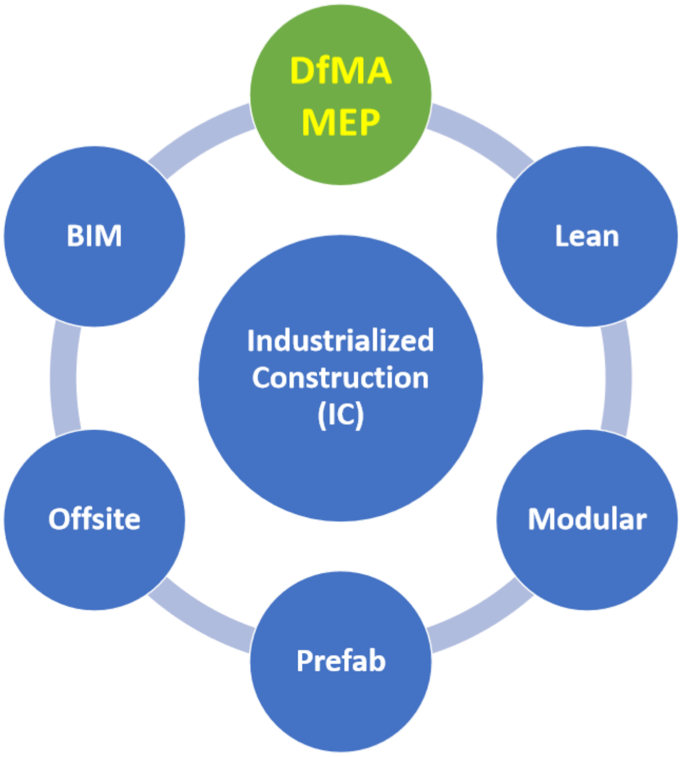
CONSTRUCTION
INDUSTRY COUNCIL
建造業議會



Reference Materials - Adopting DfMA for MEP Works

Prepared by:
AECOM Asia Company Limited

www.cic.hk

September 2021

Contents

Executive Summary

Design for manufacture and assembly (DfMA) refers to a set of principles for enabling a design process that facilitates the optimisation of all manufacture and assembly functions and contributes to the minimisation of cost and delivery time and the maximisation of quality and customer satisfaction. Originating from production industries, DfMA is considered a potential approach for the construction industry to enhance productivity, safety, sustainability and quality. It is also one of the key enablers for industrialised construction (IC).

This Guidebook aims to provide practical information for promoting the adoption of the DfMA approach to Mechanical, Electrical and Plumbing (MEP) works in Hong Kong. The optimal level of DfMA adoption for a project should be in response to the project-specific drivers including client's values and project key performance indicators (KPIs), sector category, supply chain capability, degree of repeatability possible, site/logistics constraints, etc. In order to offer guidelines for applying DfMA at different stages of projects, the structure of this Guidebook is designed based on the typical work stages of building projects in Hong Kong (as shown below). Also, information is provided about Multitrade integrated Mechanical, Electrical and Plumbing (MiMEP) which has come up in Hong Kong recently.

- Inception, Feasibility and Brief Development
- Concept Design
- Detailed Design
- Documentation and Tender
- Construction
- Handover and Post-Handover Services

It is believed that the use of building information modelling (BIM) in an integrated common data environment can drive the overall digital design and construction and streamline the DfMA work processes towards a more collaborative and integrated solution. At present, there is currently no universally accepted procurement model for DfMA. The project team members should collaborate to choose the best available procurement model option as an optimised and balanced solution after due considerations of various project factors. When applying DfMA offsite approach, it is necessary to consider best value rather than best price for the procurement strategy so that the key non-monetary benefits and full lifecycle costing are taken into account.

It is important to set KPIs for the project based on the client's objectives (e.g. shortened construction period compared to traditional approach), in order to discover benefits that can be gained by applying offsite and DfMA strategies to projects for manufacture, assembly and commissioning. The lead design professional and the specialist subcontractors appointed for the project will be required to explore and adopt innovative design and smart construction technologies to enhance construction performance holistically and to facilitate smart operation & maintenance for asset management. Most likely, this will include the use of offsite prefabrication solutions out of the DfMA spectrum (in particular, Modular integration Construction (MiC)) by fully utilising the BIM tool and lean manufacturing/construction principles (to maximise value and minimise waste).

Acknowledgements

Sincere thanks are expressed to the following bodies and organisations for providing information, useful ideas and/or comments for this study and the Guidebook.

Airport Authority Hong Kong
Architectural Services Department, Hong Kong
ATAL Engineering Group
BYME Engineering (H.K.) Ltd.
Development Bureau, Hong Kong
Dragages Hong Kong Limited
FSE Engineering Group Ltd.
Gammon Construction Limited, Hong Kong
Hilti (Hong Kong) Limited
Hip Hing Construction
Hong Kong Federation of Electrical & Mechanical Contractors Limited
Hong Kong Science and Technology Parks Corporation
Hospital Authority, Hong Kong
Housing Authority, Hong Kong
InnoTec Engineering Limited, Hong Kong
MTR Corporation
Paul Y. Engineering Group Limited
REC Engineering Co. Ltd.
Southa Technical Ltd.
Sun Hung Kai Properties Ltd.
The University of Hong Kong

AECOM, UK
AECOM Building Engineering Singapore
Bouygues Construction, Singapore
Bryden Wood, UK
Building and Construction Authority, Singapore
Crown House Engineering, UK
Dragages, Singapore
GRAHAM Group, UK
Hilti Group
Laing O'Rourke, UK
Gammon Construction Limited, Singapore
Prism Offsite Manufacturing, UK
SES Engineering Services Limited, UK
Specialists Trade Alliance of Singapore
The Garthfoot Consultancy, UK
Trans Equatorial Engineering, Singapore

List of Figures

List of Tables

List of Abbreviations

ACT	Advanced Construction Technology
AHU	Air handling unit
AR	Augmented Reality
ArchSD	Architectural Services Department, Hong Kong
ATIF	Assembling, transporting and installation frame
BCA	Building and Construction Authority, Singapore
BD	Buildings Department, Hong Kong
BDI	Boothroyd Dewhurst, Inc.
BEAM Plus	Building Environmental Assessment Method Plus
BESA	Building and Engineering Services Association, UK
BIM	Building information modelling
BMS	Building management systems
BS	British Standards
BSI	British Standards Institution
BSRIA	Building Services Research and Information Association, UK
CDE	Common data environment
CDP	Contractor Designed Portion
CHP	Combined heat and power
CIC	Construction Industry Council, Hong Kong
CITF	Construction Innovation and Technology Fund
CSD	Combined/coordinated services drawings
DEVB	Development Bureau, Hong Kong
DFA	Design for Assembly
DFM	Design for Manufacture
DfMA	Design for manufacture and assembly
ECI	Early Contractor Involvement
EOTA	European Organisation for Technical Assessment
FEHD	Food and Environmental Hygiene Department, Hong Kong
FSD	Fire Services Department, Hong Kong
FSI	Fire service installation
GB	Guo Biao (Chinese National Standards)
GBP	General building plan
GPS	Global positioning system
HAD	Home Affairs Department, Hong Kong
IC	Industrialised construction
JIT	Just-in-Time
KPI	Key performance indicator
LCSD	Leisure and Cultural Services Department, Hong Kong
LOD	Level of development
LOR	Laing O'Rourke, UK
MEP	Mechanical, electrical and plumbing
MiC	Modular integrated Construction
MMC	Modern Method of Construction
O&M	Operation and maintenance
OSC	Offsite Construction
OSM	Offsite Manufacture
PCWAs	Public Cargo Working Areas
PMV	Pre-manufactured value

PNAP	Practice Notes for Authorised Persons
Prefab	Prefabrication
RIBA	Royal Institute of British Architects
RRS	Runners, repeaters and strangers
T&C	Testing & commissioning
UK	United Kingdom
VR	Virtual Reality
VSM	Value stream mapping
WIP	Work-in-progress
WLP	Wide Load Permit

1. Introduction

Design for manufacture and assembly (DfMA) refers to a set of principles for enabling a design process that facilitates the optimisation of all manufacture and assembly functions and contributes to the minimisation of cost and delivery time and the maximisation of quality and customer satisfaction (Chen & Lu, 2018). Originating from production industries, DfMA is considered a potential approach with many benefits for the project clients and construction industry to enhance productivity and quality (Laing O'Rourke, 2013; McKinsey Global Institute, 2017).

1.1 Basic Principles and Benefits of DfMA

DfMA is a proactive design approach which focuses on ease of manufacture and efficiency of assembly to enable offsite manufacture (OSM) of high-quality construction components and efficient assembly of the components onsite for accomplishing significant improvements in productivity, safety, quality and sustainability. DfMA analysis focuses on product simplification, product costing and supplier costing to guide design decisions (BDI, 2018; Dewhurst, 2019) with the aim of using fewer design parts so that a broader product line can be created by assembling common "building blocks" modules into new products as modular design products. In general, DfMA is the combination of two design methodologies: Design for Assembly (DFA) and Design for Manufacture (DFM). Table 1.1 highlights the basic concepts of DfMA.

Table 1.1 Basic concepts of DfMA approach [adapted from BESA (2015)]

	Helps with	**Good for**
Design for Manufacture (DFM)	Simplifying component designs to make them easier to manufacture	Reducing component and product costs
Design for Assembly (DFA)	Reducing the number of components that make up an assembly and making their assembly easy and mistake-proof	Reducing assembly costs

Figure 1.1 illustrates the typical stages of a DfMA procedure (Boothroyd *et al.*, 2011). Table 1.2 shows the general DfMA guidelines and their benefits. The key characteristics of DfMA principles are minimisation, standardisation, and modular design (Gao, Jin & Lu, 2020). The DfMA procedure involves Design for Manufacture (DfM) and Design for Assembly (DfA), which are two parallel processes with interaction needed to arrive at the best design option, through optimising both manufacturing and site assembly costs from streamlining offsite production and onsite construction.

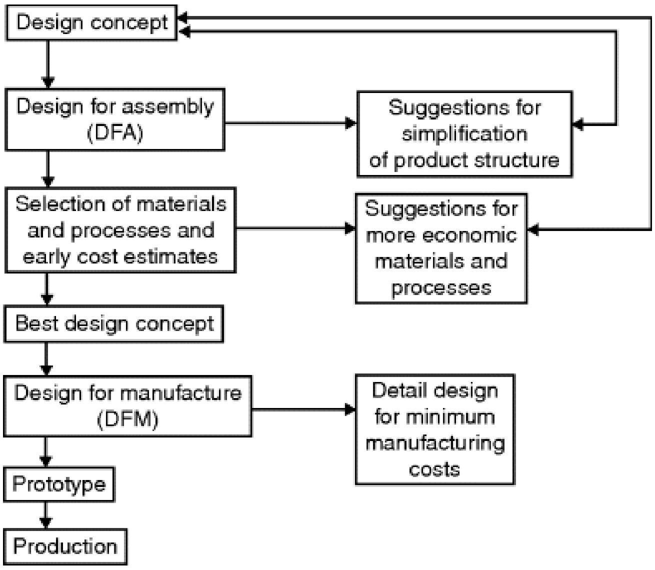


Figure 1.1 Typical stages in a DfMA procedure (Boothroyd *et al.*, 2011)

Table 1.2 General DfMA guidelines and their benefits (Bogue, 2012)

Guidelines	Benefits
1. Minimise the part count	Improved reliability, reduced purchasing and inventory costs, simplified assembly
2. Use standard, off-the-shelf parts rather than custom components	Reduced costs, lower purchasing lead times, potentially greater reliability
3. Minimise and standardise the use of fasteners/design for efficient joining and fastening	Reduced costs, simplified assembly, improved reliability, simplified repair and maintenance
4. Use as few dissimilar materials as possible	Simplified jointing, need for fewer manufacturing processes
5. Minimise the use of fragile parts	Cost reductions due to fewer part failures, easier handling and assembly
6. Do not over-specify tolerances or surface finish	Easier manufacture and reduced fabrication costs
7. Design for ease of fabrication	Cost reductions from the elimination of complex fixtures and tooling
8. Consider modular designs	Reduced costs due to simplified assembly and test
9. Aim for mistake-proof designs	Cost reductions by eliminating need to re-work incorrectly assembled parts
10. Design for simple part orientation and handling	Cost reductions due to non-value-added manual effort or dedicated fixturing
11. Design with predetermined assembly technique in mind	Cost reductions from use of proven/known techniques
12. Consider design for automated/robotic assembly	Potential cost reduction over manual methods

In principle, DfMA is a technique used during the product development and improvement process that aims to further an easy manufacturing and assembly costs reduction (Meeker & Rousmaniere, 1996; Molloy, 1998). DfMA provides a systematic procedure for analysing a proposed design from the point of view of assembly and manufacture. This procedure results in simpler and more reliable products, which are less expensive to assemble and manufacture. Basically, the DfMA objectives are to develop a product that meets all the functional needs and that is easy for manufacture and assembly. Three key objectives of DfMA are: (a) design for ease of subsequent processes, (b) automated offsite production, and (c) efficient & clean onsite installation.

The key benefits of applying DfMA in construction and MEP works include shorter construction period, reduced total cost of ownership for the client, improved workmanship and quality, less onsite construction works, improved project management, simplification by reducing unique building components, well-controlled and effective onsite assembly, better value with no cost overruns, improved safety and reliability. It is believed that there are many business opportunities for various stakeholders in the construction industry. However, to effectively apply the DfMA approach in Hong Kong, some barriers and challenges will need to be overcome.

1.2 Objectives of This Guidebook

This Guidebook aims to provide practical information for promoting the adoption of DfMA approach to Mechanical, Electrical and Plumbing (MEP) works in Hong Kong. It is written for practitioners with knowledge and experience in MEP works. While the content of the Guidebook covers building projects, the same principles generally apply to civil works projects. The terms, modules, assemblies and subassemblies are used interchangeably to refer to the products of DfMA.

