The role of Standards in offsite construction

A review of existing practice and future need

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Contents

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Executive summary

Introduction

The rise in interest in offsite construction (OC) techniques is well documented. A significant degree of attention has been given to identifying the potential benefits of OC, how these might be achieved, and the barriers to increased take up and delivery capacity. The role of Standards in this regard has also been discussed.

In order to contribute to the ongoing discussions on OC BSI has undertaken a number of initiatives, including the standards research project outlined in this report. It aims to understand the current and potential role of standards in this field, what benefits standards can bring, and what action is needed to realise those benefits.

As the National Standards Body, BSI works with industry to identify areas where standards are needed and develop them. It maintains the very sizeable portfolio of existing standards to ensure continued relevance, and it promotes UK standards practice at a European and International level through its membership of supranational Standards organisations.

The report provides a clear outline of where BSI can support industry and what actions are needed to ensure the existing standards portfolio can accommodate OC techniques, and new standards can be identified in accordance with industry need.

General Findings

Offsite Construction is changing the traditional relationships along the supply chain and creating different requirements. Designers are increasingly working directly with manufacturers, and therefore they and contractors, need to develop different skills to accommodate manufacturing requirements and complex product assemblies. There are also design considerations that are unique to OC.

The role of the manufacturer is becoming more significant in OC as they bring more of the on-site deliverables, such as the wet trades and hot trades, in to the factory or eliminate them altogether. Manufacturers are also increasingly addressing design performance in order to deliver the more complex building solutions that they are manufacturing and offering as complete, turnkey solutions.

Furthermore there is increasing focus on digital manufacturing techniques from other industries to take learnings and apply them to OC. The new platform approach, pioneered by Bryden Wood and now openly accessible, is expected to facilitate a significant increase in OC capacity through the use of a defined set of standardised building elements from which complex design solutions can be delivered.

It has been noted that these disruptions to traditional building practice mean that current contractual relationships are not always effective for OC. Industry is going some way towards addressing this through the development of new framework agreements. Clearly, the management and communication of technical information along the supply chain and the roles of testing and compliance are also impacted.

The construction industry is a highly regulated and standardised sector. Building Regulations and the Construction Products Regulation, together, reference 1,264 standards. Most of these were developed for traditional building practices. This introduces a layer of complexity around compliance when developing new products and processes. The industry is also currently undergoing digitalisation through the introduction of Building Information Modelling (BIM) Level 2.

All of this is challenging. Nevertheless participants in the research were positive about the benefits of OC. They see it as having the potential to make their industry better equipped and informed, more collaborative and open, faster, safer and more innovative in the long term.

Standards findings

The review of the current use of standards for OC presented a number of key findings.

There are very few standards applicable to this sub sector. And those few are considerably out of date. This means practitioners generally design and manufacture bespoke systems and must navigate a path through the very many cross cutting standards in the BSI construction portfolio to identify those that may be relevant (e.g. thermal, acoustic, fire performance etc.) and apply them. This layer of complexity can inhibit innovation and wider integration.

On the design side there are unique requirements for OC where a standardised process for discussing and specifying OC would benefit both design teams and clients. Aspects such as asset management, maintenance and retrofit; logistics and transport; and end of life throw up different considerations for OC. Design management standards in general, do not currently make specific reference to OC and, while this does not act as a barrier to take up it could act as discouragement to adoption.

The new supply chain relationships, arising in this area, are also presenting standards related issues. It is widely agreed that early collaboration and early commitment to a particular OC system is desirable. But that is also believed to potentially increase risk to a project. Some of the BIM Standards for library objects demand more information than many OC manufacturers are prepared to supply because of IP concerns. And there are calls for factory acceptance testing to be permitted to reduce or even replace on-site installation and commissioning compliance testing.

Regarding materials standards the picture is less complex but also problematic. As may be expected the precast concrete sector has more applicable standards than other material sectors. Steel frames fall within the scope of EN 1090 Execution of structures and are subject to CE marking. But light steel frames manufacturers need to rely on industry guidance produced by SCI. The timber industry in Europe started to develop a structural standard for floor, wall and roof elements which is considered by some to have potential, but it was abandoned due to a lack of consensus. The industry uses ETAGs (European Technical Approval Guidance) which are called up for individual products where no European Standards exist and allow for CE marking. They also use industry guidance on SIPs and CLT published by the Structural Timber Association.

There are no standards for major OC elements e.g. for modular/volumetric units, panelised systems, or pods. Elements are generally bespoke, and are individually certified as complying with Building Regulations, including compliance with standards originally written for traditional build and with cross cutting standards mentioned above.

Technical issues that were highlighted as of major interest to the industry were

- accuracy and tolerances and
- integration and connections between systems

There were many reports of clashes and fitting problems along the supply chain. One reason is that existing standards for accuracy and tolerances are out of date. As a result practitioners often simply ignore them, or assume they should be used, or establish their own tolerances sometimes without agreement between parties.

Integration between different materials and systems or between common materials and systems from different suppliers was cited as a key issue and results from lack of communication, the use of bespoke designs and single supplier interest. Whilst understandable in an innovative market and the need to protect IP, this prevents shared learnings, limits flexibility for users, and increases risk in the market place.

This is also an issue for building services, some aspects of which are well developed for OC. Poor standardisation of pipework has been reported as well as problems around connecting pipework and cables for example between modules.

Recommendations and Actions

The following have been identified as actions where BSI can help to drive the OC sector forward.

1. Addressing the existing BSI Standards portfolio

a. *A formal review of existing out of date standards* in this area is needed so that action (withdrawal/revision) can be taken.

b. Further engagement with standards makers from the materials and products sub-sectors is also needed to *review the report findings, to verify them and to explore solutions* to the gaps, barriers, and other issues that have been identified.

c. *Work with relevant BSI Technical Committees to review the need for OC* to be addressed in their individual portfolio of standards. This is particularly relevant in cross cutting standards committees.

2. New work

a. The design community must adapt to the different considerations OC imposes on them. *The development of agreed processes for design teams, including guidance and recommendations for the early design stages that also addresses supply chain relationships* would fill a clear gap in standards need. The current work BSI is undertaking with HTA Design LLP will go some way to addressing this. The proposed Standard could give rise to future parts covering different materials/assembly types.

b. BSI is also keen to work with other agencies to address *quality management, technical requirements around design performance, testing and maintenance* issues.

c. *New requirements on accuracy and tolerances that are specific to OC need to be agreed* whilst remaining cognizant of industry concerns over competitiveness with the traditional building sector. BSI has a clear role in addressing issues around accuracy and tolerances and the formal review of relevant standards (Action 1a above) will include those covering accuracy and tolerances. Work on a revision of BS 5606 has already started.

3.Further research

a. *Work needs to be undertaken to address the lack of common standards for integration and connections across OC*. This is a key issue and a major block on expansion in the sector. BSI can work with the client and design communities to understand their needs in detail and with the supply side to look at material sectors and assembly suppliers to start to explore where standards may be acceptable. It will be useful to understand, where feasible, the level of commonality that already exists in order to start with the least disruptive aspects.

BSI welcomes comments on this report and the recommendations outlined above.

Background to the report

Industry backdrop

For many decades there has been a push for the construction industry to adopt more standardised methods of construction. The UK has witnessed a gradual increase in the adoption of Offsite Construction (OC) across several areas of the building sector including student accommodation, and housing. The government is now looking to use its position to drive up the use of OC in many other types of public buildings including educational, prisons, hotels, hospitals (Simpson, 2017).

The Construction Leadership Council's Innovation in Buildings work stream (2017) recently set out key actions designed to unlock the supply and demand conundrum affecting the provision of additional housing by adopting smart construction (including OC). A strategy with three key aspects has been developed:

- Aggregate demand within city regions and Homes and Communities Agency (HCA) programmes to provide visibility to the supply chain of future volume requirements.
- Standardisation of requirements/specifications in space/pattern books including development of industry level guidance, and common standards supporting enhanced quality, and pre-manufactured value in delivery throughout the supply chain.
- Procurement – enabling achievement of this strategy through revised procurement guidance and model forms of contract.

The strategy aims to unlock private sector investment of housing industrialisation, creating jobs, wealth and export potential.

The UK government interest in OC was highlighted in November 2017 when five government departments (Department for Transport, the Department of Health, the Department for Education, the Ministry of Justice, and the Ministry of Defence) announced a presumption in favour of OC across suitable capital programmes where it represents best value for money.

The House of Lords also recently conducted an inquiry into OC to consider its potential benefits for construction and any drawbacks or obstacles to its wider use. Their findings were published on 19 July 2018[1] , and included a recommendation that, *"the Government should promote the adoption of recognised standards for off-site manufactured components within the industry by working with bodies such as the BSI and the BRE."*

In addition the recent London Assembly report recommended a Manufactured Housing Design Code[2].

The new £420 million joint government-industry construction sector deal was launched on the 5th July 2018. This aims to transform construction through innovative technologies to increase productivity and raise quality. It recommends the use of digital design and offsite manufacturing.

In the private sector, Laing O'Rourke, Berkeley Homes, Pocket Living, and Legal & General Homes are among those who have recently committed to modular expansion.

There are also industry developments towards more "platform-based" approaches to the design and construction of buildings, especially for housing. Bryden Wood is developing a blueprint of standardised products that can be used to build homes more quickly for the Greater London Authority. It is hoped that adopting a platform-based open systems architecture approach will enhance the interoperability of differing offsite systems and catalyse new supply chains (Chevin, 2018).

