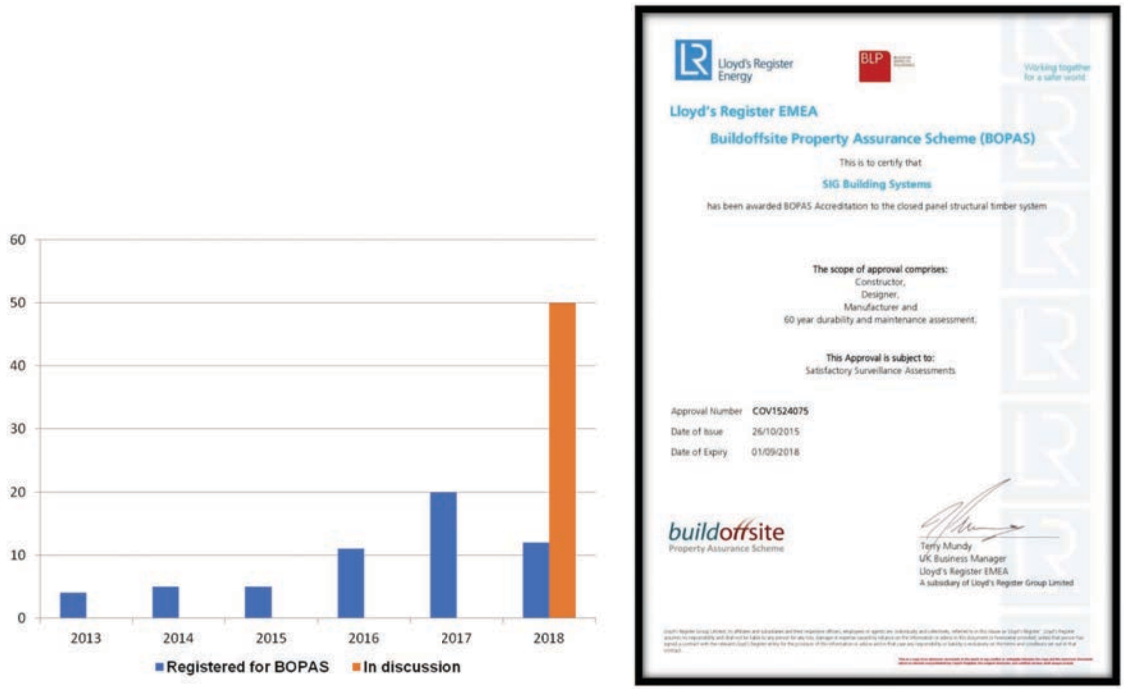


Figure 12. Growth of BOPAS Membership and BOPAS Certificate

APPROVED	IN PROGRESS	IN ADVANCED DISCUSSION	PIPELINE / IN DISCUSSION	
Stewart Milne	Glosford SIPs	Laing O'Rourke	MyPadHaus	Swift MS
Fusion	Cubicco	Aecom	Fortamedical	Kerkstoel 2000
Lime Technology	Greencore Hempsec	Horizon Offsite	Tarmac	Local Homes
BK Structures Ltd	Legal & General Homes	Berkeley Homes	Prime Structures	Metier Group
Cidark	Acemetric	EuroSips	CAPCO	Liab Flex Homes
Elements Europe	CITU	Simply Modular Ltd	Saint Gobain	Vanburgh
Enevate UK	Top Hat	Rollalong	Modcell	CCG Scotland
VRC	Wiki House	Lesko	Zed Factory	Futureway Homes
Adston	Xella Casco	Premier Modular	IKEO Group	JUB
Ilke Homes	Multibuild		PAW Structures Ltd	Streiff
Jade Global Group	Modular Residential		Low Carbon Construction	Beattie Passive
Parabuild Solutions Ltd	Hadham Construction		DMC Global	Built Offsite
SIG Building Systems	McAvoy Group		Kiss House	Dwelle
24.7 Living	Extra Space Solutions		Reach	Robertson Timber Eng
Vision Modular	Actavo		Anyo	Reach Homes
SIP BUILD	Purever		nHouse	Schoolhaus
Vinco SIPS	Mass Bespoke		Neat (UK) Ltd	Vision Built
Barclay St James	Net Zero Buildings		Housing UK	Hatch Homes
Brooke Homes	Frameclad		SuperSIPS	Space Projects
H+H /SIG	Totally Modular		Flight Timber Products	Precision Frame Systems
Dan - Wood	Modular AR Ltd		Eco Modular	Future Friendly Homes
Swan Housing Group	Modpods International		Pearce Construction	OFP Timber Frame
Modularwise	Innovare		Matrix Living	Hans Haus
	Ideal Modular		Kube	Capital HOLZ100
	SPS Envirowall		Prestige Homeseeker	Eco Offsite
	Cornish Concrete Products			
	Housing Homes Ltd			
	Save the Carbon			
	Volker Fitzpatrick			
	Caledonian Modular			
23	30	9		50