It is hoped that the Guidebook can achieve the following objectives:

(a) Provide a knowledge sharing framework for long-term DfMA implementation strategy
(b) Assist the stakeholders to fully understand their roles and responsibilities
(c) Offer guidelines for applying DfMA at various stages of projects involving MEP works
(d) Facilitate the standardisation and quality certification for new processes and products
(e) Enable best practices, quality control, statutory and incentive enactment
(f) Serve as a living document to be updated throughout the transformation journey (to include new ideas, new concepts and new development)

1.3 Structure of This Guidebook

In order to offer guidelines for applying DfMA at various stages of a project involving MEP works, the structure of this Guidebook is designed based on the typical work stages of building projects in Hong Kong which resembles the stages defined in the RIBA Plan of Work (RIBA, 2016). Split into a number of key project work stages, the RIBA Plan of Work provides a shared framework for design and construction that offers both a process map and a management tool.

Figure 1.5 shows the DfMA overlay of project work stages to the RIBA Plan of Work. The core objectives of each stage and the important DfMA issues (including DfMA strategy, BIM tasks and procurement tasks) are indicated. The details will be described in subsequent chapters of this Guidebook. It is believed that the use of building information modelling (BIM) as an integrated common data environment can drive the overall digital design construction, and streamline the DfMA work processes towards a more collaborative and integrated solution (BCA, 2016).

Chapter 1 is the Introduction which explains the background, basic DfMA concepts and objectives of this Guidebook. Chapters 2 to 7 present the important considerations of DfMA adoption for each project work stage from the outset of a project to completion and the in-use stages for the physical building assets. Chapter 8 describes the latest information and development on MiMEP. Chapter 9 serves as the conclusion. The appendices are materials for easy reference and sources of relevant information. To allow a better understanding of the important terms and principles in this Guidebook, a Glossary has been developed and is given in Appendix 1.

1.4 Information Resources and DfMA Mindset

Across the globe, a lot of studies have been carried out on the application of DfMA and offsite technologies with the intention to transform or change completely the construction industry by applying manufacturing approach and management mindset to enhance productivity as well as safety and health for the workforces (Gao, Jin & Lu, 2020; Keung, 2019; Laing O'Rourke, 2013; Lu *et al.*, 2020). The following documents are identified and may serve as reference guidelines for a wider application of DfMA for MEP works in Hong Kong. Other resources for further reading can be found in Appendix 3.

- An Offsite Guide for the Building and Engineering Services Sector (BESA, 2015)
- DfMA: Prefabricated MEP Systems (BCA, 2018)
- Design Framework for Building Services (Churcher, Ronceray and Sands, 2018)

In Hong Kong, in recent years, the Government has been promoting the adoption of Modular integrated Construction (MiC) in the construction industry (DEVB, 2020) and some pilot MiC projects have been completed (Pan *et al.*, 2020). It is believed that MiC (an innovative construction method for achieving a building product delivery) and DfMA (a design approach for design and construction process management) can work together successfully to enhance productivity, quality and safety for the construction industry. Figure 1.2 shows the DfMA mindset and its major considerations for the construction industry (RIBA, 2016). For MEP works in particular, design for maintenance is crucial for enhancing lifecycle asset performance. As maintainability of MEP plant and equipment is crucial to ensure efficient operation and lifecycle performance of MEP installations, it is important to integrate maintainability concepts and making allowance for adequate access and working space for safety and easy maintenance in the upstream design processes, thereby promoting quality design with consideration of productivity, safety and labour efficiency in downstream maintenance activities.

1.5 Level of DfMA Adoption

The optimal level of DfMA adoption should be in response to project-specific drivers including client's values and project KPIs, sector category, supply chain capability, degree of repeatability possible, site/logistics constraints, etc. In general, the higher the level of DfMA adoption, the greater the standardisation efficiencies that are possible. DfMA is expected to have a wide range of applications, from one-off small-scale to large-scale construction projects, and can benefit both cast insitu and prefabricated construction methods (Wilson, Smith & Deal, 1999a & b). Table 1.3 illustrates three levels of DfMA adoption and their respective requirements. MiC is generally considered to be the highest level product in the DfMA spectrum.

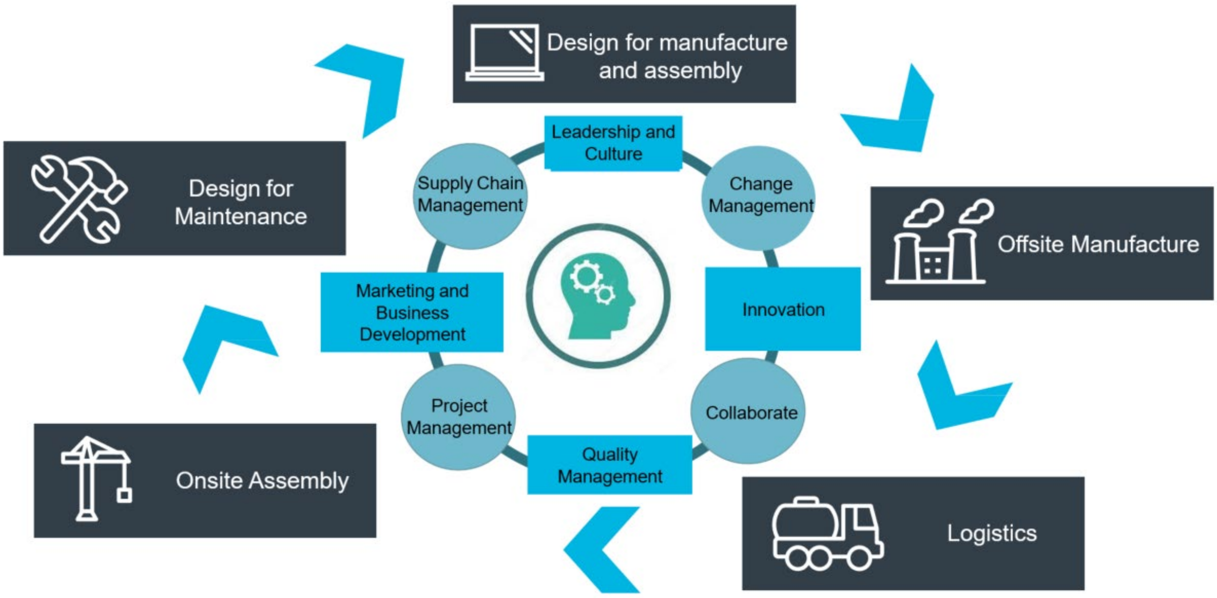


Figure 1.2 DfMA mindset and its major considerations for the construction industry

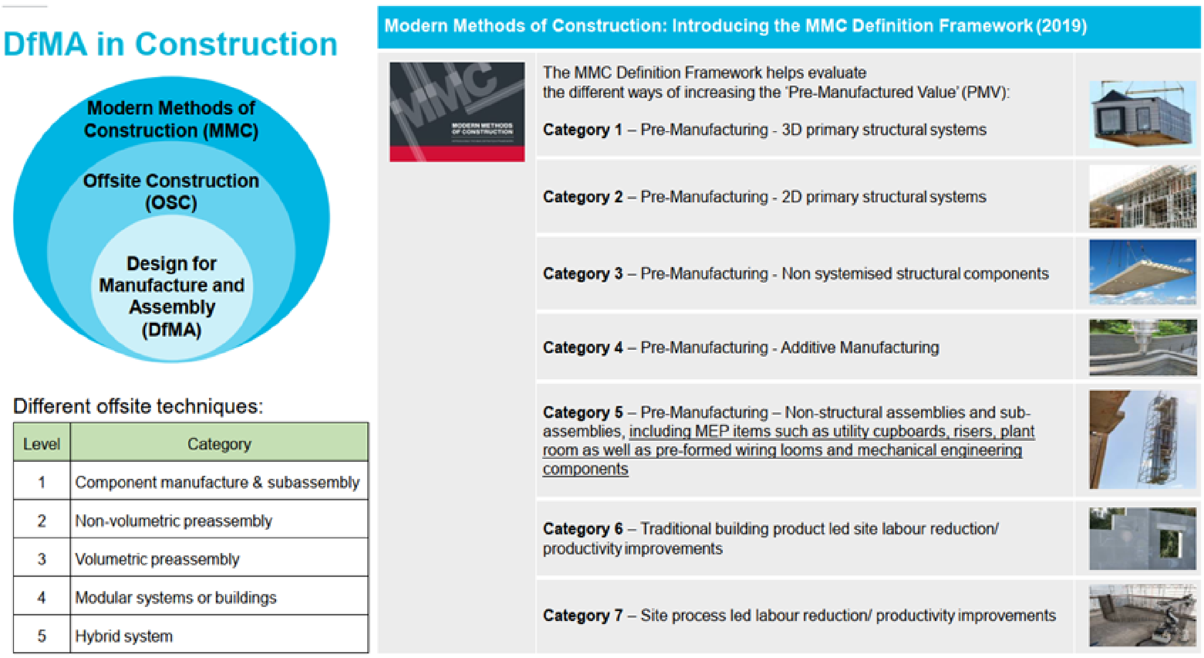
Table 1.3 Degree of DfMA adoption

DfMA Adoption Level	Description
Low level	A project might be delivered traditionally but with consideration given to the logistics and management of the construction process to adopt a "site assembly" type of approach where labour operates more efficiently and in teams. Standardisation in design may be considered to an extent. It is also possible to incorporate some DfMA elements in a project that is primarily traditionally delivered, e.g. prefabricated plant elements, prefabricated door sets or windows, etc.
Medium level	The design will be highly standardised and a significant proportion of the project will be delivered using offsite fabricated components.
High level	All or nearly all of the project is designed and delivered using prefabricated construction components with as high a degree of standardisation in fabrication as possible, procured from the supply chain in large quantities and efficiently assembled onsite.

It should be noted that adoption of DfMA and offsite methods is not a binary choice but a spectrum with different possible combinations (Keung, 2019; Liu, Nzige & Li, 2019). Table 1.4 shows different categories of offsite construction which can be considered when adopting DfMA. They are also defined under the modern methods of construction (MMC) definition framework from the United Kingdom (UK) (see Figure 1.3). To improve productivity, the MMC definitions have seven categories with increasing pre-manufactured value (PMV).

Table 1.4 Categories of offsite construction (Arif *et al.*, 2012; Gibb, 1999)

Category		Definition
1	Component manufacture & subassembly	Items always made in a factory and never considered for onsite production
2	Non-volumetric preassembly	Pre-assembled units which do not enclose usable space (e.g. timber roof trusses, flat panel units and panelised systems)
3	Volumetric preassembly	Pre-assembled units which enclose usable space and are typically fully factory finished internally, but do not form the buildings structure (e.g. toilet and bathroom pods)
4	Modular systems or buildings	Pre-assembled volumetric units which also form the actual structure and fabric of the building (e.g. prison cell units and hotel/ motel rooms)
Hybrid	Hybrid system	In addition to the Cat 1 to Cat 4 from Gibb, it is very often for a project to consist of a combination of any two or more volumetric or non-volumetric systems (extensively used in commercial and residential buildings)



DfMA in Construction

Modern Methods of Construction (MMC)

Offsite Construction (OSC)

Design for Manufacture and Assembly (DfMA)

Different offsite techniques:

Level	Category
1	Component manufacture & subassembly
2	Non-volumetric preassembly
3	Volumetric preassembly
4	Modular systems or buildings
5	Hybrid system

Modern Methods of Construction: Introducing the MMC Definition Framework (2019)

The MMC Definition Framework helps evaluate the different ways of increasing the 'Pre-Manufactured Value' (PMV):

Category 1 – Pre-Manufacturing - 3D primary structural systems

Category 2 – Pre-Manufacturing - 2D primary structural systems

Category 3 – Pre-Manufacturing - Non systemised structural components

Category 4 – Pre-Manufacturing - Additive Manufacturing

Category 5 – Pre-Manufacturing – Non-structural assemblies and sub-assemblies, including MEP items such as utility cupboards, risers, plant room as well as pre-formed wiring looms and mechanical engineering components

Category 6 – Traditional building product led site labour reduction/ productivity improvements

Category 7 – Site process led labour reduction/ productivity improvements

Figure 1.3 Modern methods of construction (MMC) definition framework from the UK

1.6 Application of DfMA to MEP Works

In fact, the idea of modular MEP elements and prefabricated construction have been applied in Hong Kong in the 1980s for a bank building in Central. Figure 1.4 shows the pictures of the bank building project installed with factory assembled modules for air handling unit (AHU)/toilet and gas turbine generator with full gears and switchboard. This can be considered as an early application of DfMA offsite approach which required a significant shift from traditional forms of design and procurement.