BSI Standards Consultation and Workshops

BSI has been monitoring activities and consulting with industry to understand the current and potential role of British Standards in the OC sector and to understand how BSI can best support developments in this emerging market.

Moreover, international standards development has begun in this area and it is essential that UK industry considers how to engage with that activity given there is currently no BSI Standards Technical Committee for OC.

Two workshops were held in 2017 leading to a number of recommendations and actions including:

- The need for ongoing engagement with key groups working on market development of OC techniques to ensure standards needs are addressed at the earliest opportunity
- Full UK participation in the International Committee ISO TC 59/ WG3 which is working on the development of new Standard ISO/CD 21723 for Modular co-ordination
- National Standards activity including
  - a proposed new Standard on terminology,
  - revision of BS 5606 Guide to accuracy in building to include clauses on offsite construction, and
  - the development of a detailed proposal for a Code of practice for the design and procurement of generic offsite systems for residential development with HTA Design LLP.
- ***A research project to be carried out to review current use of British Standards by sector in order to identify technical barriers and gaps where Standards may be needed***

BSI Standards Built Environment head Strategy Committee CB/- supported the need for a research project and BEIS funding was secured. The main body of this report presents the findings of the research that was carried out.

[1] https://www.parliament.uk/business/committees/committees-a-z/lords-select/science-and-technology-committee/inquiries/parliament-2017/off-site-manufacture-construction/off-site-manufacture-construction-publications/
[2] https://www.london.gov.uk/sites/default/files/london_assembly_osm_report_0817.pdf

Research project

Scope

The research has been undertaken by a team from Loughborough University with input from West One Management Consulting and Buildoffsite.

They were asked to investigate how the offsite construction industry uses standards, to evaluate whether current standards in this area are fit for purpose, and to identify areas where standards could usefully support the take up of OC techniques.

The work focussed on

- buildings rather than civil engineering or infrastructure
- OC elements: modular/volumetric and panelised (flat panel) systems
- materials: precast concrete, timber and steel

Outline/methodology

The study included:

(i) a desk study of relevant standards and literature;

(ii) interviews with industry experts in person, by telephone, or via email;

(iii) an online questionnaire distributed via Buildoffsite; and

(iv) an industry workshop at BSI with 12 delegates

Additional interviews and desk study analysis were conducted following the workshop and during the drafting of the final submitted report.

Conventions of terminology

Throughout the report, the term offsite construction (OC) is used and refers to *'the construction process that is carried out away from site'* (Buildoffsite, 2013). The term is often exchanged with offsite production (OSP), offsite manufacturing (OSM), prefabrication and pre-assembly, and modular or volumetric construction, amongst others.

Modern methods of construction (MMC) is a similar term, but also includes on-site technologies such as thin-jointed blockwork.

Further terms used in this report are as defined in the Buildoffsite (2013)[3] and the Offsite Hub[4] published glossary of terms, some of which are included in Appendix 3 include: Module, Composite Construction (or Hybrid), Cross Laminated Timber (CLT), Design for Manufacture and Assembly (DfMA), Panel, Prefabrication and Prefabricated Building, Structurally Insulated Panels (SIPS), Timber Frame and Volumetric Modular Construction.

Findings

1. Desk research

Improvements in quality from using OC compared to traditional are cited throughout literature (Goodier and Gibb, 2005, Vernikos *et al.*, 2012). However, practitioners have sometimes reported problems with the quality of some products and their installation processes (Hanafi *et al.* 2010), in particular where they interface with on-site works. Lessons learnt from this are often not published as the parties involved may not be keen to highlight such errors.

The advantages and disadvantages of OC described in key literature in the area are summarised in Figure 1.

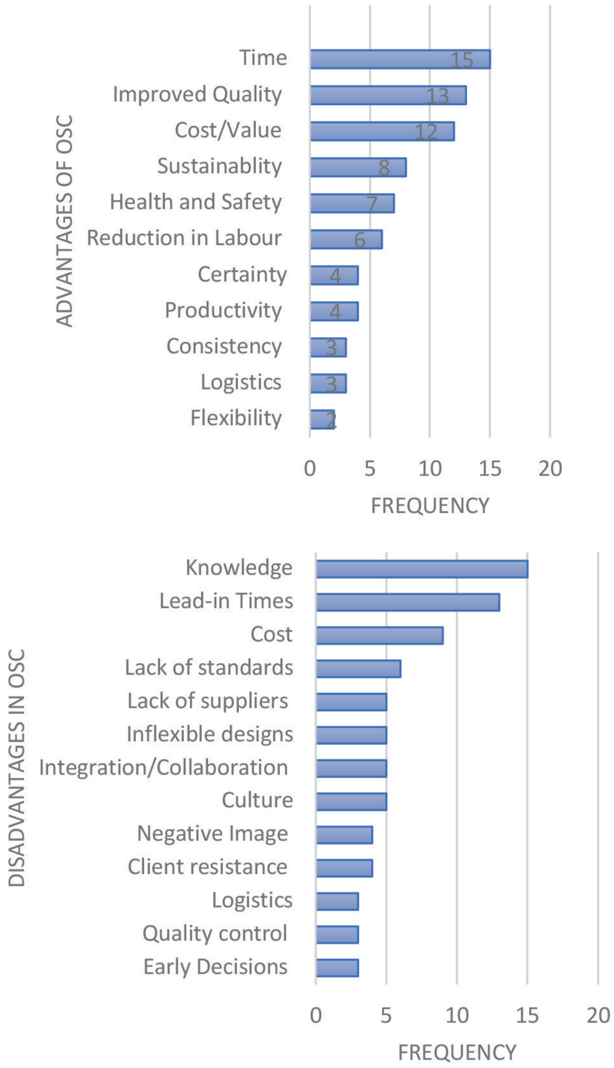

Figure 1 Advantages and disadvantages of (OC) in literature (Whitehead, 2018)

It is important to note the impact associated with lack of knowledge and lack of standards.

Long lead-in times, due to initial design development (Tam *et al.*, 2007) and manufacturing can delay a project's progress at the start (Goodier and Gibb, 2007). Blismas *et al.*, (2005) found the 'lack of early decisions' as the root constraint, as it reduces the time saving benefits associated with OC (Wong *et al.*, 2017).

Cost is often viewed as a hindrance due to the initial investment required in OC in manufacturing facilities, transport and onsite machinery (Goodier and Gibb, 2005, 2007, Tam *et al.*, 2007, Wong *et al.*, 2017). Late design changes within a project have also been cited as a difficulty of OC due to the additional cost incurred (Vernikos *et al.*, 2012). There are however, always additional costs when things change in traditional build projects, not just OC projects. This emphasises the importance of having more complete and better-integrated designs before the manufacturing and/or construction commences, which can be better enabled in recent years by BIM and other recent digital and manufacturing technologies.

The quality control required for OC has been cited as a constraint (Wong *et al.*, 2017), as without high levels of control, lower-quality products than in-situ construction can sometimes be produced. Some influential early reports within the UK construction sector suggested

[3] https://www.buildoffsite.com/content/uploads/2015/03/BoS-Glossary-of-terms-2013-web.pdf
[4] https://www.offsitehub.co.uk/glossary/

that one way to embrace innovative construction such as OC is to make greater use of standardised components (Egan, 1998).

Collaboration within UK construction is frequently berated as unsatisfactory (Farmer, 2016), due to the silo mentality of traditional trades (CITB, 2017), and its fragmentation is commonly criticised (Latham, 1994; Egan, 1998; HM Government, 2013; Farmer, 2016). All agree the consequence on the industry is in general negative, as it precludes innovation and research and development (HM Government, 2013). Fragmentation has been addressed in many prominent reports, which have encouraged the construction industry to work more collaboratively with one another (HM Government, 2013; Farmer, 2016). Within OC, collaboration is seen as crucial (CITB, 2017) due to the reduced flexibility onsite (Vernikos *et al.*, 2014).

Early contractor involvement is beneficial to help identify where OC can be used (Blismas *et al.*, 2005). Designers collaborating with suppliers also helps minimise contractor input, needs and expertise from being overlooked (Wong *et al.*, 2017), which in turn helps reduce wastage, defects and cost.

Interfaces

Pavitt and Gibb (2003) identified interfaces, joints and connections as the most common contributors to construction problems. Gibb (1999) categorised interfaces into: physical, contractual and organisational interfaces, whose management can have a significant impact on a project's success (McCarney and Gibb, 2012). OC allows for small tolerances by implementing high levels of quality control (Boyd *et al.*, 2013). This benefit can be sometimes lost however, through improper interface management (McCarney and Gibb, 2012) causing physical issues to arise.

Chen *et al.* (2008) found the lack of tolerance standards between trades to be the main reason for elements not fitting together. This reinforces Vokes and Brennan's (2013) findings of the requirement for a 'collaborative' environment to make the most of OC. Configuration management, enabled by BIM, is increasingly seen as a way of tracking components, and hence facilitating OC (Vernikos *et al.*, 2013).

Building Information Modelling (BIM)

BIM is an enabler of collaboration as it provides a platform to exchange information (Ezcan *et al.*, 2013). The use of BIM within a project also helps facilitate early contractor involvement (Vernikos *et al.*, 2014, Abanda *et al.*, 2017), which in turn can aid the implementation of OC.