Figure 13. Current Status of BOPAS Membership

In 2017 BOPAS awarded 20 certificates – double the number in 2015. In 2018 already more than 10 have been certified, with more than 40 in discussion. Modular build is the most popular system that is being assessed by the BOPAS team with 21 systems (24 systems as of Nov 2018) being accredited already in Figure 14 and it followed by Timber Frame and LGSF (Light Gauge Steel Framing). Subject to satisfactory performance throughout the accreditation process accreditation will remain valid for 3 years after which time a reassessment will be carried out. Since the Build Offsite Property Assurance Scheme (BOPAS) was launched in 2013, the BOPAS registrations have been expending to overseas and more than 15 registered companies are coming from Ireland, Europe, Eastern Europe and China.

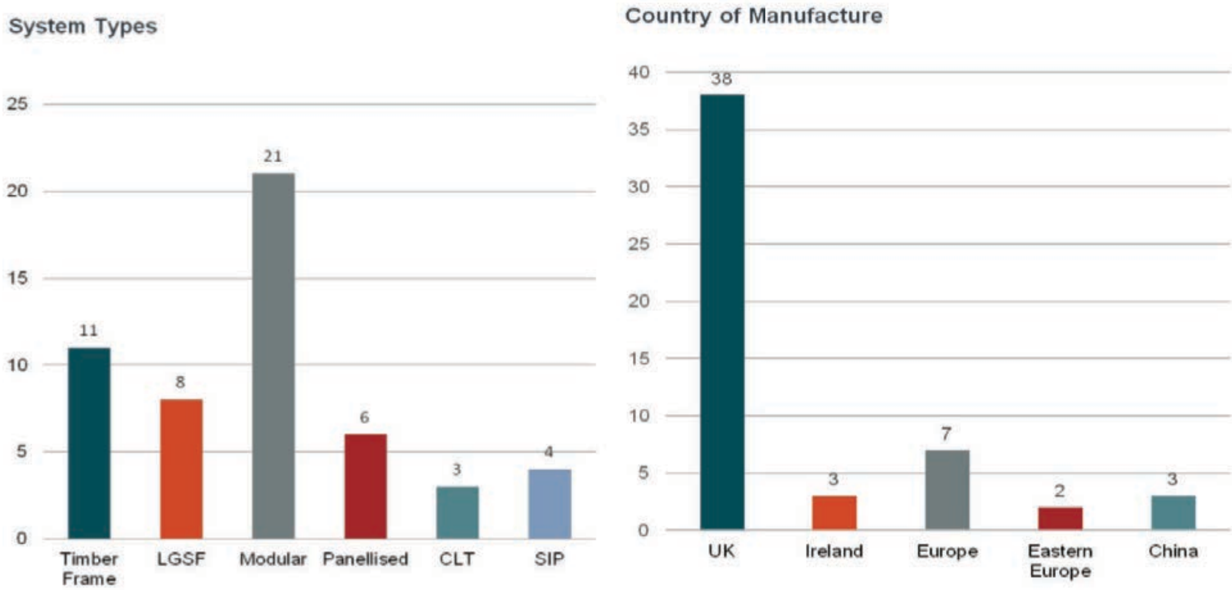


Figure 14. Summary of Types and Country of Origin in BOPAS

Here are some examples of projects which have been completed and under construction through the BOPAS Scheme.