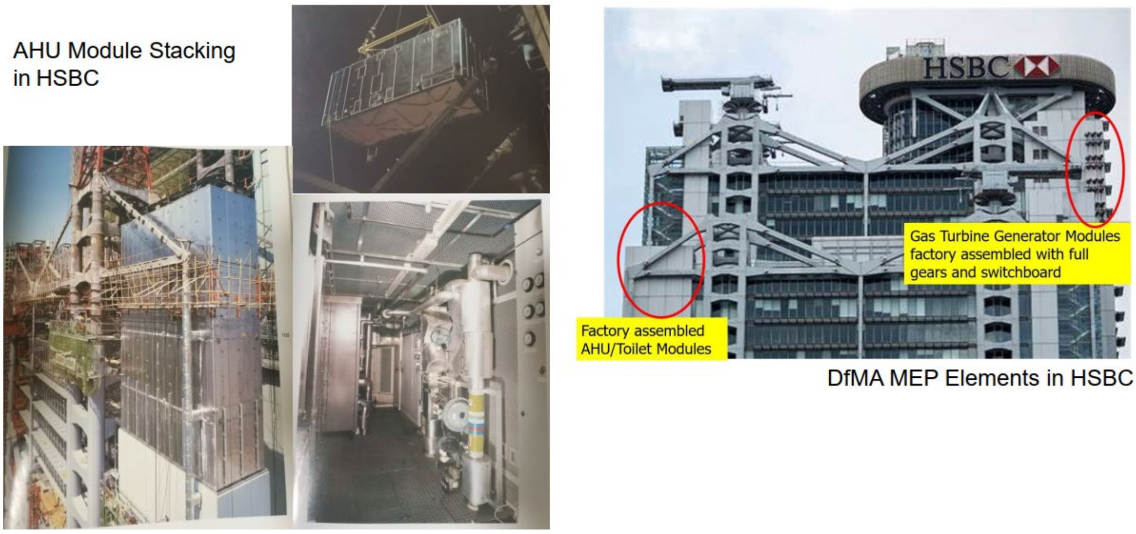


Figure 1.4 Early application of DfMA offsite approach in a bank building project in Hong Kong

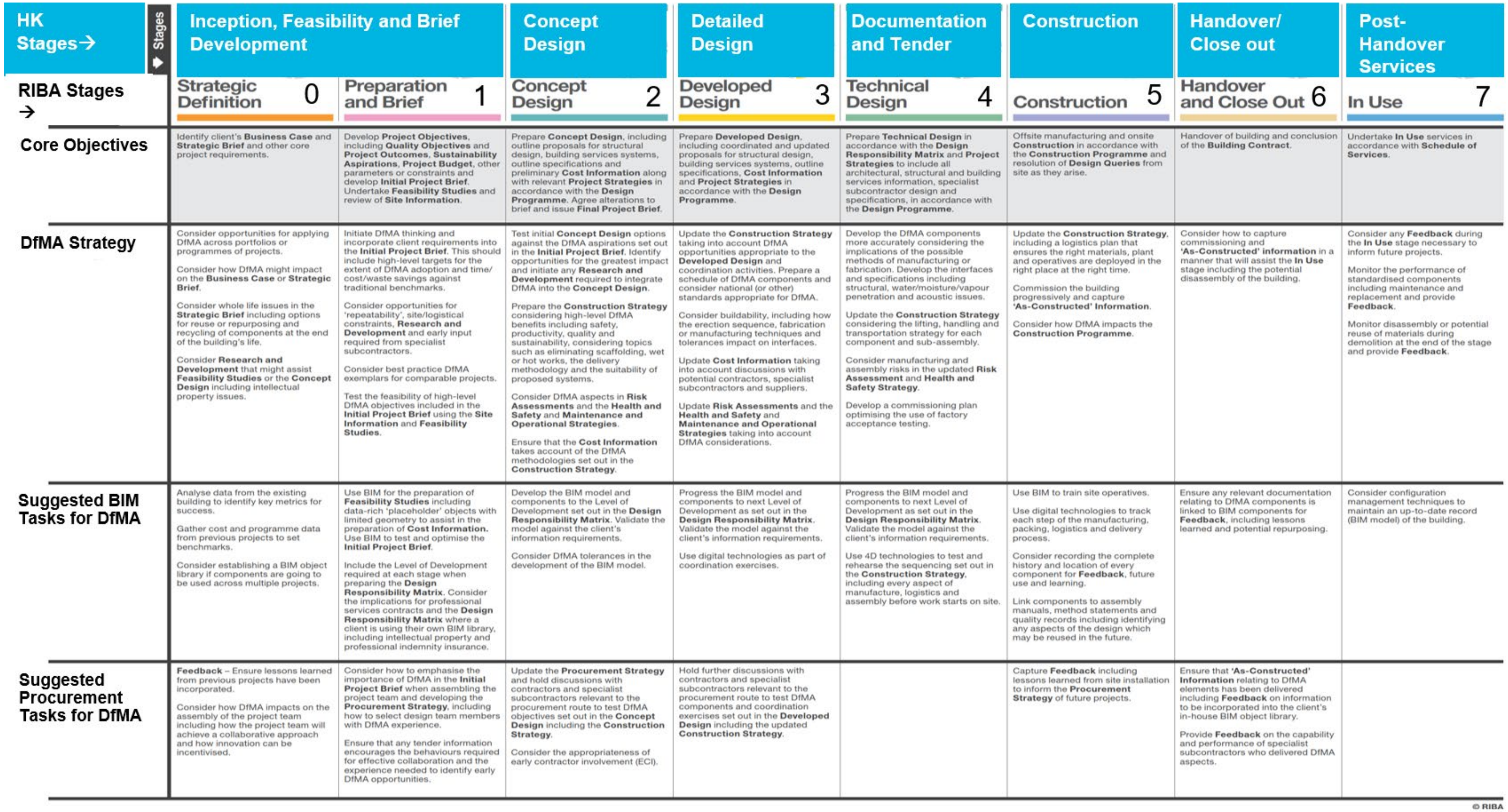
Nowadays, within the MEP sector, driven by DfMA, the use of offsite construction (OSC) is increasingly common, for example for offsite ductwork fabrication, preassembled and pre-wired pump sets, bathroom pods, preassembled and pre-wired fan coil cooling units with controls, and complete boiler rooms (BESA, 2015; Dwyer, 2019). When DfMA transforms construction into a manufacturing process, more MEP and building components are prefabricated offsite before being brought onsite for assembly. In practice, the DfMA and prefabrication options for building services components and systems will vary (Drigo & Deadman, 2019; Sands, 2019). Table 1.5 indicates major building services elements suitable for prefabrication and adoption of DfMA. Also, there is a trend that DfMA can be applied to the new electrical infrastructure, equipment and systems such as electric vehicle charging system, data centre equipment and battery energy storage systems.

Table 1.5 Major building services elements suitable for prefabrication [adapted from (Hui & Or, 2005)]

Building services systems	Examples of major elements
Mechanical ventilation & air conditioning	- Air duct system - Water pipework & fitting - Refrigerant pipework & fitting - Air conditioning equipment (e.g. air handling unit)
Fire services systems	- Water pipework & fitting - Pump sets & fittings - Smoke extraction system - Automatic fire detection & fire alarm systems
Plumbing & drainage	- Water supply pipework & fitting - Drainage pipework & fitting - Pump sets & fittings - Bathroom & toilet sanitary fittings
Electrical services	- Cable & busbar trunkings - Conduits & wiring - Power outlets & telecommunication - Electrical switchgear - Emergency generators

It is important to consider and identify suitable areas for DfMA or prefabrication within the project (ACRA, 2020). Usually adopting DfMA in areas with a higher density of MEP services (e.g. near service cores, near MEP plants) will bring about higher productivity gains. The early involvement of contractors and specialists in the coordination of MEP services will allow more time for optimising service distribution.

Smooth implementation of DfMA can be achieved with the support of new project management and delivery methods (Banks *et al.*, 2018; Gbadamosi *et al.*, 2019). For example, the Royal Institute of Architects (RIBA) has published the DfMA overlay to the RIBA Plan of Work (RIBA, 2016). One of the key recommendations is to front-load the design process by bringing specialist subcontractors and consultants on board at the early design stage.



HK Stages→ Stages	Inception, Feasibility and Brief Development		Concept Design	Detailed Design	Documentation and Tender	Construction	Handover/ Close out	Post-Handover Services
RIBA Stages →	Strategic Definition 0	Preparation and Brief 1	Concept Design 2	Developed Design 3	Technical Design 4	Construction 5	Handover and Close Out 6	In Use 7
Core Objectives	Identify client's **Business Case** and **Strategic Brief** and other core project requirements.	Develop **Project Objectives**, including **Quality Objectives** and **Project Outcomes**, **Sustainability Aspirations**, **Project Budget**, other parameters or constraints and develop **Initial Project Brief**. Undertake **Feasibility Studies** and review of **Site Information**.	Prepare **Concept Design**, including outline proposals for structural design, building services systems, outline specifications and preliminary **Cost Information** along with relevant **Project Strategies** in accordance with the **Design Programme**. Agree alterations to brief and issue **Final Project Brief**.	Prepare **Developed Design**, including coordinated and updated proposals for structural design, building services systems, outline specifications, **Cost Information** and **Project Strategies** in accordance with the **Design Programme**.	Prepare **Technical Design** in accordance with the **Design Responsibility Matrix** and **Project Strategies** to include all architectural, structural and building services information, specialist subcontractor design and specifications, in accordance with the **Design Programme**.	Offsite manufacturing and onsite **Construction** in accordance with the **Construction Programme** and resolution of **Design Queries** from site as they arise.	Handover of building and conclusion of the **Building Contract**.	Undertake **In Use** services in accordance with **Schedule of Services**.
DfMA Strategy	Consider opportunities for applying DfMA across portfolios or programmes of projects. Consider how DfMA might impact on the **Business Case** or **Strategic Brief**. Consider whole life issues in the **Strategic Brief** including options for reuse or repurposing and recycling of components at the end of the building's life. Consider **Research and Development** that might assist **Feasibility Studies** or the **Concept Design** including intellectual property issues.	Initiate DfMA thinking and incorporate client requirements into the **Initial Project Brief**. This should include high-level targets for the extent of DfMA adoption and time/ cost/waste savings against traditional benchmarks. Consider opportunities for 'repeatability', site/logistical constraints, **Research and Development** and early input required from specialist subcontractors. Consider best practice DfMA exemplars for comparable projects. Test the feasibility of high-level DfMA objectives included in the **Initial Project Brief** using the **Site Information** and **Feasibility Studies**.	Test initial **Concept Design** options against the DfMA aspirations set out in the **Initial Project Brief**. Identify opportunities for the greatest impact and initiate any **Research and Development** required to integrate DfMA into the **Concept Design**. Prepare the **Construction Strategy** considering high-level DfMA benefits including safety, productivity, quality and sustainability, considering topics such as eliminating scaffolding, wet or hot works, the delivery methodology and the suitability of proposed systems. Consider DfMA aspects in **Risk Assessments** and the **Health and Safety** and **Maintenance and Operational Strategies**. Ensure that the **Cost Information** takes account of the DfMA methodologies set out in the **Construction Strategy**.	Update the **Construction Strategy** taking into account DfMA opportunities appropriate to the **Developed Design** and coordination activities. Prepare a schedule of DfMA components and consider national (or other) standards appropriate for DfMA. Consider buildability, including how the erection sequence, fabrication or manufacturing techniques and tolerances impact on interfaces. Update **Cost Information** taking into account discussions with potential contractors, specialist subcontractors and suppliers. Update **Risk Assessments** and the **Health and Safety** and **Maintenance and Operational Strategies** taking into account DfMA considerations.	Develop the DfMA components more accurately considering the implications of the possible methods of manufacturing or fabrication. Develop the interfaces and specifications including structural, water/moisture/vapour penetration and acoustic issues. Update the **Construction Strategy** considering the lifting, handling and transportation strategy for each component and sub-assembly. Consider manufacturing and assembly risks in the updated **Risk Assessment** and **Health and Safety Strategy**. Develop a commissioning plan optimising the use of factory acceptance testing.	Update the **Construction Strategy**, including a logistics plan that ensures the right materials, plant and operatives are deployed in the right place at the right time. Commission the building progressively and capture **'As-Constructed' Information**. Consider how DfMA impacts the **Construction Programme**.	Consider how to capture commissioning and **'As-Constructed' information** in a manner that will assist the **In Use** stage including the potential disassembly of the building.	Consider any **Feedback** during the **In Use** stage necessary to inform future projects. Monitor the performance of standardised components including maintenance and replacement and provide **Feedback**. Monitor disassembly or potential reuse of materials during demolition at the end of the stage and provide **Feedback**.
Suggested BIM Tasks for DfMA	Analyse data from the existing building to identify key metrics for success. Gather cost and programme data from previous projects to set benchmarks. Consider establishing a BIM object library if components are going to be used across multiple projects.	Use BIM for the preparation of **Feasibility Studies** including data-rich 'placeholder' objects with limited geometry to assist in the preparation of **Cost Information.** Use BIM to test and optimise the **Initial Project Brief**. Include the Level of Development required at each stage when preparing the **Design Responsibility Matrix**. Consider the implications for professional services contracts and the **Design Responsibility Matrix** where a client is using their own BIM library, including intellectual property and professional indemnity insurance.	Develop the BIM model and components to the Level of Development set out in the **Design Responsibility Matrix**. Validate the model against the client's information requirements. Consider DfMA tolerances in the development of the BIM model.	Progress the BIM model and components to next Level of Development as set out in the **Design Responsibility Matrix**. Validate the model against the client's information requirements. Use digital technologies as part of coordination exercises.	Progress the BIM model and components to next Level of Development as set out in the **Design Responsibility Matrix**. Validate the model against the client's information requirements. Use 4D technologies to test and rehearse the sequencing set out in the **Construction Strategy**, including every aspect of manufacture, logistics and assembly before work starts on site.	Use BIM to train site operatives. Use digital technologies to track each step of the manufacturing, packing, logistics and delivery process. Consider recording the complete history and location of every component for **Feedback**, future use and learning. Link components to assembly manuals, method statements and quality records including identifying any aspects of the design which may be reused in the future.	Ensure any relevant documentation relating to DfMA components is linked to BIM components for **Feedback**, including lessons learned and potential repurposing.	Consider configuration management techniques to maintain an up-to-date record (BIM model) of the building.
Suggested Procurement Tasks for DfMA	**Feedback** – Ensure lessons learned from previous projects have been incorporated. Consider how DfMA impacts on the assembly of the project team including how the project team will achieve a collaborative approach and how innovation can be incentivised.	Consider how to emphasise the importance of DfMA in the **Initial Project Brief** when assembling the project team and developing the **Procurement Strategy**, including how to select design team members with DfMA experience. Ensure that any tender information encourages the behaviours required for effective collaboration and the experience needed to identify early DfMA opportunities.	Update the **Procurement Strategy** and hold discussions with contractors and specialist subcontractors relevant to the procurement route to test DfMA objectives set out in the **Concept Design** including the **Construction Strategy**. Consider the appropriateness of early contractor involvement (ECI).	Hold further discussions with contractors and specialist subcontractors relevant to the procurement route to test DfMA components and coordination exercises set out in the **Developed Design** including the updated **Construction Strategy**.		Capture **Feedback** including lessons learned from site installation to inform the **Procurement Strategy** of future projects.	Ensure that **'As-Constructed' Information** relating to DfMA elements has been delivered including **Feedback** on information to be incorporated into the client's in-house BIM object library. Provide **Feedback** on the capability and performance of specialist subcontractors who delivered DfMA aspects.	