BIM libraries provide a platform for companies to share their products in the form of BIM objects, helping ensure information associated with the product is correct within the model (Abanda *et al.*, 2017). However, sometimes too much or inadequate information is supplied through the BIM object, partly due to the lack of standards in terms of BIM object information content. This is needed so that manufacturers can provide sufficient information for design requirements at specific (RIBA) plan of work stages whilst not revealing commercially sensitive proprietary design and production information. It is also needed in a way that is structured so as not to repeat information throughout a BIM model each time a product or assembly is used. The competitive nature of the construction industry however, leads to many BIM objects being kept private (Abanda *et al.*, 2017). This enforces Vernikos et al"s (2014) statement that BIM only works "within a collaborative contractual environment".

Design changes can be detrimental once OC has begun fabrication (Robinson *et al.*, 2012, Vernikos *et al.*, 2012), due to the lack of flexibility (Nadim and Goulding, 2010, Vernikos *et al.*, 2013). Further to this, a 'lack of expertise' in BIM has been cited throughout literature as one of the main barriers of OC (Eadie *et al.*, 2013, Vernikos et al, 2013, Abanda *et al.*, 2017, Sun *et al.*, 2017), but as with any new technology or approach, this will improve over time.

2. Standards review

The identification and analysis of the current use of standards was carried out in order to learn what standards are used in this area, how they are used and how effective they are to enable BSI to understand any issues with their existing portfolio of standards in order to respond to industry needs through its many standing Technical Committees, and the stakeholder groups of which they are comprised.

Four KPIs were used to assess the standards currently being used for OC.

These are:

- Relevance: is the document written specifically for the OC sector?
- Level of consensus: what is the extent of participation and agreement involved in the document's development? (see Figure 1 below)
- Completeness: does the scope of the standard include all the elements deemed necessary for the task or are there gaps?
- Usability: level of clarity, applicability, and any barriers to the task

A detailed table of results of the standards review can be found in Appendix 4. Broad findings are given below.

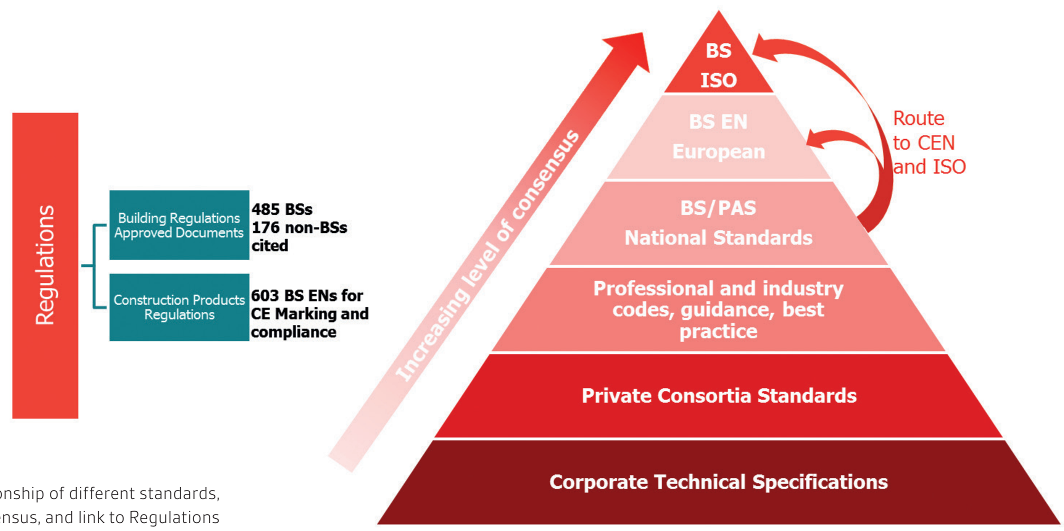

Figure 2 the relationship of different standards, their level of consensus, and link to Regulations

2.1 General Standards

Current British Standards covering the Built Environment sector are predominately (or even solely) designed for conventional construction and therefore do not sufficiently cover the issues encountered in OC.

Nevertheless a range of standards from a variety of sources: International (BS ISO), European (BS EN), National (BS and PAS), and industry standards are used for the design and construction of OC. Unfortunately many of them e.g. for the design of joints in buildings (ISO 2445:1972), tolerances and accuracy (BS 5606:1990 and BS 6954-1:1988) and modular co-ordination (BS 6750:1986) are considerably out of date and industry participants in this study expressed their view that some are limited and have not kept up with advances and developments in manufacturing and OC technology, in particular with regards to tolerances and onsite operations. Some however are currently being revised (BS 5606:1990).

Some general design management standards such as BS 7000-4:2013 do not specifically consider OC, hence whilst not actually excluding its use, potentially discourage it. Several ISOs on modular coordination exist, but do not seem to be greatly used by industry.

Other standards are beginning to appear for some forms of OC e.g. BRE's BPS 7014, and this could be a possible route for supporting other forms. Documents and initiatives from industry have also recently been developed in response to need (e.g. RIBA DfMA overlay, BOPAS).

2.2 Pre cast concrete Standards

Similar to in-situ concrete construction, precast concrete design is governed by the Structural Eurocodes (BS EN 1992), which are thought by some practitioners to restrict the application of OC in instances such as twin wall construction and at joints and connections.

Some product standards have been revised and updated to account for changes in manufacturing techniques and the introduction of new product ranges such as for precast cladding (BS 8297:2017). However, other standards, such as those for wall elements (BS EN 14992) and for hollow core slabs (BS EN 1168), are thought to also need reviewing.

Problems associated with dimensional tolerances and permitted deviations have been reported for some precast concrete standards. Some precast standards are 'informative' rather than 'normative', and therefore do not offer prescriptive guidance. New materials for use in concrete are being developed, and some of these developments are already being catered for e.g. alkali-activated cements covered by PAS 8820:2016.

In general, the precast concrete product standards are strong in providing information on dimensions, tolerances and the manufacturing process, but less so for construction and/or installation. Overall, they are "quite good for 'product' design, rather than 'structural' design". All the precast concrete product standards in general cover conformity, inspection and CE marking. Information on bearing stresses, bearing lengths and permitted deviations is generally missing. It is the stated intention of European Technical Committee CEN/TC 250 Structural Eurocodes to seek agreement to remove these items from BS EN 1992-1-1:2004+A1:2014, clause 10.5 (Tables 10.2 to 10.5) and refer the designer to product standards.

At present EN 1992 refers to BS EN 13369:2013 Common rules for precast concrete products, for bearing lengths, but the Standard only contains an allowable tolerance on length. (NOTE BS EN 13369 will shortly be revised)

2.3 Timber Standards

The structural design of timber is governed by Structural Eurocodes (BS EN 1995), which are used as the basis for most OC timber structural design. BS 5268-2 for permissibly stress design is also still sometimes used, despite being withdrawn in 2017.

It was noted that in OC, where more durability is required (e.g. during the transport and lifting stages) stronger boards are used. There are also special requirements for elements subject to humidity such as bathroom pods / floors / ceilings where moisture protection is required. Cementitious material (in addition to gypsum) based construction boards incorporating reinforcing fibres also need to be considered in these circumstances.

There is little in the way of formal Standards in this area and industry currently uses a variety of documents from different sources for the design of SIPS and CLT including the Structural Timber Association (STA), European Organisation for Technical Approvals (EOTA), British Board of Agrément (BBA). Many CLT manufacturers are based in central Europe and Scandinavia and therefore rely on the research and assessments conducted over many years by their local institutions.

BS 4978:2007, covering softwood strength grading, was identified as being used but it was noted that tolerances are sometimes not sufficiently tight. A draft European standard (prEN 14732) covering prefabricated timber elements was viewed as being potentially useful, but work has been abandoned due to a lack of consensus in committee.

Respondents stated that there is no standard for factory process, and they rely on Quality Management System standards such as ISO 9001:2015. Respondents further said that there is a clear gap that could be filled by an OC timber standard in the UK, and that "a BS kit build specification could be useful". Alternatively a new standard based on the abandoned prEN 14732 and Quality Management Systems could be developed.

2.4 Steel Standards

The structural design of steel is governed by the Structural Eurocodes (BS EN 1993) and structural product standard (BS EN 1090). These are used as the basis for OC steel design and fabricated elements such as service risers, panels and whole modules. These were reported to be adequate for the design of individual members, but are not comprehensive or complete for the additional requirements of whole modular design (e.g. for robustness, diaphragm action, second order effects, disproportionate collapse, fire design etc.), for connecting together OC components such as panels and modules, or for designing composite structures (e.g. a steel frame with a concrete core).

Some withdrawn standards for steel structures appear to continue to be used by industry (BS 5950-1:2000), while other standards are being used inappropriately (e.g. from the timber sector). It is understood that some design consultancies have developed their own specifications and have adopted tighter dimensional tolerances, which are more cost effective in the overall context of the build.

Industry standards such as the Steel Construction Institute's SCI P402 and previously P302 are also used for steel panel and modular.

Comments on the National Structural Steel Specification (NSSS) suggested that the tolerances and deflections might be excessive compared with offsite manufactured products, systems or elements and therefore may not facilitate OC.

Issues were noted around stability for lightweight structures and the fact that there is little information on how to analyse X-braced frames or frames / modules using the diaphragm action of boards. Guidance on robustness for modular systems was also noted as lacking.

2.5 Composite buildings Standards

No design guidance was found to exist for composite buildings and industry is currently using a combination of materials standards such as Structural Eurocodes for concrete (BS EN 1992) and steel (BS EN 1993). The mixed use of concrete cores and steel structures was stated as being potentially problematic because the steel (used for the structure or assembly of modules) is more dimensionally accurate than the concrete core, so allowance for deviations need to be considered. Many of the connections of offsite constructed steel modules to on-site plates cast into the in situ concrete are welded on site. The overall composite structure can be overdesigned and hence inefficient and wasteful.