Example Project 1: Urban Splash

Example Project 2: Apex House – Vision Modular

Example Project 3: Essential Living & Elements Europe

Example Project 4: Swan Housing Association – Nu living

Example Project 5: Brooke Homes

1.3.! Benefits and Issues of BBA and BOPAS

The British Board of Agrement (BBA) covers over 49 different products areas within the construction industry including timber and steel structures, wall, floor, roof, finish, openings, building services components. With a BBA Certificate, all relevant Building Regulations are considered along with other requirements like Codes of Practice and NHBC requirements, so certificate holders can satisfy themselves that all levels of fitness for use have been met without the need for multiple Certificates. That means they save time, money and hassle. Additionally, BBA Assessments go above and beyond what is required from a national standard, in particular with reference to Regulation 7 in England and Wales – Materials and workmanship or Regulation 8 in Scotland – Durability, workmanship and fitness of materials.

In contrast, the Buildoffsite Property Assurance Scheme (BOPAS) exists to provide assurance to the lending community that innovatively constructed properties will be sufficiently durable as to be readily saleable for a minimum of 60 years and the BOPAS scheme provides an assurance of the safe and competent delivery of offsite products conforming to contract specifications. This is achieved through compliance with the requirements detailed in this document, involving all aspects of the business operation including systems processes and procedures, together with handover interfaces, from design through offsite manufacture and construction/ assembly to client handover; all being tested against the arrangements for sustaining quality delivery, dealing with environmental and project changes and the control measures that are applied to mitigate delivery risks.

Director of Product Development in Stewart Milne Group said “ BOPAS accreditation has been invaluable to our company. Not just in terms of giving comfort to the major mortgage lenders and insurers that our Sigma II Build System is durable for at least 60 years but in providing advice on our systems and processes which has enabled us to fine tune how we operate making us more effective as a business and ensuring we stand out in the industry.”

There’s a will in government to make offsite work, though the mechanisms could be stronger. Alongside development and innovation funds that provide incentives, Homes England is understood to be considering introducing requirements for offsite homes to be built on land it releases, or tied to any grant, providing more pipeline and encouraging investors into the market. Yet, there has not been any incentive provided by the Government for offsite construction.

In July 2018, the House of Lords Science and Technology Committee (the Committee) published a report noting that the current labour shortage is only likely to worsen in the coming years and suggested that offsite construction and manufacturing could play a key role in helping the Government meet its target of delivering 300,000 homes per year by the mid-2020s. This view was supported in ‘The Farmer Review of the UK Construction Labour Model – Modernise or Die (2016)’ and the Farmer Review suggest that the Government has a role to play by encouraging clients to change their behaviours (through fiscal or planning system incentives) and buy manufacturing- led construction rather than traditional. Also, Homes England are seeking a way of having a good design and using innovative housing construction products such as modern methods of construction (MMC) through their Development and Innovation funds.

References and Bibliographies

BBA (2017) the British Board of Agrément ebook
BIS (2013) UK Construction: an economic analysis of the sector
BLP (2015) Written Evidence from BLP Insurance
BOPAS (2018) Guidance document
BSA (2016) Laying the foundations for Modern Methods of Construction
Construction Excellence (n.d.) Legal Guide to Off-site Manufacturing, Retrieved 10th January 2019 from https://www.constructingexcellencesw.org.uk/assets/OFFSITE//ceswlegalguideoff-site.pdf
CITB (2017) Building Skills for Offsite Construction
Construction Excellence (2004) Off-Site Production
Experian (2018) UK Construction Forecast, Volume 24: Issue 3
Famer (2016) The Farmer Review of the UK Construction Labour Model – Modernise or Die
Glenigan (2018) Construction Outlook-Forecast for 2019-2020
Homes England (2018) Community Housing Fund Prospectus
Housing Corporation (2007) Design and quality standards
Housing Corporation (2003) The Scheme Development Standards 5th Edition
HSE (2009) Off-Site Production in the UK Construction Industry- A Brief Overview
KPMG (2016) Smart Construction Report_how offsite manufacturing can transform our industry
Lloyd's Register (2018) BOPAS Guidance Documents
NHBC (2016) Modern methods of construction - Views from the industry
Parliamentary Office of Science and Technology (2003) Modern Methods of House Building. London: POST.
Science and Technology Select Committee (2018) Off-site Manufacture for Construction: Building for Change
Steinhardt, & Manley. (2016). Adoption of prefabricated housing-the role of country context. Sustainable Cities and Society, 22, 126-135.
UKCES (2013) Technology and skills in the construction industry
Wafaa Nadim, Jack S. Goulding, (2010) "Offsite production in the UK: the way forward? A UK construction industry perspective", Construction Innovation, Vol. 10 Issue: 2, pp.181-202

Website

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