© RIBA

Figure 1.5 DfMA overlay to the RIBA Plan of Work [adapted from RIBA (2016)]

2. Inception, Feasibility and Brief Development

The inception, feasibility and brief development encompasses the “strategic definition” (Stage 0) and “preparation and briefing” (Stage 1) of the RIBA Plan of Work (RIBA, 2020). During the strategic definition stage, the client’s business case and strategic brief are assessed to ensure they have been properly considered and the scope of the project is defined. The preparation and briefing stage involves developing the initial project brief, carrying out feasibility studies and assembling the project team ready for concept design to commence.

2.1 Core Objectives

At this point, the core objectives are to identify the client’s business strategy and related core project requirements to subsequently develop project objectives and KPIs (see 2.2.1), quality objectives, project outcomes, sustainability considerations and budget feasibility against the site limitations and other constraints. Appropriate DfMA strategy and considerations should be initiated with a high-level target for DfMA adoption (see Table 1.3) in order to maximise the time/cost savings, safety/productivity enhancement and waste reduction against traditional practice, taking into consideration the scale and repeatability of the DfMA products.

Parallel actions should be taken to ensure that the stage for concept design will be as productive as possible. The initial project brief should include a requirement for DfMA to be adopted, to encourage the design team to embrace the approach. Given the increasing use of BIM and modern technologies, it is essential that the team is properly assembled with the core digital skills and understanding of DfMA implementation for MEP works.

2.2 DfMA Strategy and Considerations

It is beneficial to consider opportunities for applying DfMA across portfolios or programmes of projects and to evaluate how DfMA might impact on the business case or strategic brief. Also, it is necessary to consider opportunities for repeatability, site/logistical constraints, and early input required from specialist subcontractors. Very often, it is useful to consider best practice DfMA exemplars for comparable projects and test the feasibility of high-level DfMA objectives using the site information and feasibility studies.

2.2.1 Key Performance Indicators (KPIs) and Productivity

To promote DfMA effectively and successfully in building projects, the patronage and insistence of the client is a key driving factor. It is important to identify the key performance indicators for the project based on the organisation objectives of the client. In general, the items listed in Table 2.1 are common KPIs, either as driving or constraining factors. In fact, KPIs may vary from client to client. As an example, the KPIs listed in Table 2.2 and Figure 2.1 are adopted in some of the publicly funded projects. Instead of limiting the perspective to a project alone, there may be wider gains by considering the overall property or project portfolio of the client as a whole to discover benefits that can be gained by applying offsite and DfMA strategies to a set of projects for manufacture, assembly and commissioning. The lead design professional and the specialist subcontractors appointed for the project will be required to explore and adopt innovative design and smart construction technologies to enhance construction performance and to facilitate smart operation & maintenance, which will include the use of offsite prefabrication solutions out of DfMA by fully utilising the BIM tool.

Table 2.1 Common KPIs either as drivers or constraints

Drivers	**Constraints**
Cost factors (minimum construction cost vs, the whole project cost)	Site constraints (area restriction, access limitation, environment control, neighborhood restriction, transportation/ delivery restriction, multi-trade interfaces restriction, cost of available workforce)
Time factors (time certainty, design time, onsite time, and overall project time)	Process factors (supply chain availability, design change flexibility, standardisation and customisation)
Quality factors (normally accepted standard vs lifecycle performance predictability)	Procurement constraints (experience, early contractor engagement, single-source restriction, lowest cost only, element-specific costing)
Design/aesthetic factors (high profile and iconic vs regular and repetitive approach)	
Sustainability factors and lifecycle costs (minimise energy and environmental impact during construction vs those for ‘build-for-use’ finished building)	Lifecycle costs may not be a priority consideration for clients in ‘build-for-sale’ projects
Health and safety	

Table 2.2 KPIs examples adopted in publicly funded projects

Environmental performance	Energy efficiency
Ease of maintenance	Maintenance cost
Floor layout efficiency	Design and construction programme
Manpower consumption (onsite & offsite)	Quantity of construction waste
Flexibility for future change in room usage	Flexibility for late design change
Impact on neighborhood (noise, water pollution, dust, traffic, etc.)	Productivity in construction (for both insitu construction onsite and offsite portions)

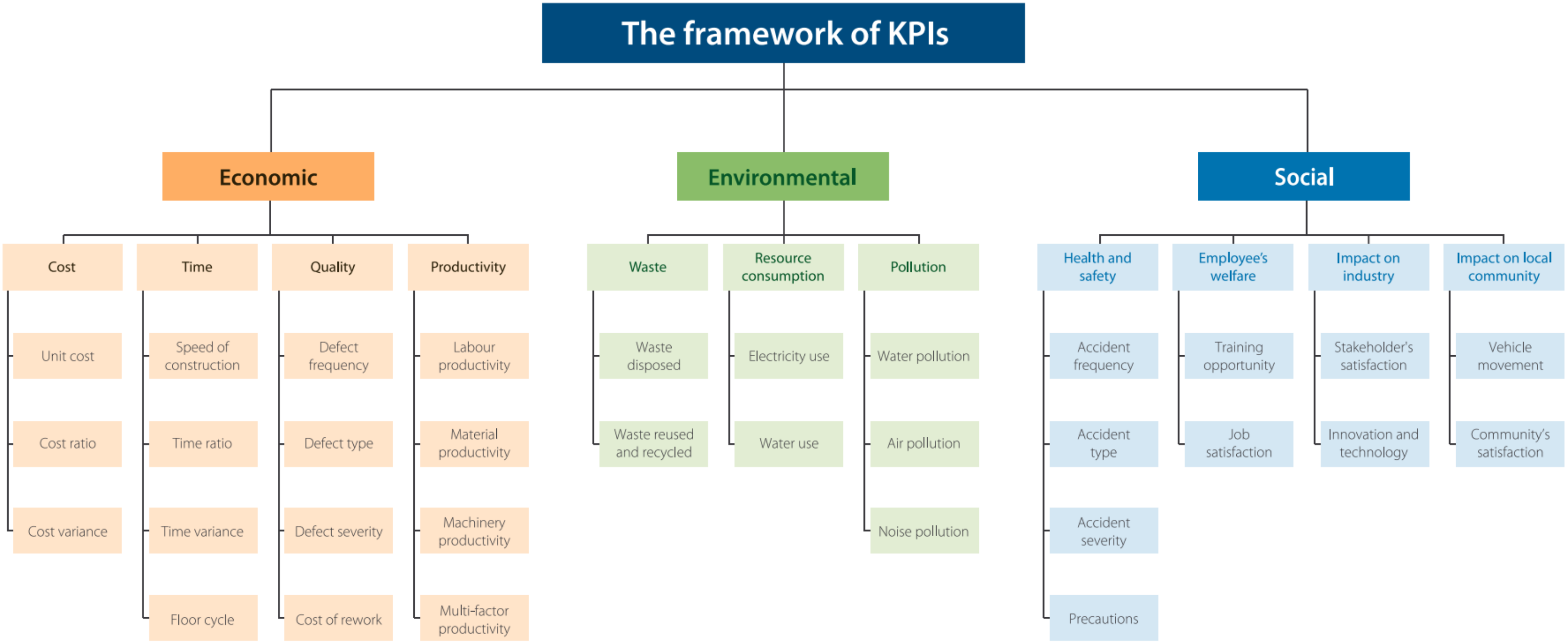


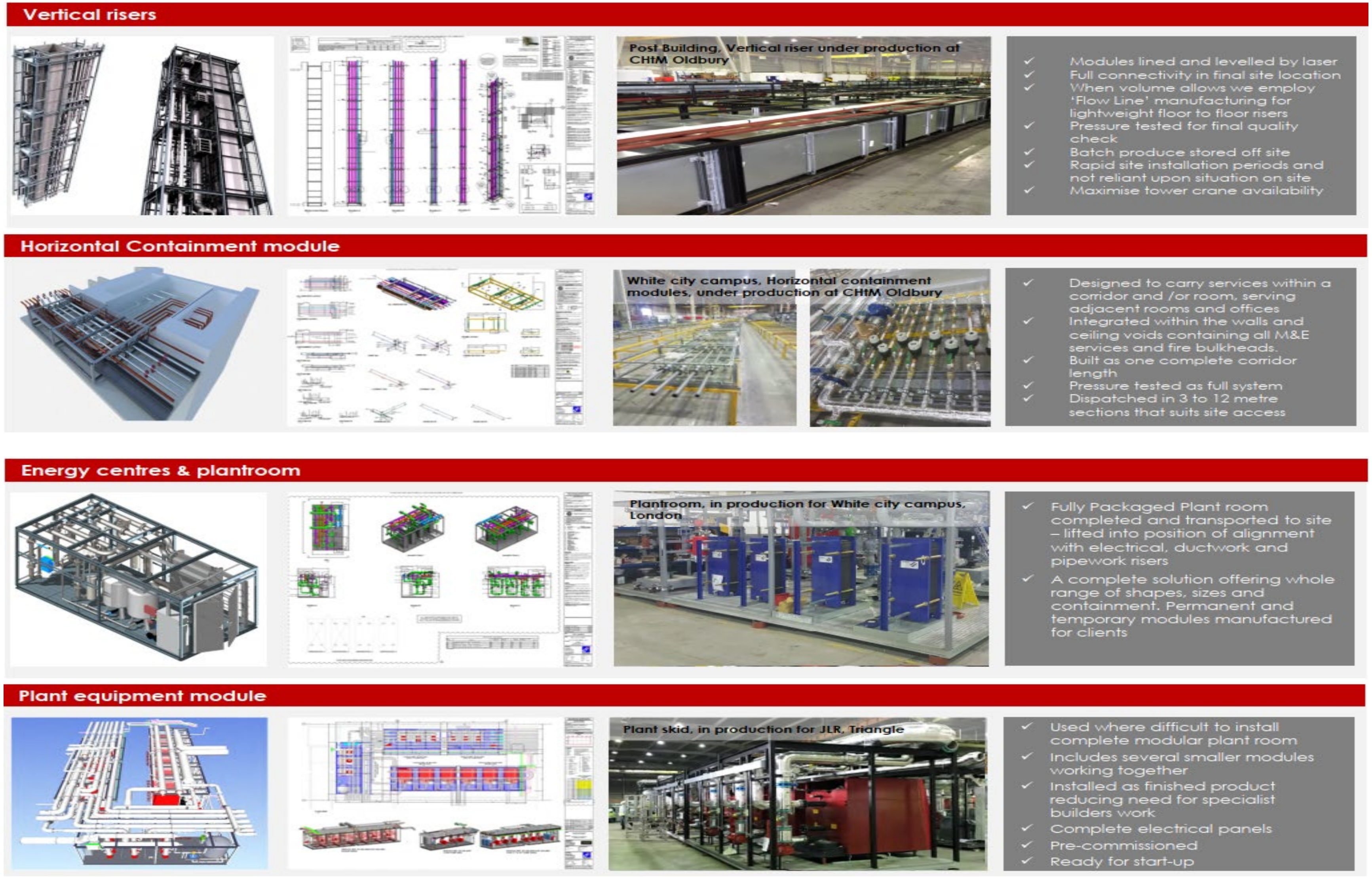
Figure 2.1 Systematic framework of KPIs for MiC performance measurement (Pan *et al.*, 2020)

2.2.2 Standardisation and Design Options

It is advisable to identify opportunities to adopt existing “off the shelf” products or use client-specific standard products or designs developed. When analysed holistically, most sectors have common core requirements across multiple projects and may be adopted after due consideration of project-specific requirements. Even facilities designed with standardised modules may still be interesting, innovative and varied as standardised elements may in turn release design resources to focus on the iconic aspects. Decisions made at the portfolio or programme level may then be incorporated into the individual project briefs.

Some major clients may have been creating their own BIM object libraries of standardised elements that they prefer for their projects. Similarly, at the specialist subcontractor level of the supply chain, the offsite suppliers may have already developed their own BIM object libraries for their preferred components for cost effective customised assemblies, such as plant rooms, vertical risers or horizontal service distribution modules. Examples are given in Figure 2.2.

For MEP works, it is important to allow enough time to consider a range of design options (Figures 2.3 and 2.4) so as to avoid inappropriate or undesirably limited design flexibility, as well as to develop a holistic view of the project to minimise the difficulties encountered at the construction stage to achieve time certainty and overall time saving. For example, an over detailed design for a building’s services system may pre-determine the construction sequence or at least limit the scope for preassembly. The creation of a vertical riser in a frame rising through multiple floors may be more efficient than having a smaller assembly for each floor or for fitting components in the traditional manner. However, lifting restrictions onsite may prevent this option from being used. Similarly, if there are already systems available for constructing such a building, these proprietary supply chains may be excluded if the design contains too much restrictive details prior to tendering. Various design options will require inputs across the construction value chain, and enough time should be allowed for design in BIM software and collaboration among the client, his consultants (or in-house designer/project manager), builder, MEP specialist subcontractors and prefabricator of MEP modules, before construction starts.