Clear gaps in guidance for calculations were noted around the inter-connectivity of 2D (panel) and 3D (module) components; diaphragm action of different types of boards and combination of boarded walls and X-bracing based on their relative stiffness. Designers sometimes use timber standards to calculate the diaphragm action in light steel or modular buildings due to the aforementioned lack of guidance in steel standards.

2.6 Building Information Modelling (BIM) Standards

The Standard for library objects for architecture, engineering and construction (BS 8541) is published in six parts. In principle the Standards can be used for OC however tolerances are an issue. BS 8541 also asks for a level of detail regarding finished components/ products which offsite manufacturers may not want to disclose in order to protect their intellectual property and commercial advantage, so these standards could be considered a potential barrier to OC.

In other industries limited information is provided about the composition of an assembled sub-product or how it is made. For the construction industry one solution could therefore be the incorporation of more groups of assembled components that could provide useful shorthand and clarify what is essential to communicate to designers, owners and maintainers, whilst enabling product manufacturers to protect their intellectual property. The terminology and symbols could be extended to cover sub-assemblies, assemblies and buildings / structures.

The question of testing is also an issue for OC whereby in house testing could be satisfactory and external independent testing of every product variation may severely limit product development.

2.7 Other non-BSI standards

RIBA Plan of Work 2013 Designing for Manufacture and Assembly (DfMA)[5] . This is focussed on design but covers many forms of OC. It is complete with regards to the through-life process of design and construction, but does not mention other standards. It is useful to help the architect (and client) consider at which stages DfMA (or OC) needs to be considered, from initial client discussions, through design, to final construction, handover and use. It also covers suggested BIM tasks.

BOPAS (Buildoffsite Property Assurance Scheme)[6] *and Guidance document.*This is a certification scheme that was developed with Buildoffsite, RICS, Lloyds Register, BLP, Allianz, banks. It can be applied to most forms of OC. To date, there has been a wide take up in the housing sector. There are twenty-three products / technologies currently approved in the UK and eight under assessment (per BOPAS website 12/09/18). The majority are volumetric modular systems.

BRE Product Standard, BPS 7014, Standard for Modular Systems for Dwellings[7]. This is a draft industry product standard which was issued in April 2018. The BPS is set to provide a route to certification for modular systems for use in the construction of residential buildings. According to BRE, "BPS 7014 will complement existing sector standards and initiatives, such as those being explored with Buildoffsite"[8].

3. Issues raised by industry

The following provides some of the commonly held views that were raised during the engagement and workshop discussion phases of the project, which were naturally wide ranging.

They do not necessarily represent a consensus of opinion.

3.1 Common design standards and design management

Design needs to be flexible, coordinated, open and collaborative. Considering offsite in the design stage is essential, and there must be consideration for the system employed, its manufacture, and assembly. Some clients and developers however, noted that there can be a risk in too early a commitment to a particular system.

Conversely manufacturers need to better address design needs such as design flexibility, assembly with other elements, and use of technology such as BIM.

It was felt by some that a complete rethink of the existing design process, for example using Systems Engineering methodologies, could benefit OC.

3.2 Whole life performance of buildings

Observations concerning OC's ability to deliver as effectively as traditional build included the need for systems to achieve the required design life in practice. Buildings need to be high quality and durable, with any potential defects or damages from poor design, fitting or transport minimised and rectified.

Particular issues raised included the need to address any damage during transport and onsite storage. Adequate control measures, including return and repair procedures are not always in place.

Maintenance and repair of elements and end of life considerations were also raised as needing to be addressed.

3.3 Knowledge sharing

Comments from industry highlighted the view that the construction sector, including the offsite sector, does not share knowledge and expertise sufficiently well, and thus does not capture learnings effectively. This is vital for any new or expanding sector.

[5] https://www.ribaplanofwork.com/
[6] https://www.bopas.org
[7] https://bregroup.com/wp-content/uploads/2018/04/Overview-of-DRAFT-BPS-7014_Standard-for-Modular-Systems-for-Dwellings_24.04.18.pdf
[8] https://bregroup.com/expertise/innovation/offsite-construction/

It was noted that elements of offsite components are often subject to IP therefore the composition of elements are not shared. This was considered to be of potential concern regarding some behavioural aspects such as fire performance.

Further comments however, noted that the combination of component fire performance data does not necessarily represent the performance of an assembly containing them. Whole assemblies need testing in their own right and requirements for that may need to be established.

3.4 Communication and coordination

Good communication, understanding and coordination across all parties, including the client, designer, manufacturer and contractor/ installer, were considered to be essential. Concerns were raised around poor configuration management (including change / concession management) and a poor understanding of the process capabilities of different manufacturers. The potential disconnect between the client and design decision making was also an item of concern.

BIM is believed to have the potential to help in this area but only if it is used properly.

3.5 Integration

Problems around integrating different materials, systems, and/or modules were highlighted. The lack of standardised connections across different manufacturers was noted, as was the observation that this exists even across systems of the same material. This particularly affects onsite assembly teams.

It was further noted that offsite elements do not always perform in an integrated way. This was considered to be not just a manufacturing but a process issue. Examples included window fitting, risks arising from use of incompatible materials leading to problems such as corrosion problems in pipework systems, and a lack of robustness connecting volumetric modules.

3.6 Fitting tolerance

Tolerances were the subject of significant debate among consultees who highlighted interfaces between the module and substructure, structural frame, cladding or other modules as potentially problematic. There were reports of clashes and/or fitting problems due to a lack of agreed codes of practice along the supply chain from design to construction.

It was broadly accepted that installation tolerances in offsite workmanship are significantly tighter than those set for onsite techniques. Nevertheless areas of concern included the dimensional accuracy of substructures, modular unit to service connections, a lack of understanding of what is control critical regarding the offsite-onsite interface, and the way volumetric systems fit together, in order to ensure necessary functionality such as plumbing access and effective fire stopping.

4. Long term Industry goals

When asked about long term goals for the industry, workshop participants highlighted the following with regards to offsite construction.

4.1 To be better-equipped and informed

The industry focus should be less on single technology and more on hybrid/composite structures (not steel vs. timber vs. concrete etc.) and allow the use of interchangeable (modular) units, from multiple manufacturers.

Bases should be set for establishing market acceptability for new products and systems, including full disclosure of performance tests. Products and systems that are derived from performance based specifications enhance control of delivered products.

4.2 To be more collaborative and open

Genuine collaboration between competitors would drive innovation for the common good e.g. by standardising connection details. This would also enable shared learning so that known problems are not repeated and continuous improvement can be achieved.

Establishing an environment in which informed clients share offsite knowledge would act as a catalyst to support the sector.

Co-operation with organisations developing initiatives such as component library and pattern book approaches should be encouraged. Working with the NSCS[9] and NSSS[10] would help to ensure "right-first–time" fits.

4.3 To be a faster, safer, more innovative industry

Industry needs to be confident that OC is fit for purpose and durable. This will enable it to become an accepted option for the delivery of a construction project.

The construction industry will be safer as a result of more construction taking place in well-organised factories rather than construction sites which have more inherent risk.

There will be more automation such as

- Automated compliance checking (using BIM + AI)
- Guides for offsite testing and prototyping

as a result construction projects will be delivered more quickly and in a more streamlined (smarter) way.

[9] National Structural Concrete Specification (NSCS)
[10] National Structural Steelwork Specification (NSSS)

Conclusions and Recommendations

General conclusions

The initial desk research phase identified a number of issues preventing the growth of OC. Lack of standards is one of them. The perception of higher cost; a lack of quality control; poor collaboration along supply chains; and problems with interfaces were also identified. The fact that the construction industry is undergoing considerable change as a result of the implementation of BIM Level 2 should also be acknowledged as having an impact.

The lack of general standards was confirmed in the detailed standards review phase. Many of the formal standards that exist are considerably out of date and there is very little new standards development taking place in this space. Even relatively new standards, such as those for BIM, are not addressing OC requirements. As a result industry is using standards written for the traditional building sector, or industry guidance where it exists, or using no standards at all.

Some material sectors are doing more in this area than others. The precast concrete sector has most developed standards. The steel sector is using existing structural Eurocodes and structural product codes alongside some industry guidance. The timber industry has fewest developed standards and is using industry guidance for the most common elements (SIPS and CLT), or taking the European technical approval route to CE mark individual products.

The engagement and workshop phase of the research explored the need for standards and identified key gaps where standards could help industry to overcome some of the issues noted above.

The detailed conclusions have been categorised into four broad themes: design; accuracy and tolerances; integrations and connections; terminology and knowledge sharing. Within these areas there are a number of activities that BSI can undertake to help overcome barriers to the increased take up of OC. These are laid out in the recommendations.

Design

The design phase of a project is where consideration of OC solutions can ensure the most benefits and discussions between practitioners and clients at the earliest stages will enable this. These early discussions need to address a number of aspects for which design teams are not necessarily equipped. There is no standardised process in place although the RIBA Plan of Work DfMA provides very useful guidance. Existing standards for managing design such as BS 7000-4 do not currently include specific references to OC, which could act as a discouragement to its use.

Unique to OC are the different logistical and transport issues that OC creates and thought needs to be given to these during the design stage. Modular buildings and prefabricated elements must be able to withstand the additional forces and pressures imposed during transportation and lifting. These are currently considered on a case by case basis.