Vertical risers

Post Building, Vertical riser under production at CHtM Oldbury

- ✓ Modules lined and levelled by laser
- ✓ Full connectivity in final site location
- ✓ When volume allows we employ 'Flow Line' manufacturing for lightweight floor to floor risers
- ✓ Pressure tested for final quality check
- ✓ Batch produce stored off site
- ✓ Rapid site installation periods and not reliant upon situation on site
- ✓ Maximise tower crane availability

Horizontal Containment module

White city campus, Horizontal containment modules, under production at CHtM Oldbury

- ✓ Designed to carry services within a corridor and /or room, serving adjacent rooms and offices
- ✓ Integrated within the walls and ceiling voids containing all M&E services and fire bulkheads.
- ✓ Built as one complete corridor length
- ✓ Pressure tested as full system
- ✓ Dispatched in 3 to 12 metre sections that suits site access

Energy centres & plantroom

Plantroom, in production for White city campus, London

- ✓ Fully Packaged Plant room completed and transported to site – lifted into position of alignment with electrical, ductwork and pipework risers
- ✓ A complete solution offering whole range of shapes, sizes and containment. Permanent and temporary modules manufactured for clients

Plant equipment module

Plant skid, in production for JLR, Triangle

- ✓ Used where difficult to install complete modular plant room
- ✓ Includes several smaller modules working together
- ✓ Installed as finished product reducing need for specialist builders work
- ✓ Complete electrical panels
- ✓ Pre-commissioned
- ✓ Ready for start-up

Figure 2.2 Examples of BIM objects and related products by an offsite manufacturer (Courtesy of Laing O'Rourke)

Figure 2.3 Design options for prefabricated MEP modules in the UK (Wilson, Smith & Deal, 1999a)

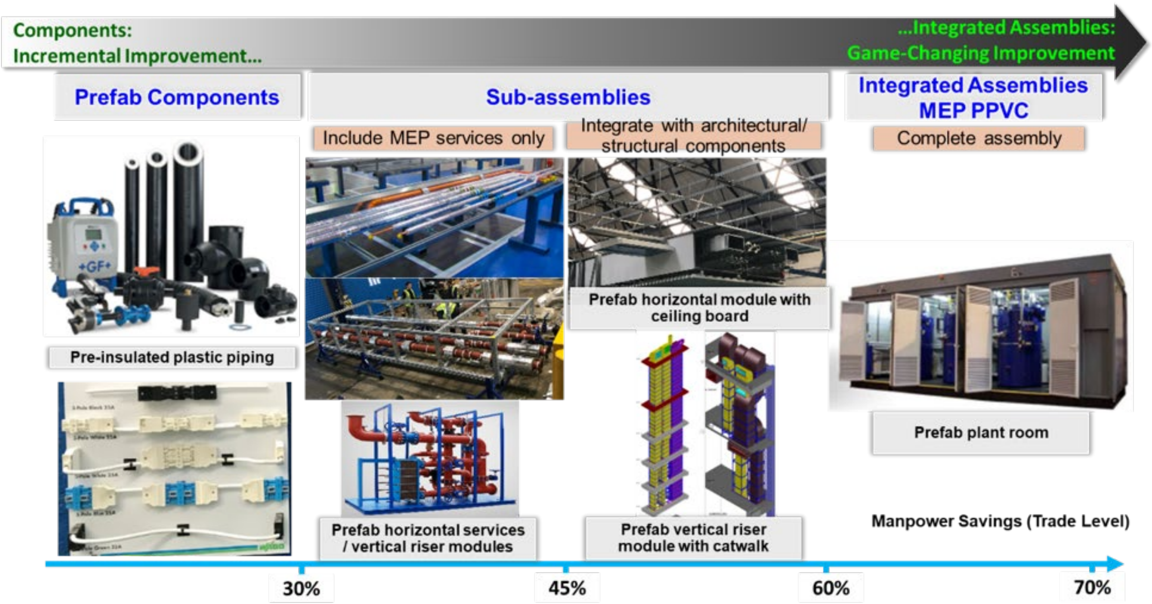


Figure 2.4 Design options for prefabricated MEP modules in Singapore (Courtesy of the BCA, Singapore)

2.2.3 Offsite and Onsite Activities

To enable exploration for including offsite elements into the concept design at the next stage, it will be very helpful to look at how similar facilities have been constructed in the past locally or in overseas projects (see also Table 1.4). For example, data centers, plant rooms, pumping stations, educational and pre-school facilities, hospitals and laboratories have all been constructed offsite with significant building and engineering services content. Many large facilities have also been developed as hybrid projects with a traditionally constructed structure containing extensive use of modularised and unitised assemblies of services equipment. Examples of suitable building projects with similar facilities include schools, laboratories, operating theatres, car parks and water treatment and pumping stations, to name just a few (see Appendix 5 for cases studies and job references). To seamlessly integrate the onsite assembly and offsite manufactured modules with the more traditionally constructed onsite elements, two critical tasks should be included in the brief to ensure they are adequately addressed:

- The management of interfaces between the different work packages
- A structured approach to the analysis, design, integration, testing and acceptance of the systems

2.3 BIM Tasks

One way the DfMA implementation can be managed effectively is through the use of BIM (BCA, 2016). The use of BIM on the project will contribute significantly to manage the work package interfacing. For example, the documents of BIM standards BS PAS 1192-2 (BSI, 2013) or BS EN ISO 19650-1, 2, 3 and 5 (BSI, 2019a & b, 2020a & b) describe the information delivery assessment of needs and procurement. They also provide guidance on how defining volumes within tunnels (Figure 2.5) or a building (Figure 2.6) can be used for special coordination of services. In addition, the documents define how information can be shared by a project team in a common data environment (CDE).

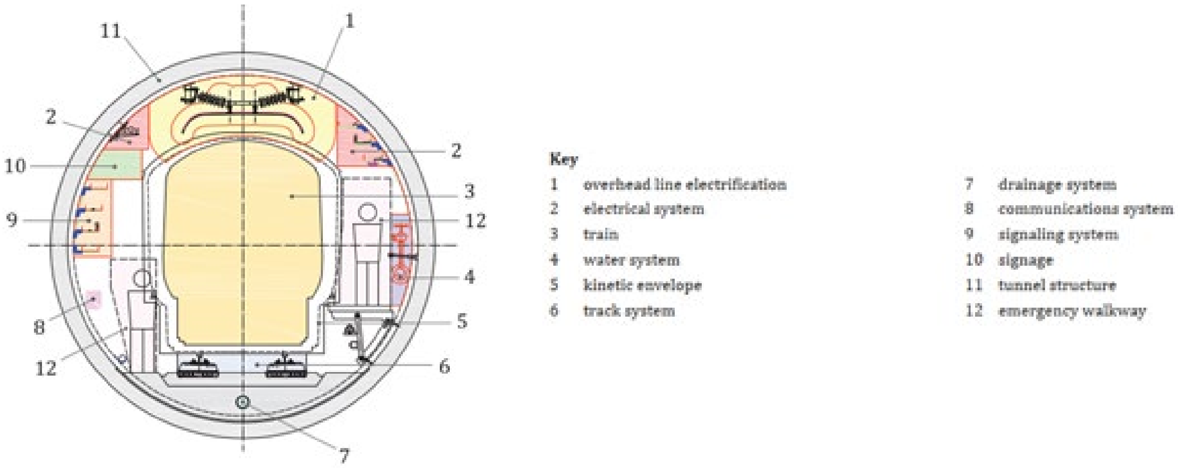


Figure 2.5 Illustration of federation of tunnel cross-section systems in a rail project [From Figure A.1 in BSI (2019a)]

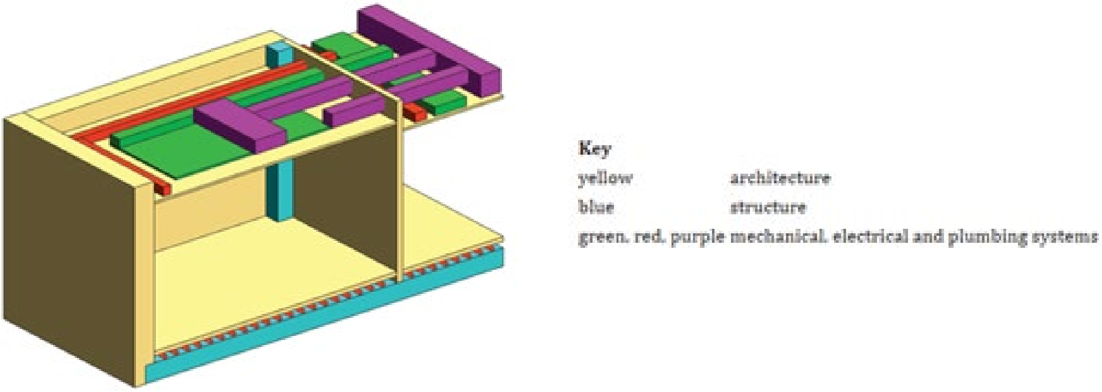


Figure 2.6 Illustration of spatial federation strategy by discipline in a building project

[From Figure A.2 in BSI (2019a)]

The suggested BIM tasks for DfMA at this stage are summarised in Table 2.3 (RIBA, 2016).

Table 2.3 Suggested BIM tasks for inception, feasibility and brief development

- Analyse data from the existing building to identify key metrics for success
- Gather cost and programme data from previous projects to set benchmarks
- Establish a BIM object library if components are going to be used across multiple projects
- Use BIM for the preparation of feasibility studies including data-rich placeholder objects with limited geometry to assist in the preparation of cost information
- Use BIM to test and optimise the initial project brief
- Include the level of development (LOD) required at each stage when preparing the design responsibility matrix (see Appendix 4 for details)
- Consider the implications for professional services contracts and the design responsibility matrix where a client is using their own BIM library, including intellectual property and professional indemnity insurance

BIM should be used throughout the project lifecycle to enhance and improve the coordination amongst various stakeholders during the design, construction, operation and maintenance of the project and to facilitate effective decision making at key stages. A BIM execution plan should be established for project-specific purpose to be adopted for the subsequent procurement and implementation in the subsequent stages.

2.4 Procurement Tasks

The suggested procurement tasks for DfMA at this stage are summarised in Table 2.4 (RIBA, 2016).

Table 2.4 Suggested procurement tasks for inception, feasibility and brief development

- Ensure feedback/lessons learned from previous projects have been incorporated
- Consider how DfMA impacts on the assembly of the project team and how to emphasise the importance of DfMA in the initial project brief, including how to select design team members with DfMA experience
- Ensure that tender information encourages the behaviours required for effective collaboration and the experience needed to identify early DfMA opportunities

A procurement strategy should be established based on the considerations and objectives set out at the strategic definition stage, in order to select and execute procurement for internal resources, design consultants, specialist advisors, contractors, etc., to tally with the DfMA process in the subsequent stages. To fully realise the potential for construction efficiencies through DfMA, it is important to have specialist construction knowledge as part of the design team from the early stages (BCA, 2016). This may be part of the services of the main design consultant or it could be provided by a separate construction consultant. Alternatively, early involvement of the contractor and specialist subcontractors would enable the design team to tap on their experience and expertise in developing proposals for offsite fabrication and onsite assembly.

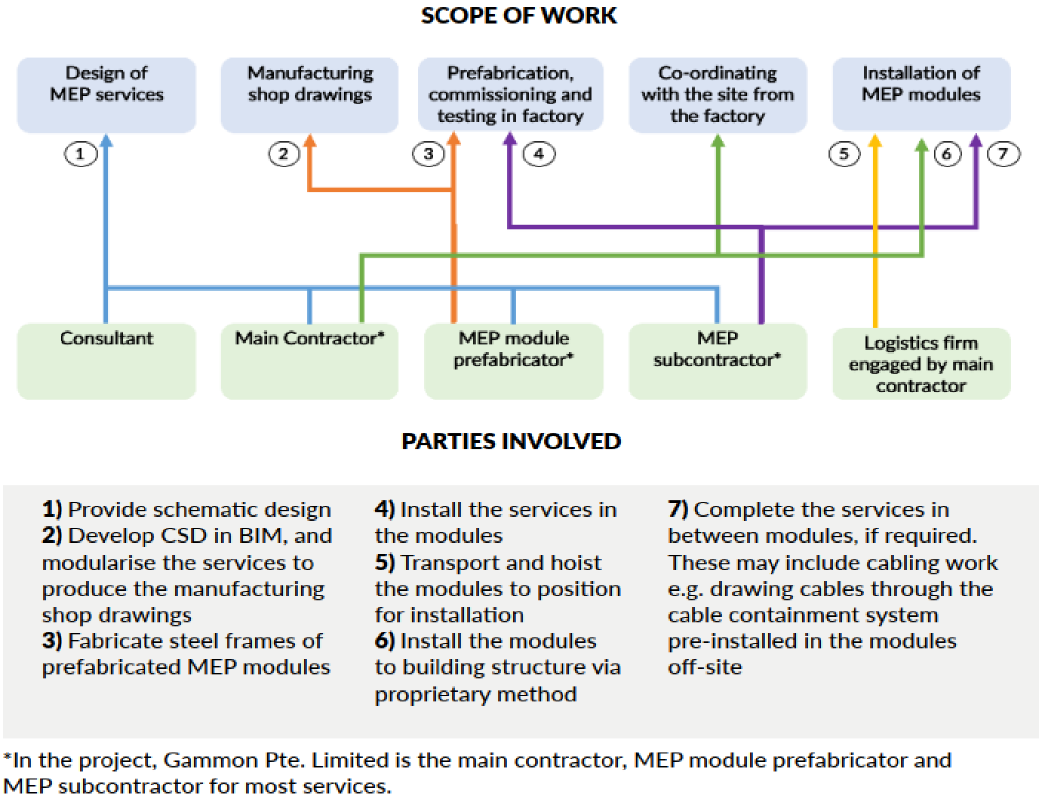
When adopting DfMA approach in a project involving MEP works, a reference design framework for building services (Churcher, Ronceray and Sands, 2018) and the related pro formas (in its Appendices A and B) can be used to provide guidance on design activities, responsibilities and deliverables for the project team. Examples can be found in Appendix 4.

2.4.1 Project Team and Workflow

For DfMA implementation, the project team may be more complex than that for the traditional approach and will include at least the following:

- MEP consultants
- Main contractor
- Trade-specific MEP specialist subcontractors (Mechanical, Electrical, Plumbing and Fire Protection)
- Fabricators, installation specialist and maintenance specialist

There will be stringent requirements for BIM MEP model coordination, combined/coordinated services drawings (CSD) and offsite manufacturing support. For example, Figure 2.7 illustrates the scope of work by different parties for the MEP modules at the Global Switch Data Centre project in Singapore discussed in BCA (2018). In the project, the main contractor developed the detailed BIM model based on the system design by the designer/design consultant. A MEP prefabrication factory was set up to produce all the modules by the main contractor. While a structural engineer was engaged to design the support and frames of the modules, the onsite installation, testing and commissioning of the MEP systems were undertaken by the main contractor and specialist subcontractors engaged by them.



1) Provide schematic design
2) Develop CSD in BIM, and modularise the services to produce the manufacturing shop drawings
3) Fabricate steel frames of prefabricated MEP modules
4) Install the services in the modules
5) Transport and hoist the modules to position for installation
6) Install the modules to building structure via proprietary method
7) Complete the services in between modules, if required. These may include cabling work e.g. drawing cables through the cable containment system pre-installed in the modules off-site

*In the project, Gammon Pte. Limited is the main contractor, MEP module prefabricator and MEP subcontractor for most services.

Figure 2.7 Prefabricated MEP modules in the Global Switch Data Centre project in Singapore (BCA, 2018)

Another example of workflow to support DfMA of high-quality MEP modules is shown in Figure 2.8. The flow chart is developed and adopted by Prism, the manufacturing arm of SES Engineering, a building services contractor based in the UK.

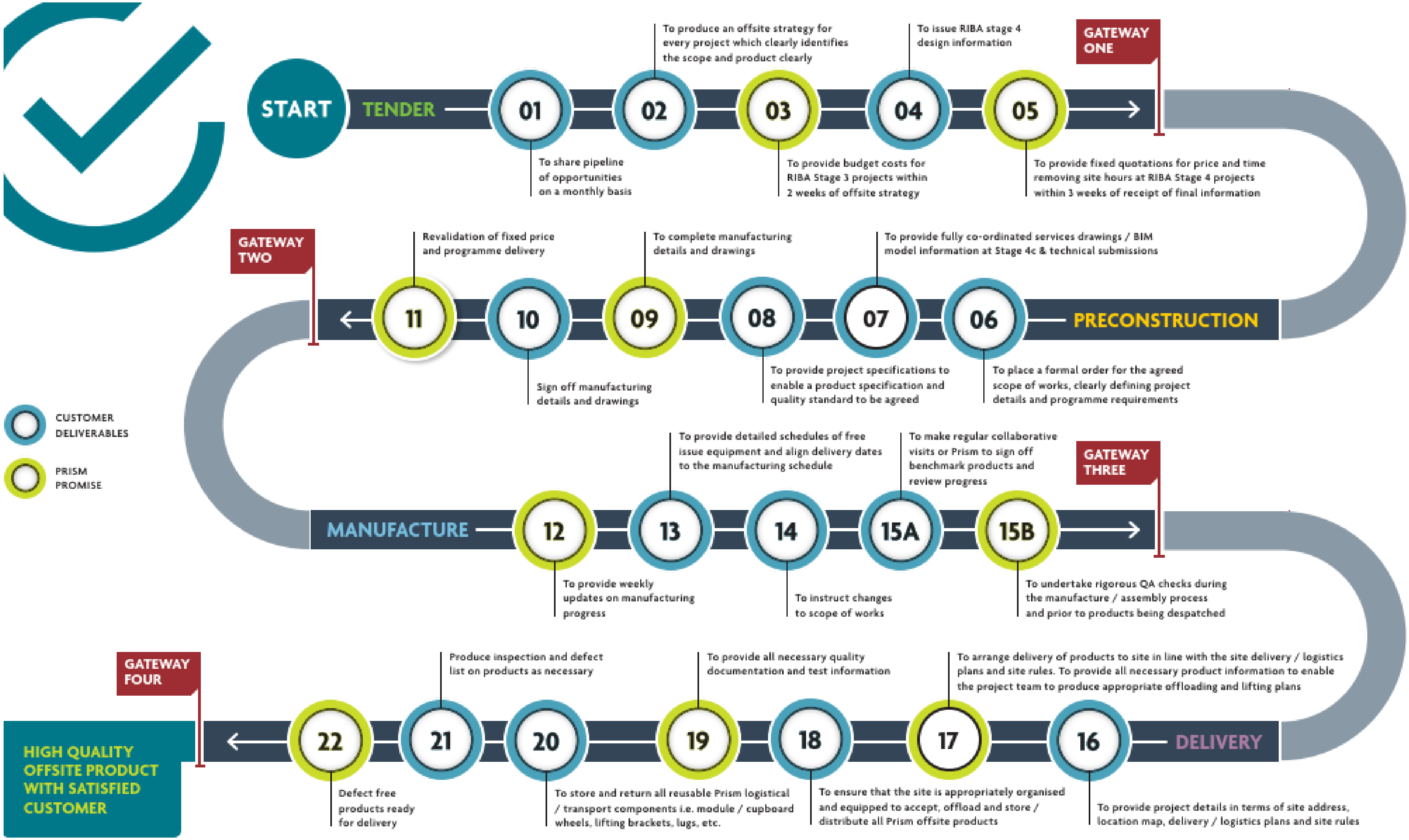


Figure 2.8 Prism's flow chart for prefabrication of MEP modules (Source: https://www.ses-ltd.co.uk/wp-content/uploads/2020/09/Spreads-Prism-Brochure-Updates-25.85.20-No-MD.pdf)

2.4.2 Quality and Standards

In general, the quality standards that are applicable to onsite work also apply to offsite work, but in factory-controlled conditions it will be easier and more cost effective to achieve them. However, new quality standards may emerge from forthcoming innovations such as 3D printing and other digital innovations. There are many quality standards covering work in manufacturing facilities, the manufacture process and operation of products, and the safety and quality of buildings during construction, occupancy and use, which will be applicable and must be strictly followed for OSC (Liu, Nzige & Li, 2019; Sands, 2019).

Procurement of offsite construction can involve production in Mainland China and other countries. Wider consideration for adoption of Chinese national standards (Guo Biao, GB) and other international standards, when considered of equivalent quality, may make it easier for overseas companies to quote for work to maximise the cost effectiveness. An example of this could be in the area of structural frames that support services, where Eurocodes or other equivalent standards are applicable.

2.4.3 Statutory Requirements and Guidance

The MEP design proposal should be in full compliance with the relevant statutory requirements and the relevant design guidelines. Any deviations should be brought up, discussed, and approved by the relevant authority prior to work being done. At present, in Hong Kong, reference could be made to the latest guidance/circulars related to MiC issued by the relevant government bureau/departments and other regulatory bodies (CIC, 2020a&b). Table 2.5 shows a list of the related guidance notes/circulars. Further information can be found in Appendix 2. The proposal and related building plans should clearly indicate that MiC is to be adopted according to the guidance/circulars.

Table 2.5 Guidance/circulars related to MiC in Hong Kong

(a) Buildings Department:
- Practice Note for Authorised Persons, Registered Structure Engineers and Registered Geotechnical Engineers (PNAP) ADV-36 on Modular Integrated Construction

(b) Construction Industry Council:
- Reference Material on the Statutory Requirements and Reference Material on Logistics and Transport for Modular Integrated Construction Projects

(c) Electrical and Mechanical Services Department:
- https://www.emsd.gov.hk/en/supporting_government_initiatives/mic/
- Guidance Note on Fixed Electrical Installations with Modular Integrated Construction Method
- Guidance Note on Household Electrical Products with Modular Integrated Construction Method
- Guidance Note on Gas Supply Installations
- Guidance Note on Supply of Energy Label Prescribed Products at MiC Projects

(d) Fire Services Department:
- FSD Circular Letter No. 3/2019 Guidance Notes on Submission, Approval and Acceptance Inspection of Fire Service Installations and Equipment in Modular Integrated Construction Building Projects issued by the Fire Service Department

(e) Water Supplies Department:
- Circular Letter No. 2/2019 Procedures for Applications for Water Supply in New Building Projects adopting "Modular Integrated Construction" Method

2.4.4 Payment, Collaborative Approach and Works Contracts

With DfMA and offsite construction, the budget and cash flow planning should be as flexible as possible to accommodate alternative procurement routes for offsite options. For example, a different payment schedule than traditional practice can be used to give a deposit to reserve factory capacity or arrange for offsite/factory payment.

With the offsite works running along the onsite activities at a different work sequence, there will be changes in the contractor's pricing methodology, payment certification methodology, the bill of quantity, or schedule of works in the case of a lump sum contract. Traditionally, payment will be certified for works done or materials delivery onsite. With the offsite work arrangement, the MEP specialist subcontractor may claim part of the contract amount for the modules completed in the factory, before the installation of these modules onsite and there will also be potential insurance coverage cost for offsite work-in-progress (WIP) modules. Offsite work progress payment is important to encourage offsite work. The following approach should be considered when designing the payment arrangement for offsite work:

- Payment for completed modules, not materials
- Liability for completed modules belong to the owner after handover
- Payment for (Just-in-Time) completed modules (see also Section 6.2.5)
- No payment for immature completed modules not meeting the minimum level of completeness specified

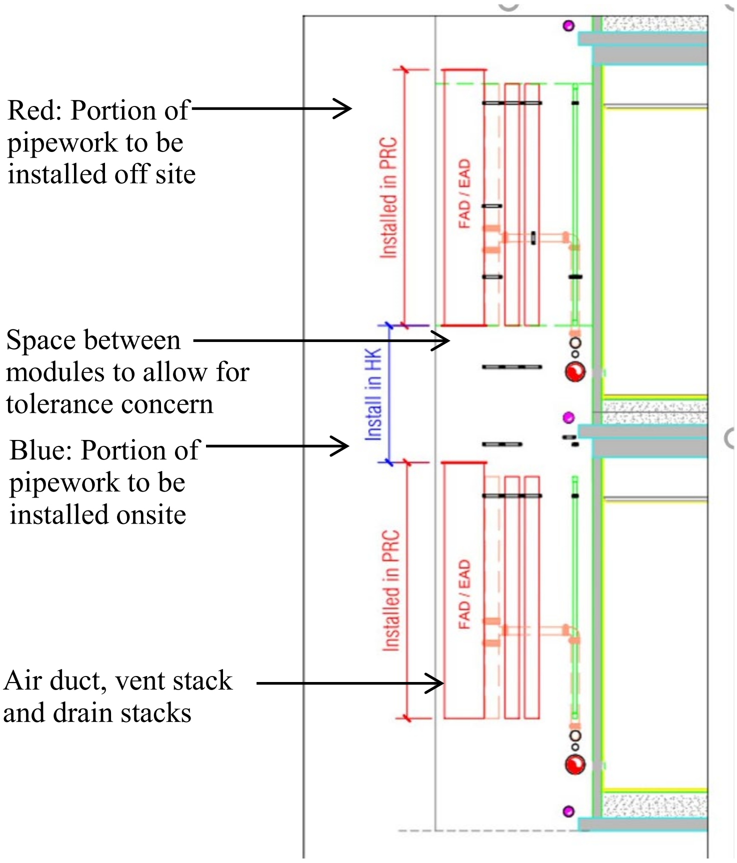
Execute early delivery of products ahead of schedule or out of sequence may impact the overall construction plan, due to congestion of the site and the need to shuffle materials around. Payment shall be aligned for the correct delivery of the right quality items at the planned time.

In fact, most suppliers of offsite construction assemblies prefer a collaborative rather than transactional approach on procurement. If they can be involved from the earliest project stages, this would allow them to submit ideas and advice to the designer and provide the expertise on the use of offsite components and assemblies that the designers may lack.

Also, in the future stages, enough time should be allowed for preparation of BIM-based CSD to be endorsed by all relevant project parties and approval on materials and mock-ups prior to mass production of the MEP modules. Even though the onsite interfaces can be minimised and rationalised, enough time should be allowed to facilitate seamless coordination between onsite and offsite tasks.

Even though the procurement for works contracts may not be immediate, the procurement strategy at this stage should consider the following:

- If early involvement of contractors or specialist subcontractors is required, what will be the better options, on how and when, to be chosen under the organisation governance?
- Though it will be preferable to give to a single awardee for full cycle of prefabrication to avoid contractual dispute, it needs research on availability in the supply chain.
- What will be the potential demarcation/interface matrix between parties? (see Figure 2.9 for an example)



(a) Demarcation plan

(b) Installation delivered

Figure 2.9 Demarcation of offsite and onsite MEP works for an MiC module (Courtesy of ATAL Engineering Limited)

3. Concept Design

Concept design (Stage 2 of RIBA Plan of Work) generally takes place after feasibility studies and options appraisals have been carried out and a project brief has been prepared. It represents the design team's initial response to the project brief. A concept design that has been developed with DfMA in mind will be robust, leading to a more efficient design process at the later stages.

3.1 Core Objectives

The core objectives at this stage are to prepare concept design including outline proposals (architectural, structural, building services systems), outline specifications, preliminary budget and implementation design programme. The project team should also agree with the client alterations to the initial project brief and issue the final project brief. Table 3.1 shows the expected deliverables for general and MEP aspects at this stage. Based on the construction type and project requirements, the DfMA aspirations and offsite strategies can be assessed and applied in the respective outline proposals.

Table 3.1 Expected deliverables at the concept design stage

General aspects:

- Sustainability strategy (including green building initiatives & BEAM Plus assessment)
- Review of the cost information, project estimates & contract strategy
- Development of construction strategy, work stage programme & resources plan
- Reports on ground investigation, site constraints/surveys & utility provisions
- Reports on preliminary environmental review & systematic risk management
- Statutory compliance, universal accessibility design & buildability evaluation
- Sketch design report & outline proposals including innovative design for construction performance enhancement, smart operation/maintenance, health & safety strategy
- Final project brief, outline specifications and BIM execution and collaboration plans

MEP aspects:

- Key design criteria, indicative loadings, servicing strategy & primary services distribution
- Site analysis on constraints, utility connections & existing facilities
- Concept sketch drawing, concept schematic diagrams & BIM MEP coordination models
- Outline proposal on MEP design & system selection, zoning, major plant space & location
- Design standards, statutory requirements, calculations & checklists
- Rough indication of MEP cost/budget estimates
- Evaluation of energy saving efficient features & renewable/clean energy applications

3.2 DfMA Strategies and Considerations

In developing a DfMA strategy as part of the construction strategy, the project team should consider high-level benefits including safety, productivity, quality and sustainability so as to identify opportunities for the greatest impact and if needed initiate any research and development required to integrate DfMA effectively into the concept design. For example, material wastage can be minimised through optimal routing of MEP services. It is also the right time to consider DfMA aspects in the risk assessment and the health & safety in maintenance & operation strategies. In addition, it is necessary to ensure that the cost information takes account of the DfMA methodologies set out in the construction strategy.