Where OC solutions are agreed for a project, the question of which offsite system to use arises. Current practice is to commit early to a particular system and carry out a design for manufacture and delivery. This early commitment can increase risks around delivery which can jeopardise a project if a particular supplier is unable to fulfil the contract.

Further issues pertaining to the relationship between design and manufacturing were identified as follows.

The recent evolution of the BS 8541 BIM standards has generally been helpful with respect to OC. That said the requirements on product manufacturers appear to demand much more disclosure of intellectual property (IP) than is required in other product manufacturing industries such as automotive or consumer electrical goods. This is a particular issue with assembly manufacturers and could act as a potential barrier to the ongoing development of OC solutions in construction.

Similarly, if the designs are owned by the ultimate client, it may be difficult to realise the full savings if they are not willing to invest in production tooling or incentivise suppliers to do so.

There is currently a lack of clarity around factory acceptance testing of OC elements and whether factory testing can be used to reduce subsequent testing at the installation and commissioning stages i.e. to demonstrate compliance with building regulations or clients' specifications. Research may be needed into the maintainability of performance during transport and installation.

Finally, questions were raised regarding in use design, in particular whether sufficient consideration is given to maintenance and repair of OC buildings and elements. Good OC design should identify the components requiring maintenance (as well as those that do not), and supply guidance regarding how this could be achieved.

Accuracy and tolerances

Tolerances are the subject of significant debate within the OC industry. It is widely accepted that OC can be more accurate than traditional build but issues remain. There were numerous reports of clashes and fitting problems from design through to construction and installation.

Out of date standards was cited as the main cause. Current standards simply do not address the recent advances in BIM, DfMA, improved manufacturing accuracy, increased measurement and surveying equipment capabilities and on site advances.

As a result the standards are rarely used. It was reported that tolerances were not necessarily agreed by parties or they used differing standards or guidance. Alternatively manufacturers sometimes establish their own tolerances and accuracy requirements.

More up to date guidance is required for identifying and specifying the tolerances that are critical for offsite assemblies / products.

The following interfaces were identified as needing particular consideration:

- substructure/foundation to module*,
- module to module,
- module to structural frame, and
- module to cladding.

(* NOTE In this context modules may be volumetric, panelised, or skid mounted)

As it stands, if designers do not specifically identify and quantify the critical tolerances, the tolerances in existing standards may not be compatible with the assemblies and products supplied.

Integration and connections

Problems around integration were widely voiced during the research. The difficulty of integrating different materials, systems, and/or modules, from different suppliers into a common building was cited as a key issue.

The connections between components, systems and/or modules supplied by different manufacturers are problematic even when the same materials are used, but more especially when combining different systems or materials (e.g. SIPS, CLT, steel, precast concrete etc.). This is because suppliers usually use individual bespoke, and hence incompatible, connections.

This issue applies both to structural members and elements and to non-structural e.g. pod assemblies, or flooring.

When it comes to building services some aspects are well developed for OC such as modular wiring and service risers. However connectors sometimes do vary, as sometimes does the coordination of different services. Pipework is widely assembled offsite, e.g. pipe racks and service risers, but examples of poor standardisation have been reported. There is a lack of guidance for connecting pipework and cables between modules. In particular volumetric modules may need a continuous cable to be used for sections of, for example, a fire safety system.

Terminology and Knowledge sharing

The construction sector does not share knowledge and expertise sufficiently which, given the different supply chain relationships becomes more important in the OC sector compared with traditional on site construction.

The terminology applied across OC is currently fragmented and inconsistent due to the standards being old and out of date and new initiatives and experience giving rise to new terminology. Discrepancies exist across different standards makers as well as across the main material sectors and components suppliers. This is confusing for industry.

Recent industry guidance such the RIBA Plan of work 2013 DfMA and the Buildoffsite Glossary of terms are helping in this regard.

Further developments such as the platform approach to offsite, defining "pre-manufactured value" of OC, and increasing use of digital manufacturing techniques, will inevitably generate new terms and definitions which will need to be agreed and disseminated widely.

General Recommendations

A number of issues around existing standards and their usability for OC have arisen. It is important to identify where reference to OC and consideration of particular OC requirements could and should be included in the existing portfolio.

A formal review of the existing, out of date standards is needed so that appropriate action can be taken. Further engagement with standards makers from the materials sub-sectors is needed to review the findings highlighted by the research, to verify them and to explore solutions to the gaps, barriers and other issues that have been identified.

Work with the BIM Standards community is especially important as increased use of OC is one of the key enablers for increasing productivity alongside digitalising the industry. The issue around product information is something that could be quickly explored.

Design

OC imposes different considerations on the design community. A process Standard for design teams and their clients, providing guidance and recommendations for the early design stages and supply chain relationships would fill a clear gap in the market.

BSI is currently in discussions with HTA Design LLP to develop a new Standard for the design and procurement of generic offsite systems for large scale residential development. The Standard aims to assist designers to support clients in setting procurement pathways from early in the development cycle which enable them to better capture the speed and quality benefits of OC without becoming over committed to the use of a single supplier prior to achieving a planning permission. This is achieved by making clear early decisions which help deliver scheme designs suited to a range of OC options. The scope is currently limited to modular volumetric offsite systems, closed panel offsite systems and open panel offsite systems. This work could form a basic framework allowing for further parts and additional system types to be developed as needed.

Issues around the performance of OC, its testing, and maintenance needs further investigation with the industry and the relevant regulatory authorities. BSI can work with external stakeholders to address these aspects and to identify where standards solutions can provide the necessary support.

Accuracy and tolerances

Many of the problems in this area can be resolved by standards. Out of date standards, originally written for traditional build, need to be withdrawn or revised to ensure they are applicable to current industry needs. New requirements need to be agreed and established to include the recent advances in improved accuracy and measurement techniques. It is vital for the industry to have an agreed, usable standard they can specify to avoid incompatible assemblies and products causing problems on site.

Industry concerns that this could put the sector at a disadvantage to the traditional building industry, which is likely to continue to be asked for lower tolerances need to be addressed in any standards development.

Integration and connections

Standardised connections for OC elements would bring significant benefits to the wider industry. It would increase flexibility for design, reduce risk and enhance maintenance delivery. It would help to resolve potential resistance to pattern book approaches as it would allow different elements and assemblies to be integrated through the use of common connections.

There are a number of issues with standardising in this area including potential resistance from individual manufacturers and across the different suppliers.

It is important to take a pragmatic approach and work with the client and design communities to understand their needs in detail. It will then be necessary to work with the supply side to look at material sectors and assembly suppliers to start to explore where standards may be acceptable. It will be useful to understand, where feasible, the level of commonality and best practice that already exists in order to identify the least disruptive, key aspects to facilitate OC. From a standards development perspective, this is what leads to a broadly accepted, consensus outcome.

Specific areas that were identified for early consideration include:

- sets of common connection designs in order to specify an agreed set of considerations such as loading and other actions
- designs and locations or floor interface specifications for bathroom pods for use across different buildings types and sectors (e.g. hotels, hospitals, prisons, airports, student accommodation, residential buildings etc.)
- better guidance for connecting pipework and cables between modules, in particular volumetric modules. For example, a continuous cable may need to be used for sections of a fire safety system.

Terminology and Knowledge sharing

A need and opportunity exists for a more comprehensive and pan-industry approach to terminology. A new Standard would be subject to review and amendment enabling ongoing updates to be added as necessary. Such a Standard should be widely available, free at the point of access in order to maximise dissemination and use.

Work is required with the OC and BIM community to review the information required within (BIM) libraries, and in what format, to gain agreement and consensus across OC stakeholders. Recent BSI activity on product data templates needs to be reinstated to look at this activity.

Guidance on collaboration between clients, designers and manufacturers with respect to IP ownership and management could be helpful to ensure sustainable, repeatable productivity benefits are delivered and improved upon over time.

Appendix 1 Standards

General

ISO 1006:1983	Building construction. Modular coordination. Basic module
ISO 1040:1983	Building construction. Modular coordination. Multimodules for horizontal coordinating dimensions
ISO 6513:1982	Building construction — Modular coordination — Series of preferred multimodular sizes for horizontal dimensions
ISO 6512:1982	Building construction — Modular coordination — Storey heights and room heights
ISO 6514:1982	Building construction — Modular coordination — Sub-modular increments
ISO 2445:1972	Joints in building — Fundamental principles for design
BS 5606:1990	Guide to Accuracy in Building
BS 6954-1:1988	Tolerances for building. Recommendations for basic principles for evaluation and specification
BS 6750: 1986	Specification for modular coordination in building
BS 7000-4:2013	Design management systems. Guide to managing design in construction
RIBA 2013	Plan of Work DfMA Overlay
BOPAS	Buildoffsite Property Assurance Scheme
BPS 7014	BRE standard for Modular Systems for Dwellings
Buildoffsite	Glossary of Terms 2013

Concrete

BS EN 1992	Eurocode 2 Design of concrete structures
BS EN 1991-1-1:2002	Actions on structures. General actions. Densities, self-weight, imposed loads for buildings
BS EN 13369:2018	Common rules for precast concrete products
BS EN 14992:2007+A1:2012	Precast concrete products - wall elements
BS EN 1168+A3, 2011	Precast concrete products - Hollow core slabs
BS EN 14843:2007	Precast concrete products - Stairs
BS EN 13747:2005	Precast concrete products – Floor plates for floor systems
BS EN 15037-1	Precast concrete products – Beam and block flooring
BS EN 13224:2004	Precast concrete products – Ribbed floor elements
BS EN 13225:2013	Precast concrete products - Linear structural elements
BS EN 13670:2009	Execution of concrete structures
BS 8297:2017	Design, manufacture and installation of architectural precast concrete cladding. Code of practice
PAS 8820:2016	Construction materials. Alkali-activated cementitious material and concrete. Specification.