Based on the available information on site conditions and constraints, it is important to set the concept for the scope, scale, form and primary design criteria which will dictate the technical studies for spatial arrangements, architectural/structural/MEP philosophy and other building design approach. Very often, studies on initial concept design options are required to explore and identify innovative design and smart construction technologies to enhance construction performance and to facilitate smart operation & maintenance, which shall include but not limited to the use of offsite prefabrication, DfMA (including MEP and MiC) by fully making use of the BIM tool. The various onsite and offsite options (see Table 1.4) should be evaluated in terms of performance, with measurable aspects against the client's KPIs established in the earlier stage, the ability to deliver the project safely within the budget and the construction programme.

At the concept design stage, it will be better not to dive into too much details to avoid missing of big wins for reaping the benefits for health, safety, waste reduction, sustainability, maintainability, etc. Instead of considering MEP alone, it will be better to consider holistically on how to facilitate lean construction (maximise value and minimise waste), for example, by minimisation of scaffolding, onsite storage, temporary protections, access gridding, craneage and other logistics requirements. Table 3.2 highlights the important considerations for the strategic planning and concept development.

Table 3.2 Important considerations for strategic planning and concept development

- Architectural: Selection of DfMA applied areas and demarcate repeating space/areas for DfMA to maximise repetition and standardisation
- Structural: Structural design to enable prefabricated MEP modules by adopting methods for optimising the depth of the beams and their strength to support MEP modules; structural arrangement to take into account key MEP spatial requirements and accommodate the space for optimum MEP routing, e.g. allowance of standardised beam web openings to optimise combined structural and MEP floor zones and avoid cranking of MEP services going underneath the downstand floor beam; structural bay size and modularisation strategy to take into account the quantity and complexity of onsite splicing locations between the prefabricated MEP modules pre-installed and integrated with the structural modules
- MEP: Standardisation, modularisation & integration to facilitate DfMA efficiency

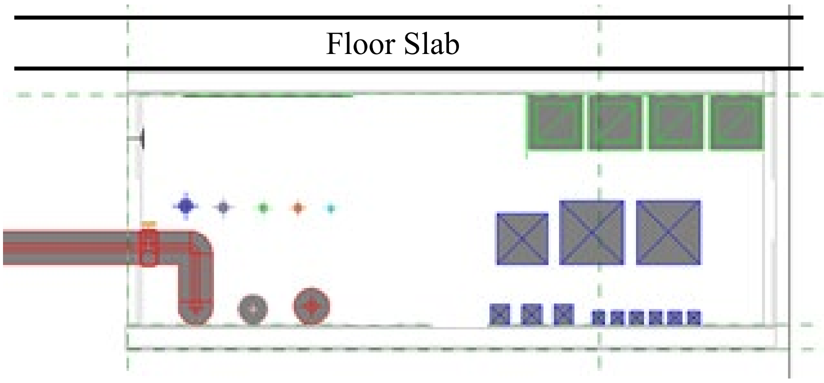
3.2.1 Design and Configuration of MEP Modules

It is recommended to rationalise the subdivision of MEP systems to enhance wider adoption of modules for plant rooms, services risers, horizontal distribution against the nature and functions of various built asset elements with their commonality to maximise standardisation. For instance, service apartments and hotels will lend itself to multiple vertical distribution whereas industrial and low-rise buildings may tend to use more horizontal distribution. To achieve the goal, collaboration among the project team members is needed to establish key strategies for plant/equipment location, distribution and room, and test against each building fabric and structure. As such, amble time is required for the design and customisation stage.

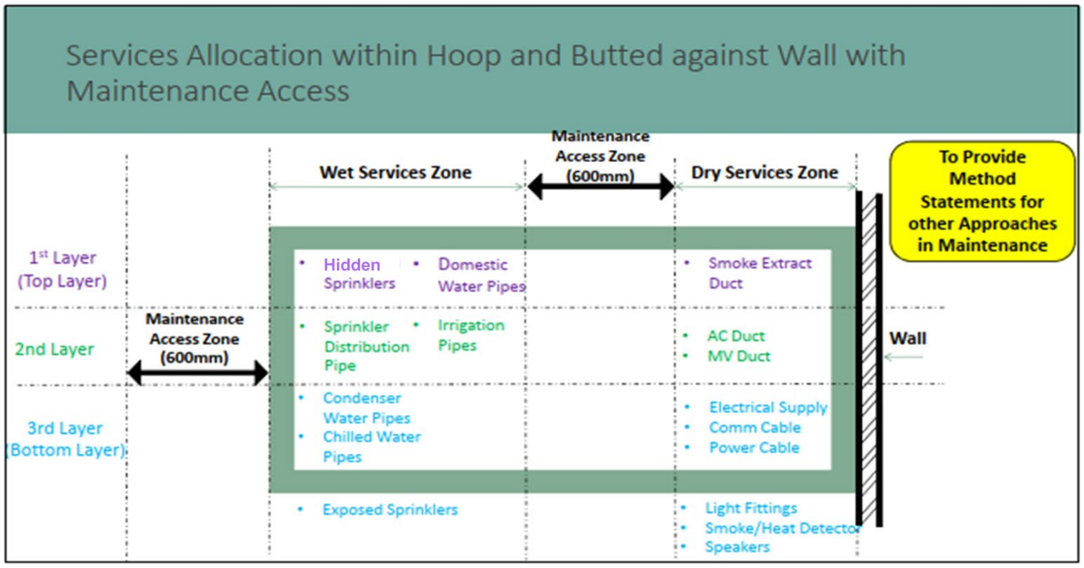
Early coordination of MEP services and spatial allowance will be advantageous. Constraints for installation and maintenance should be addressed early to avoid impact on pre-finished works in the later stage. Upfront design coordination in conjunction with structural prefabrication component is important. For effective design and configuration of the MEP modules, it is necessary to consider the integrity, expansion flexibility, maintenance, waste minimisation, and impact on structure and fire risk/safety. Usually, it is beneficial to maximise the use of any module frame by including as many services and other non-MEP elements as possible such as dry lining, access flooring and the like and ensure the cost plan allocation reflects the intended delivery. Table 3.3 shows the other practical considerations for MEP modules. Figure 3.1 shows the design philosophy for multi-service horizontal MEP module. Figure 3.2 indicates the provision of a 'red zone' of a minimum width of about 600 mm at the centre of the MEP horizontal module for workers to access both edges of the ceiling modules or installing a cat ladder in the middle of the module if there is space.

Table 3.3 Practical design considerations for MEP modules

- Establish key protocols for BIM execution across the building lifecycle for design, manufacture, installation, operation, maintenance & facility management
- Identify & foresee any unknown in future, e.g. allowance for future expansion/replacement
- Accessibility & maintainability of MEP modules should be duly considered
- Identify any dependencies on the programme, e.g. time for securing watertightness, possibility to lift riser modules together with the structural elements, time & space for moving the modules through the sites, etc., following the circulation corridors & allocated services spines
- Adopt identical modules as much as possible and try to minimise the unique elements which may not be totally avoidable
- Consider the space & the way to execute connection details to avoid complicated or difficult onsite interface
- Allocate enough space requirements for survey by laser, photogrammetry & other digital tools of building space which can help with obtaining accurate information for design & logistics arrangement
- Clearly identify the locations and spatial requirements of the equipment where regular inspection, maintenance, repairing and replacement of the equipment / system are to be conducted
- Avoid the blockage by supporting frame of the module for free access



(a) Elevation of a horizontal ceiling multi-service horizontal module



(b) Allocation of MEP services within a horizontal module with maintenance access (Courtesy of BCA Academy, Singapore)

Figure 3.1 Design philosophy for multi-service horizontal MEP module

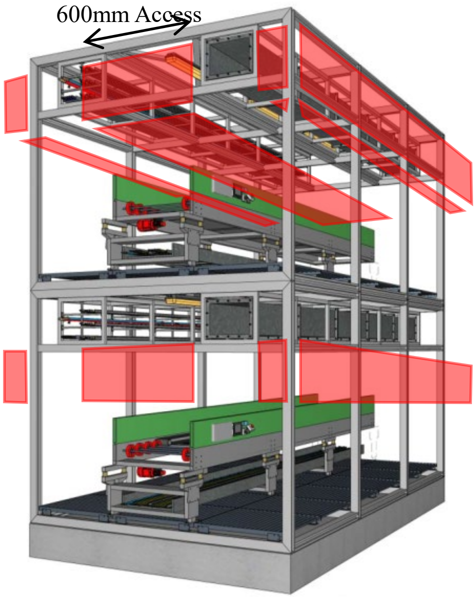


Figure 3.2 Possible configuration of work accesses ('red zones') for horizontal module (Courtesy of AECOM UK)

3.2.2 Design for Maintenance

Design for maintenance is concerned with achieving a good design that considers the general care and maintenance of equipment and the repair actions that follow a failure (BCA, 2019). If maintainability is considered and inherent to the building system and MEP design, it can ensure the ease, accuracy, safety, and economy of maintenance tasks within that system. The purpose of maintainability is to improve effectiveness and efficiency of maintenance by timely integration of design and construction knowledge with operations and maintenance (O&M) experiences into the project design at an early stage. Implementing design for maintenance will prevent impractical, unsafe or costly maintenance of MEP plant and equipment. It will also help to reduce the risk of MEP equipment failure and prevent uptime being impacted and total lifecycle costs increasing significantly.

In fact, the maintenance of prefabricated MEP installations will not vary much compared to that of conventional MEP installations (ACRA, 2020). Basic maintenance considerations (e.g. location & orientation of valves, and safe access and working space for maintenance activities) will need to be incorporated into the design before the modules are fabricated. For most MEP systems, the major considerations of maintainability design factors include:

- Provision of sufficient working space and headroom for maintenance work, including inspection, repair and replacement of components or equipment
- Provision of adequate access and appropriate facilities (e.g. working platform) for carrying out the required maintenance work
- Avoidance of the need of maintenance work at height or in confined spaces and consideration of minimised maintenance interventions and inconvenience to the building occupants
- Provision of appropriate means and methodology for replacement of any modular MEP plant (e.g. the AHUs) and associated components

Reference could be made to the checklist in the BCA 2019 Design for Maintainability Guide (Non-residential) which has been included the Reference: https://www1.bca.gov.sg/docs/default-source/docs-corp-buildsg/sustainability/dfm-guide-non-residential.pdf

3.2.3 Fire Safety Compliance, Water Leakage and Tolerance

To ensure the integrity of MEP modules and to comply with fire safety requirements, the use of right materials for construction should be considered carefully. The respective building products/materials/systems should comply with the fire test performance requirements stipulated in the fire code and fire safety guidelines. Consultation with the authorities should be sought to avoid any non-compliance to the fire safety requirements. In addition, if a fire-rated duct runs through the module, the entire module frame and associated supports must be fire-rated. If the horizontal ceiling module is used in fire-rated spaces e.g. smoke stop and firefighting lobbies, a fire-resistant board must be incorporated, in accordance with the local statutory requirements.

The arrangement of MEP services within a horizontal ceiling module requires careful consideration on the potential risk of undesirable leakages from mechanical services, e.g. sanitary waste pipe and potable water pipe. For example, in corridors with limited width, electrical services should always be installed above any plumbing and sanitary services.

Additional protection barriers can be installed between water pipe joints and electrical services above or nearby. If the width of the corridor allows, electrical services can be installed on one side in the module while the sanitary and plumbing pipes installed on the other side (Figure 3.3).

Tolerance of gradient of pipe-works connections should be considered. Angle and levelling of fittings may be affected after the module is positioned in-place. Design and planning should consider tolerance of these level differences.

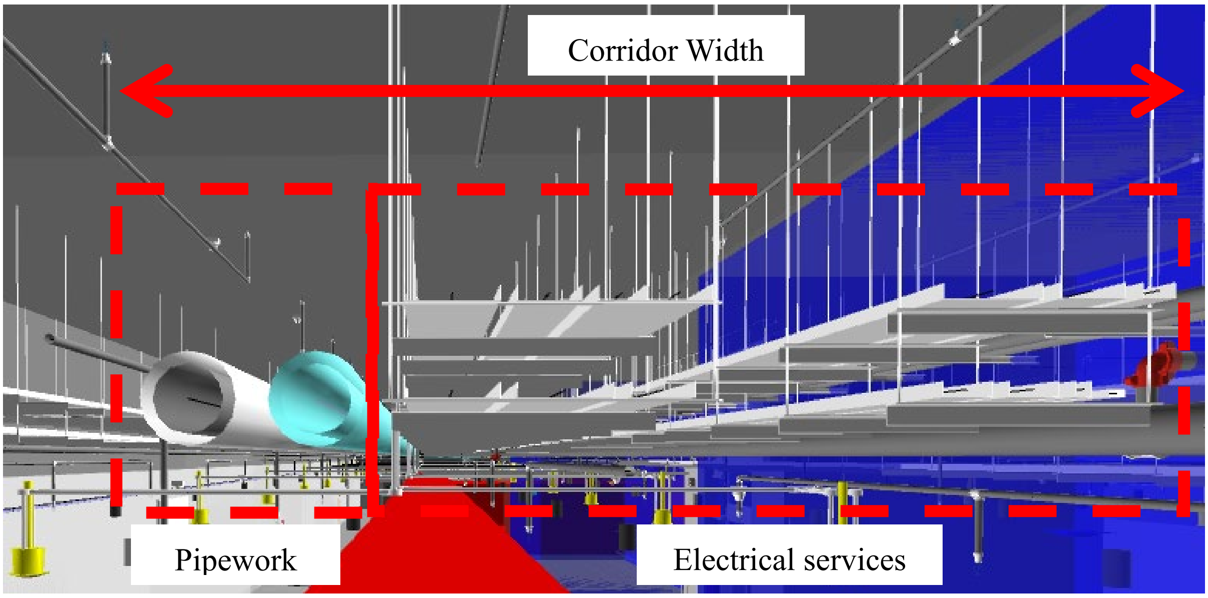


Figure 3.3 Separation between different trades of building services

3.2.4 Flexible Joints and Connections

For DfMA application, it will be apparent that flexible connection pieces may play an important role to offer a quick connection with flexibility needed to compensate for misalignment, absorb noise and vibration, compensate for thermal expansion/contraction, and/or permit movement of other connecting elements. In addition to the anchoring requirements to guide and control the flexible movement, their application also should take into account the statutory restrictions. When considered necessary, prior approval from the relevant statutory bodies should be obtained in a timely manner, apart from relevant installation requirements.