Timber

BS EN 1995-1-1:2004+A2:2014	Eurocode 5: Design of timber structures. General. Common rules and rules for buildings
prEN 14732 (work abandoned)	Timber structure – prefabricated wall, floor and roof elements – requirements
BS 5268-2:2002	Structural use of timber. Code of practice for permissible stress design, materials and workmanship
BS 4978:2007+A2: 2017	Visual strength grading of softwood. Specification

EOTA TR 019, Technical report	Calculation models for prefabricated wood-based loadbearing stresses skin panels for use in roofs, 2005.
Structural Timber Association	Technical Bulletins 1 to 6.
Structural Timber Association	Engineering Bulletin. EB10. SIP Construction
Structural Timber Association	ADN 14.1 – 14.5. Advice notes.
EAD 130013-00-0304	Solid wood slab element to be used as a structural element in buildings
Structural Timber Association	Engineering Bulletin. EB11. CLT - An Introduction
European Technical Approval Guidelines	Timber frame building kits.
European Technical Approval Guidelines	Prefabricated building units

Steel

BS EN 1990: Eurocode	Basis of structural design
BS EN 1991: Eurocode 1	Actions on structures
BS EN 1993: Eurocode 3	Design of steel structures
BS EN 1090-2:2018	Execution of steel structures and aluminium structures. Technical requirements for steel structures.
BS 5950-1:2000	Structural use of steelwork in building. Code of practice for design. Rolled and welded sections
BS 6399-1:1996	Loading for buildings. Code of practice for dead and imposed loads
SCI P402 (2015), Steel Construction Institute	Light Steel Framing In Residential Construction

BIM

BS 8541-1:2012	Library objects for architecture, engineering and construction. Identification and classification. Code of practice
BS 8541-2:2011	Library objects for architecture, engineering and construction. Recommended 2D symbols of building elements for use in building information modelling
BS 8541-3:2012	Library objects for architecture, engineering and construction. Shape and measurement. Code of practice
BS 8541-4:2012	Library objects for architecture, engineering and construction. Attributes for specification and assessment. Code of practice
BS 8541-5:2015	Library objects for architecture, engineering and construction. Assemblies. Code of practice
BS 8541-6:2015	Library objects for architecture, engineering and construction. Product and facility declarations. Code of practice

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Appendix 3 Glossary of terms

Buildoffsite (2013) and the Offsite Hub publish a comprehensive glossary of terms, which has formed the basis for this work. Key terms used in this work include:

Offsite Construction: Largely interchangeable terms referring to the part of the construction process that is carried out away from the building site. This can be in factory or sometimes in specially created temporary production facilities close to the construction site (or field factories).

Module: These terms would imply a level of modular coordination. However, more commonly, they refer to volumetric building modules where the units form the structure of the building as well as enclosing useable space. The terms are also sometimes used to describe room modules, which do not incorporate their own superstructure. They are particularly popular for hotels and student residences due to the economies of scale available from many similar sized modules and the benefit of reduced site construction time.

Composite Construction (or Hybrid): A generic term covering a wide variety of construction techniques, particularly where two different materials are used in combination to fulfil a specific function. For example, composite floor slabs can compromise in situ concrete with profiled metal decking, which acts as structural reinforcement. These slabs are supported on hot-rolled steel beams. Often, the beams are composite themselves, using shear connectors (normally welded headed studs) to achieve structural efficient with good spanning capability. Composite Construction can also use pre-cast concrete slabs with a composite structural screed. Composite Construction is also known as Hybrid Construction.

Cross Laminated Timber (CLT): Increasingly popular as part of hybrid builds and multi-storey timber structures, CLT panels are precision-manufactured to any dimension and shape from single-layer timber boards then glued together at right angles to form large solid timber panels for walls, floors and roofing. CLT panels have huge structural potential and are suitable for most building types.

Design for Manufacture and Assembly (DfMA): In the construction industry, Design for Manufacture and Assembly (DfMA) involves improving quality through the application of efficiency. Finding the most efficient way of delivering a project reduces the resources required (whether this is measured in cost, time, carbon, waste or labour) while increasing positive aspects such as health and safety, quality, certainty. A DfMA solution can be achieved to a higher quality at lower cost and in less time. DfMA takes many forms, but the common factor is the application of factory (or factory-like) conditions to construction projects.

A DfMA solution starts by understanding the end product and draws upon the range of suppliers and systems and production processes available. Design for manufacture tends to simplify components. Design for assembly tends to combine components, make their assembly fool proof and lifting and positioning easy. Varying degrees of "granularity" can be added according to the project requirements. Volumetric solutions create as much of the finished product as possible in the factory, with on-site labour minimised. "Flat pack" or panelised create a kit of parts that can be quickly assembled on site. Often prefabricated sub-assemblies (M&E services, for instance) are deployed in conjunction with more traditional build elements. For some situations, traditional build elements may be used but the site is effectively turned into a factory. Pre-packed "fit out kits" are delivered to the work face with everything needed for the work. Waste is virtually eliminated, along with the most common causes of delay on site, i.e. lack of materials, follow-on trades and reworking. DfMA also allows for buildings to be deconstructed more safely, with components or even entire buildings able to be reconfigured or redeployed elsewhere. This is the ultimate form of sustainable construction.

Panel: A generic term describing a planar unit, typically manufactured offsite, which may or may not have a structural as well as have an enclosure function. Related terms: Panel Building System, Pre-cast Flat Panel System, Advanced Panel Timber Frame, Structurally Insulated Panels (SIPs)

Prefabrication and Prefabricated Building: This is a general term for the manufacture of entire buildings or parts of buildings offsite prior to their assembly onsite. Prefabricated buildings include both portable buildings and various types of permanent building systems. Offsite is now the more commonly used term for permanent buildings procured in this manner. Systems: CLT, Glulam, Hybrid, LGSF, MEP, Pods, Precast Concrete, SIPS, Timber Frame, Volumetric Modular

Structurally Insulated Panels (SIPs): SIPS are primarily a timber-based panel that consists of two parallel faces – usually oriented strand board (OSB) or cement-bonded particleboard – with a rigid core of polyurethane (PU) foam or expanded polystyrene (EPS) inside, SIPS are a cost-effective and energy-efficient solution to a wide range of building types and can provide airtight walls and roofs. SIPS panels also offer high levels of insulation due to the use of the in-filled material. Properly used, SIPS need no other structural frame supporting them. Systems: SIPS Components: Building Boards.

Timber Frame: Timber frame building can consist of wall panels, alongside floor and roof panels – often referred to as cassettes. These can also be open panel or closed panel. Open panels are timber frame wall panels, comprising studs, rails and sheathing on one face and a breather membrane. Closed panels also include linings on the faces of the panel, a vapour barrier and breather membrane. Closed panels may also include fitted windows, openings for doors and service routes. Manufactured in factory conditions, these cassettes and panels are brought to site and fixed together to form a rigid load-bearing superstructure. These consist of timber studs and beams, stiffened on one side with oriented strand board (OSB) and plasterboard.

Volumetric Modular Construction: Volumetric modular units are large building elements that can be linked together to form complete buildings without the need for additional superstructure. The internal fit-out, finishes and building services are pre-installed and commissioned in the modules prior to leaving the factory ensuring that defects are minimised and quality control is very high. The external façade, claddings and roof treatments are usually installed onsite. Volumetric units plant rooms or flexible living and working spaces. Applications include commercial offices, public buildings, hotels, airports, sport stadiums, hospitals, universities and schools.

Appendix 4 Standards Review

Standard number	Level of consensus	Relevance to OC	Completeness	Usability
ISO 1006:1983	ISO	Modular construction Applies to the design and construction of buildings of all types in accordance with the principles and rules of modular coordination laid down in ISO 2848.	Out of date Last reviewed and confirmed in 2015 therefore remains current, but will be replaced by ISO/CD 21723.	Establishes the value of the basic module for use in modular coordination of buildings.
ISO 1040:1983	ISO	Modular construction Applies to the design and construction of buildings of all types in accordance with the principles and rules of modular coordination laid down in ISO 2848.	Out of date Last reviewed and confirmed in 2009, therefore this version remains current, but will be replaced by ISO/CD 21723.	Modular coordination – Multimodules for horizontal coordinating dimensions. Basic value 1 M = 100 mm
ISO 6513:1982	ISO	Modular construction Applies to the design and construction of buildings of all types in accordance with the principles and rules of modular coordination laid down in ISO 2848.	Out of date Last reviewed and confirmed in 2013, therefore this version remains current, but will be replaced by ISO/ CD 21723.	Modular coordination - specifies preferred multi modular sizes for horizontal dimensions
ISO 6512:1982	ISO	Modular construction Specifies sizes of modular storey heights and modular room heights for all types of buildings in accordance with the principles and rules of modular coordination as laid down in ISO 2848 and ISO 6511.	Out of date Last reviewed and confirmed in 2013, therefore this version remains current, but will be replaced by ISO/ CD 21723.	Modular coordination - establishes storey heights and room heights for vertical dimensions of OC modular
ISO 6514:1982	ISO	Modular construction Applies to the construction of buildings of all types in accordance with the principles and rules of modular coordination as laid down in ISO 2848.	Out of date Last reviewed and confirmed in 2013, therefore this version remains current, but will be replaced by ISO/ CD 21723	Modular coordination — Sub-modular increments, for determining the distance between modular reference planes of a modular grid
ISO 2445:1972	ISO	Many forms of OC Basic principles for the design of joints in building. 3 properties: geometrical, structural and environmental properties of joints.	Out of date. There is scope for developing standards in the form of specifications for generic types of interfaces that could be used for connecting similar or different systems (e.g. floor to frame or wall / bathroom pod connection manifolds / pods to floors to name a few).	Numerous designers and builders have reported limitations in the standard for supporting the design and realisation onsite of joints and interfaces.
ISO/CD 21723	ISO	Aims to establish the values of basic modules, multi-modules for horizontal coordinating dimensions and sub-modular increments for use in modular coordination of buildings.	The standard also specifies sizes of modular storey heights and modular room heights, and series of preferred multi-modular sizes for horizontal dimensions for all types of building in accordance with general principles and rules for modular coordination.	Draft Standard in development not currently available.

Standard number	Level of consensus	Relevance to OC	Completeness	Usability
BS 5606:1990	British Standard	Most modular and OC Explains and provides examples of principles that relate to accuracy in building construction.	Out of date. Developed for on-site activity. The standard does not take into account the current state of the art re: surveying and in-factory measurement systems, nor provides guidance on the identification of critical dimensions for design integration. It also lacks details on the integration of mechanical and electrical services modules into buildings, which could reduce the need for framing such modules.	Limited, especially during onsite operations. Lacks guidance for identifying and specifying tolerances and accuracy critical for the integration of offsite assemblies / products. Designers need to identify and quantify the critical tolerances as the tolerances in existing standards may not be compatible with the assemblies and products supplied.
BS 6954-1:1988 Co-numbered ISO 3443-1:1979	British Standard	Most modular and OC	Out of date Incorporates tolerances achievable by pre-1979 manufacturing methods, with more basic automation and much larger dimensional accuracy requirements. The standard does not take into account the current state of the art re: surveying and in-factory measurement systems, nor provides guidance on the identification of critical dimensions for design integration. It does not provide for differing performance capabilities within supply chains, e.g. enabling the specification of tolerances that are achievable repeatedly by (say) the top quartile of suppliers of, for example, a structural system, thus reducing the need for the use of complex fixings or intermediate (secondary) structural members.	Suggestion by some building contractors that this does not satisfy the requirements for offsite construction. Lacks guidance for identifying and specifying the tolerances and accuracy that are critical for the integration of offsite assemblies / products.
BS 6750: 1986	British Standard	Modular construction Provides rules for modular reference systems used in the design of buildings; for the position of key reference planes; and for the sizing of buildings, their components and materials.	Out of date Limited to dimensions. Does not take into account the current state of the art with respect to surveying and in-factory measurement systems and provide guidance on the identification of critical dimensions when it comes to design integration. Lacks the integration of mechanical and electrical services modules into buildings, possibly reducing the need for framing such modules.	Due to poor collaboration and bad communication designers face complications when communicating with installers onsite as the design information is misinterpreted or ignored. This is supposed to be covered by BS6750. needs more on "structural movements and tolerances", even "BIM with cost and programme".

Standard number	Level of consensus	Relevance to OC	Completeness	Usability
BS 7000-4:2013	British Standard	General standard for all construction with no specific mention of OC. Provides guidance on management of the construction design process at all levels, for all organizations and for all types of construction projects. Covers the management of design activities throughout the life-cycle of a construction project, from the point when the client initiates a project.	Does not mention OC. Guidance could be added to ensure that designs are not taken to too detailed a level before the onsite / offsite or procurement method decisions are taken.	Could be reviewed from an OC perspective as offsite suppliers routinely have to re-design for modularity before they can tender for a job, which puts them at a disadvantage to traditional builders in terms of time to respond to tender invitations. Also to review how "systems engineering" processes, including "configuration management" could be incorporated into an enhanced design management process, compatible with Level 3 BIM and concurrent engineering.
RIBA 2013	Industry guidance	DfMA focussed, but covers many forms of OC.	Complete regards the through-life process of design/construction, but does not mention specific standards.	Useful to consider at which stages DfMA (or offsite) needs to be considered, from initial client discussions, through design, to final construction, handover and use.
BOPAS Scheme guidance document	Produced by RIBA, Bryden Wood, Buildoffsite, The Offsite Management School, RICS, Lloyds Register, BLP, Allianz, banks	Developed specifically for OC assurance. Wide take up in the housing sector. 23 products / technologies approved and 8 under assessment (per BOPAS Web site 12/09/18).	Guidance for BOPAS certification rather than a standalone document therefore lacks a minimum set of core requirements. Applicable to all OC, not restricted to volumetric modular products or systems.	Lack of core requirements means manufacturers are locked in to one scheme therefore may need to certify to multiple requirements set out by different schemes such as BRE, HSBC.
PAS Modular Housing Design Standard	Draft Industry product standard - in development	Initially modular/volumetric housing, steel and CLT.	The first version will be deliberately limited in scope to "steel-based volumetric modular systems for the housing sector". Subsequent versions will be developed to widen the scope to other offsite systems and materials, including SIPS and timber frame. It will cover design, structure, technical performance, environmental, services, site logistics, and commercial.	In development.
BPS 7014	BRE publication issued April 2018	modular systems used for residential buildings	The BPS provides a route to certification for modular systems for use in the construction of residential buildings.	Developed to complement existing sector standards and initiatives, such as those being explored with Buildoffsite.

Standard number	Level of consensus	Relevance to OC	Completeness	Usability
Glossary	Produced for Buildoffsite	Specific to OC	Last revised in 2013. May have some omissions relating to recent innovations.	Very relevant to OC. Some trade organisations use slightly different definitions of some terms but it covers a comprehensive range of offsite activities and systems.
European Technical Approval Guide 023	EOTA Guide	Prefabricated Building Units, designed as box-like structures but transportable to site in flat-pack or three-dimensional format.	The structural elements are prefabricated and assembled in a factory. They usually comprise a frame of metal, metal and timber or concrete. The Units may form a building individually or in conjunction, horizontally and/or vertically, with other units and rapidly provide a weatherproof envelope, possibly subject to final weathering, jointing between units, connection to services and any foundation connections.	Provides performance requirements against the Construction Products Regulations essential requirements for approval and certification.
PRE-CAST CONCRETE				
BS EN 1992	European Standard	Structural components e.g. all structural precast, including twinwall.	If the reinforcement requirements in the standard were amended more twinwall could be manufactured offsite.	Some users believe that the manufacture of offsite concrete products is restricted by EC2. More guidance is needed for precast interfaces and for BS 8597.
BS EN 1991-1-1:2002	European Standard	Structural components e.g. all structural precast, including twinwall.	Doesn't cover the mechanics at joints and connections where designers have to design as focus is on conventional construction.	Manufacturers have to figure out how to make and install it such that it matches the mechanical bearing of the conventionally designed. There is not a single source or any complete standard or code to deal with this issue.
BS EN 13369:2018	European Standard	All precast concrete products. Provides 'common rules', the precast product standards are written 'by exception' to EN 13369 i.e. they either accept what is in EN 13369 or have mirror clauses that elucidate or supersede those in EN 13369.	'Common Rules' ie has a lot on dimensions and tolerances, and manufacturing information but little on construction. Covers "unreinforced, reinforced and pre-stressed concrete products made of compact light, normal and heavy weight concrete". Does not consider or cover major areas of integration and assembly onsite.	The most useful section is on tendon slippage, which is often used in disputes between the manufacturer and the consultant. Annex A allows reduced cover compared with BS 8500-1 for certain elements, e.g. cover for exposure XC3 can be reduced from 25 mm to 20 mm if you satisfy certain compressive strength and water absorption requirements, but again it's 'informative' enabling a consultant to dispute it.
BS EN 14992: 2007+A1:2012	European Standard	Prefabricated (precast) walls, e.g. twin wall.	For normal or lightweight concrete prefabricated walls.	Issues sometimes exist with dimensional tolerances, wall cladding, performance.

Standard number	Level of consensus	Relevance to OC	Completeness	Usability
BS EN 1168+A3, 2011	European Standard	Precast slabs.	Includes requirements and basic performance criteria for precast hollow core slabs of pre-stressed or reinforced concrete. Covers terminology, performance criteria, tolerances, physical properties, test methods and transportation and erection. Lacks guidance on composite slabs, cantilevers and continuous construction, but then it is a 'product' standard.	Very useful for designers and manufacturers, but does not help site work very much, although there is some obvious guidance for filling joints and at ends. Fills gaps that BS8110 and EC2-1-1 leave, such as dimensioning the cross section (top flange, web thickness), spacing between tendons, vertical splitting and bursting stresses in narrow webs, torsion, punching shear, concentrated loads, fire resistance, lateral load distribution. A major problem is shear capacity in fire is 'informative' rather than 'normative'.
BS EN 14843:2007	European Standard	Precast concrete monolithic stairs.	Gives requirements for materials, properties, test methods, production of precast concrete monolithic stairs. Also covers precast concrete elements such as individual steps used to make reinforced and/or pre-stressed concrete stairs.	Surface finish/flatness and dimensional tolerances are sometimes problematic.
BS EN 13747:2005	European Standard	Precast concrete floor plates for floor systems.	No further information.	No further information.
BS EN 15037-1:2008	European Standard	Precast concrete beam and block flooring.	Provides requirements, test methods and evaluation of conformity for precast beams intended for use in structural floor and roof systems.	No further comments.
BS EN 13224:2004	European Standard	Precast concrete ribbed floor elements.	Little useful information in the main text, but lots of 'informative' annexes.	The best thing about this standard is Annex B on Minor Elements.
BS EN 13225:2013	European Standard	Precast concrete linear structural elements.	Identifies requirements, the basic performance criteria and evaluation of conformity for precast linear elements made of reinforced or pre-stressed normal or lightweight concrete for use in the construction of the structures of buildings and other civil engineering works, except bridges.	An improvement on 2004 version.
BS EN 13670:2009	European Standard	Precast concrete beams, slabs, columns etc.	Provides common requirements for execution of concrete structures and applies to in-situ work and prefabricated concrete elements, covering both permanent and temporary concrete structures. Looks at falsework and formwork, reinforcement requirements, prestressing, concreting, precast concrete elements and geometric tolerances.	No further information.

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BS 8297:2017	British Standard	Architectural precast concrete.	Covers design, manufacture, transport and installation. Revised in 2017 to account for changes in manufacturing techniques and product ranges introduced over the last 20 years.	Good. Includes more relevant tolerances and more accurate definitions compared to EN 14992.
PAS 8820:2016	Publicly Available Specification	Alkali Activated Cements are capable of being used to create precast products.	Could be extended to include composite uses e.g. in combination with Portland cement based concrete or other composite materials.	Currently undergoing review - initial feedback has been positive.
TIMBER				
BS EN 1995-1-1:2004 +A2:2014	European Standard	Most OC structures eg flat panel, SIPs, CLT, timber frame.	Applicable to solid timber, sawn, planed or in pole form, glued laminated timber or wood-based structural products, e.g. LVL or wood-based panels jointed together with adhesives or mechanical fasteners.	applicable to the design of buildings and civil engineering works in timber.
prEN 14732	Draft European standard abandoned due to lack of consensus	Flat panel construction - prefabricated wall, floor and roof elements.	Abandoned. A new approach is planned at CEN level, where new work items will cover: • prEN 14732-1 Structural elements with mechanically fixed sheeting made of wood based boards/ panels or gypsum boards/panels on both faces • prEN 14732-2 Structural elements with mechanically fixed sheeting made of wood-based boards/ panels or gypsum boards/panels on one face • prEN 14732-3 Structural elements with adhesively bonded sheeting made of wood based boards/ panels or gypsum boards/panels on both faces • prEN 14732-4 Structural elements with adhesively bonded sheeting made of wood based boards/ panels or gypsum boards/panels on one face	One respondent noted that it "would work well with different tolerances – just needs to be ratified".
BS 5268-2:2002	British Standard	Flat panel frame timber construction, floor cassettes, SIPs, glulam.	Withdrawn Standard (no longer maintained).	Still used by industry as provides guidance and recommendations for structural use of timber in load-bearing members including test method, design criteria, information on quality and grade stresses, workmanship and treatments which can be applied to OC.
BS 4978:2007+A2: 2017	British Standard	Timber frame, CLT	Provides two visual methods of strength grading softwood: general structural grade (GS) and special structural grade (SS). Not applicable to hardwood.	Lacks specification on how to realise acceptable tolerance e.g. the "tolerance is pretty loose – and can lead to conflict onsite"

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EOTA Technical report 019	European Organisation for Technical Approvals guidance	SIPS	Roofs only – provides calculation models for certification and CE marking of: stressed skin panels: • closed box type double-skin, without wooden ribs, with loadbearing insulation • closed box type double-skin, with wooden ribs and loadbearing insulation • open box type single-skin, with wooden ribs and loadbearing insulation • closed box type double-skin, with wooden ribs and non-loadbearing insulation or without insulation • open box type single-skin, with wooden ribs and non-loadbearing insulation or without insulation	Used by industry to design SIPS according to STA.
Structural Timber Association TB1-6	Industry guidance	SIPS	Design guides on structure, fire, acoustics, thermal, durability, sustainability.	Used by industry to design SIPS – no further comments.
Structural Timber Association EB10	Industry guidance	SIPS	Design guidance on SIP construction.	Used by industry to design SIPS– no further comments.
Structural Timber Association ADN 14.1 – 14.5. Advice notes	Industry guidance	CLT	Design guidance for detailing and installation of panelised CLT building structures.	Used by industry to design CLT– no further comments.
EAD 130013-00-0304	European Assessment Document	CLT	Generic performance requirements for approval and certification of solid wood slab element – element of timber boards jointed by dovetail connections made of sawn solid wood boards – between 2-6 layers – for use for walls, floors, roofs.	used by industry to design CLT– no further comments.
Structural Timber Association EB11. CLT - Introduction	Industry guidance	CLT	Design guidance on CLT construction.	used by industry to design CLT– no further comments.
European Technical Approval Guide 07	EOTA guide	Timber frame building kits	A "kit" being a special form of a "construction product" consisting of several "components" which are: - placed on the market together with one CE Marking - assembled on site and thus become an "assembled system" when installed.	Basis of approval and certification - used for timber OC.

Standard number	Level of consensus	Relevance to OC	Completeness	Usability
STEEL				
BS EN 1990		Used for OC e.g. service risers, modules and panels.	Mostly complete.	"Partial factors on vertical loading (1.5/1.35) are less than to BS 5950-1 but partial factors for lateral loads are higher which can mean stability is more problematical especially for lightweight structures".
BS EN 1993	European Standard	Used for OC e.g. service risers, modules and panels.	OK for loading, and adequate for individual member design.	Generally more conservative than previous BS 5950. "The problem arises in the stability design where sway effects have to be included explicitly in design to Eurocodes but there is little information on how to analyse X-braced frames or frames/modules using diaphragm action of boards. Also with modules, second order effects due to deviations in installation should be taken into account but no guidance is given on this." "There is no relevant guidance on robustness of modular systems so designers consider the case of selective removal of modules or parts of modules at the loads at the accidental limit state."
BS EN 1090-2:2018	European Standard	Used for OC e.g. service risers, modules and panels.	Focus is on mechanical resistance, stability, serviceability and durability. Sections cover specifications and documentation, constituent products, preparation and assembly, welding, mechanical fastening, erection, surface treatment, geometrical tolerances and inspection and testing.	"There is a need to address inaccuracies in manufacture and in installation, particularly of modular systems."
BS 5950-1:2000	British Standard	Used for OC e.g. service risers, modules and panels.	Withdrawn BS therefore not maintained. Provides recommendations for the design of structural steelwork using hot rolled steel sections, flats, plates, hot finished structural hollow sections and cold formed structural hollow sections.	Mentioned by an offsite designer who confirmed its use "if requested". "It can still be used. It's regarded as obsolete, as EC 3 is now predominantly used / requested". BS5950 is still accepted and is often used for relatively small buildings, with EC3 more used for more substantial/larger structures. Publicly-funded buildings however, including housing association buildings, have to be to Eurocodes. Some large clients also insist.
SCI P402 2015, Steel Construction Institute	Industry guidance	Steel frames - panels and modules mainly.	Guidance for overall design of light steel frames for residential.	Commonly used by industry – no further comments.

Standard number	Level of consensus	Relevance to OC	Completeness	Usability
Building Information Modelling BIM				
BS 8541-1:2012	British Standard	Assemblies or sub-assemblies. COBie is a requirement of UK central Government clients.	The COBie schema is for coding asset information to transfer design information into asset management systems that is usable at a detailed product level but less so at a sub-assembly or assembly level. Table D1 "IFC examples" does not currently contain large scale assemblies, e.g. types of plant room or a bathroom pod.	COBie is not an easy system to understand. Some (large) construction clients have their own asset information identification systems and do not use COBie. The standard is a "best practice guide" rather than a requirement for Level 2 BIM compliance.
BS 8541-2:2011	British Standard	OC could use most if not all of the 2D symbols described in this standard.	The terminology and symbols do not currently cover sub-assemblies, assemblies and buildings / structures. There is a lack of template definitions of attribute requirements for sub-assemblies and assemblies that could meet this standard. Further work is required on defining levels of detail of both graphical and other information at different project stages. It could include guidance on critical dimensions (and their tolerances) for integrating OC elements. Table 5 could include symbols for a range of standard (sub-assembly and assembly) module types.	Usable but the incorporation of more groups of assembled components could provide a useful shorthand, improve productivity and clarify what is essential to communicate to designers, owners and maintainers, whilst enabling product manufacturers to protect their intellectual property.
BS 8541-3:2012	British Standard	Relevant to OC as a guide to the development of objects for sub-assemblies and assemblies	The dimensional aspects need to refer to how to treat production tolerances, probably through references to other (revised) standards whilst permitting variations from these in a way that would take precedence over the generic standard for construction tolerances where necessary for the integration of OC.	It could be more usable if dimensional tolerance information were to be included for coordination purposes.
BS 8541-4:2012	British Standard	Relevant to OC as a guide to the development of objects for sub-assemblies and assemblies	The dimensional aspects need to refer to how to treat production tolerances, probably through references to other (revised) standards whilst permitting variations from these in a way that would take precedence over the generic standard for construction tolerances where necessary for integration of OC.	As above, it could be more usable if dimensional tolerance information were to be included for coordination purposes.