(a) Flexible Air Duct Installation

Licensing authorities such as FEHD, LCSD and HAD require the issue of Letter of Compliance (Ventilating System) by the FSD. If prefabricated flexible air ducts would be provided in premises requiring license(s), the design and installation etc. of the flexible air ducts shall comply with FSD’s requirements, including but not limited to the following:

- Paragraph 7, Part XI, FSD Circular Letter No. 4/96: The flexible duct/connectors used in mechanical ventilating systems shall comply fully with specific class(es) of UL 181 or of the latest BS 476: Part 6 and pass the puncture test specified in Paragraph 7.1.2. The products accepted by the FSD can be found in the Approved and Acceptance Material List published by the Ventilation Division of the FSD. Other installation requirements are reiterated in A Guide to Application of Letter of Compliance for Ventilating System issued by the FSD.

- Paragraph 6, A Guide to Application of Letter of Compliance for Ventilating System (September 2019): Flexible ducts are not permitted for main air distribution or penetrate through fire compartments and their lengths should not exceed four (4) metres. The flexible duct material and construction have to conform to the recognised fire performance and puncture test standard prescribed in the above Circular Letter. External insulation shall comply with BS 476: Part 7. Flexible duct made from tin foil is not acceptable.

Also, the installation of flexible ductwork or duct joints shall comply with the technical specification for the project. In case of government building projects, Clauses B2.4, B2.5 and C2.4, etc. of the General Specification for Air-Conditioning, Refrigeration, Ventilation and Central Monitoring & Control System Installation in Government Buildings of the Hong Kong Special Administrative Region (AC_GS) (2017) shall be referred.

(b) <u>Flexible Sprinkler Installation</u>

The contractor shall obtain prior approval from the FSD and WSD on the application of flexible sprinkler droppers before any installation/ prefabrication. At present, approval must be considered on a project-by-project basis.

Also, the flexible sprinkler droppers shall be of approved model(s) by Underwriters Laboratories (UL), Factory Mutual (FM) or Loss Prevention Certification Board (LPCB). The contractor shall follow the installation guidelines published by the manufacturer.

(c) <u>Cable Connections</u>

Fixed electrical installations shall comply with the Electricity (Wiring) Regulations (Wiring Regulations). Compliance with the Code of Practice for the Electricity (Wiring) Regulations should achieve compliance with the relevant aspect of the Wiring Regulations. For wiring installation involving offsite works, the Guidance Note on Fixed Electrical Installations with Modular Integrated Construction Method by EMSD shall be referred. Major considerations are described hereafter.

If a box is proposed to terminate the cables for completing the circuits between the modules, this box for termination of cables shall comply with BS 4662 or IEC 60670-1. The terminal block shall comply with the IEC 60947-7 series. The wires at a termination box shall be distinctively labelled to facilitate wire checking. The wires shall be straight-run without any joints between terminal points or equipment terminals. Also, the most relevant provisions from the Code of Practice are given below for easy reference:

- General technical requirements on conductors, joints and connections per Code 13; and
- General workmanship on installation of tables and cable termination per Codes 25C and 25D.

If prefabricated wiring system is proposed for permanent fixed electrical installations, the system shall comply with BS 8488 or equivalent, while incorporating cable couplers conforming to BS EN 61535 or equivalent. The cable couplers shall be distinctively labelled to facilitate electrical circuit checking. The prefabricated cables should be run in a vertical or horizontal direction if practicable. The cables should be secured flat on the surface of walls, columns, partitions or ceilings throughout the entire route. Also, the wiring system shall be installed by a Registered Electrical Worker (REW) or skilled person(s) under the instruction of REW, including the connection and disconnection of cable couplers.

(d) Flexible Connectors for Pipework

For plumbing installation, flexible joint provision shall be clearly indicated in relevant vertical plumbing line diagram (VLPD) in the plumbing proposal, which is usually prepared and submitted by the consultant engineers during design stage along with the Form WWO 542.

Also, the flexible joint shall be of model(s) with valid General Acceptance (GA) issued by the WSD. The model(s) shall be tested BS EN 12266-1:2012, for criteria listed in Section B9 of the Technical Requirements for Plumbing Works in Buildings (November 2020). The installation work shall be carried out by a Licensed Plumber or other designated persons under the provision of the Waterworks Ordinance.

For drainage installation, there is no specific approval required by the Building Authority for flexible joint at present.

In conclusion, if considered beneficial for a general application guideline to be established by the relevant statutory body, a collaboration between the relevant industry group and the statutory body may offer a better and more efficient mechanism to nurture a wider application.

3.2.5 Logistics Considerations

Logistics can have significant impacts on developing the concept design and modularisation including their size, weight and composition. The designer/design consultant may need to have knowledge on this and otherwise, early advice may be required from a specialist subcontractor and assisted with some swept path and logistics analysis in conjunction with the BIM site model (Figure 3.4) to establish the available delivery route and the tentative delivery programme.

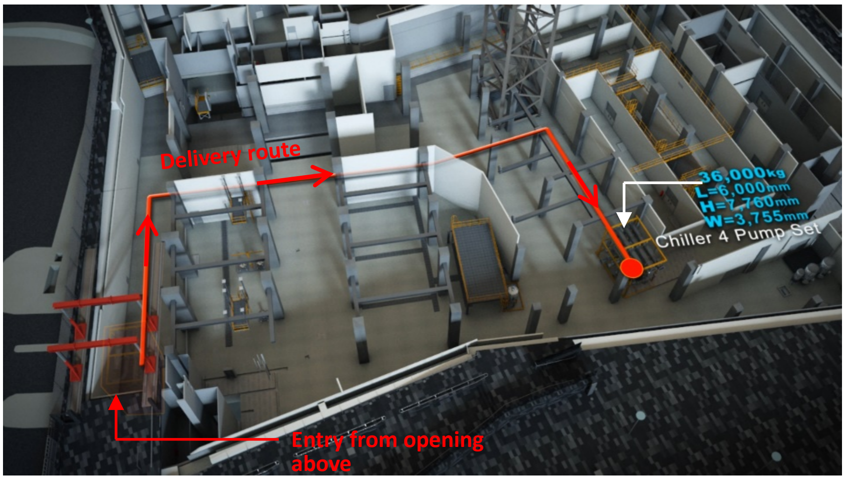


Figure 3.4 Logistics analysis for a chiller pump set in conjunction with the BIM model (Courtesy of Crown House Engineering)

The maximum size, extent of modularisation, services strategy, materials specifications, etc. will be influenced by several factors. For example, the length of each module is subject to the project requirements and standard sizes of materials supplied. In overseas projects, the typical length of each module is either 6 metres or 12 metres because pipes are supplied in these lengths.

Should the MEP modules fall outside the permitted geometrical parameters, a Wide Load Permit (WLP) is required under local regulatory requirements. Table 3.4 summarises the essential logistics factors. Further information can be found in CIC (2020a).

Table 3.4 Essential logistics factors

Factor	Description
Road transport	Avoid difficulty and high cost for transportation of the modules to the site against the wide load permit (road traffic control) application, environmental control on noisy work, etc.
Craneage & lift	Type and capacity will vary with respect to site constraints, access and oversailing of adjacent building or other obstacles. For large MEP modules, a tower crane may be required to lift them. Careful consideration must be given to how modules are lifted and installed in congested areas.
Site constraints	They include a good site access suitable for low loaders, turning circles, radii for large vehicles, as well as a predetermined delivery route within the site to the designated location. Laydown for modules may not be immediately craned into position. Arrangement of parking space may be necessary for deliveries awaiting crane time. Watch out for obstruction by overhead wires, potential temporary road closures and/or permits.
Manufacturer constraints	They include the delivery routes from factory to site, the delivery time, the flexibility for movement in the manufacturing space.
Construction programme and sequence	The best approach is often to combine the module elements together to fully share the usage of facilities for handling structure, façade and other architectural elements. The cast-in details, e.g. fixings may be determined at an early point and openings should be appropriately left if the services modules are to be installed post structural and façade completion.
Component supply	With increasing globalisation of supply chains, some modules or components will be sourced overseas. Component supply with long lead time should form part of an early assessment and be part of pre-construction programming.

3.3 BIM Tasks

The BIM tasks include development of the BIM model and components with DfMA adaptability to the level of development set out in the design responsibility matrix (see Appendix 4 for details). The BIM model should be validated against the client's information requirements. The DfMA tolerances in the development of the BIM model should be considered. Certain extent of early contractor or specialist subcontractor input may be established and executed to support the BIM tasks.

The concept design BIM model will present basic building services proposals, connections to incoming services and utilities, locations of plant areas using rectangular blocks, and routes of main pipes, ducts and electrical distribution in such detail as to show the incorporation of the engineering services in the project as a whole and with respect to any treatment zoning across the floor-plate. Major elements and systems are shown but not detailed components. Figure 3.5 gives an example of 3D view of a concept design model.

In general, the design of MEP modules should be generated from the CSD which are produced in BIM. The contents and LOD in BIM to be delivered at each project stage, as well as the role of each project member, should be clearly defined before commencement of design. The objective of the coordination approach is to ensure that each designer is fully aware of the existence of other services which may otherwise cause clashes. Having established the possible optimal routing, the design of each service is carried out in sequence. The priority of MEP services can vary according to the nature of the project, but the procedure usually involves drawings to be returned to the architect for approval after each service has been introduced. Some alteration is expected in coordination with other designs.

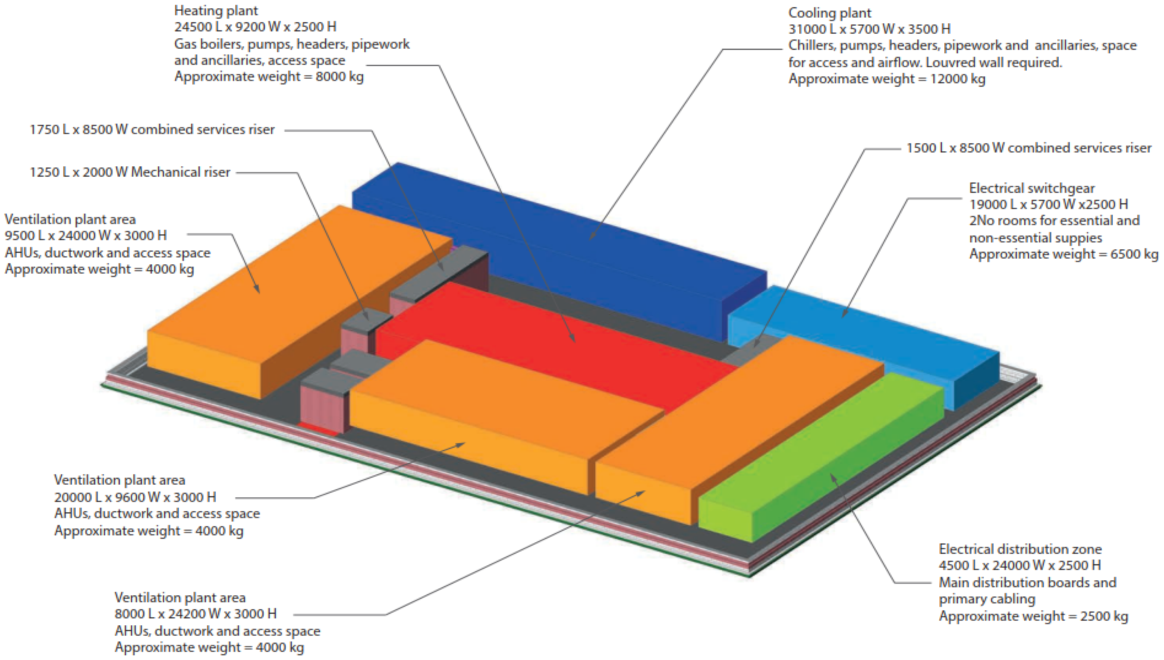


Figure 3.5 3D view of a concept design model (Churcher, Ronceray and Sands, 2018)

3.4 Procurement Tasks

The procurement strategy should be updated as a result of the concept design study. Discussions with contractors and specialist subcontractors should be carried out along the procurement route to test DfMA objectives set out in the concept design including the construction strategy. Adopting a procurement policy with early contractor involvement in the design process may be considered if appropriate.

3.4.1 Adoption of Early Contractor Involvement (ECI)

Under traditional procurement approach, procurement of the MEP subcontractors for any MEP trades are segregated from each other and that of the main contract. Each selected MEP subcontractor will eventually be appointed as a subcontractor of the main contractor. In some cases, the tender and/or award of the subcontract packages may only occur during the construction period, after the main contract has been awarded. With a clean contractual break between design and manufacture, therefore, traditional procurement limits the opportunity for DfMA.

Implementation of DfMA in MEP requires a different approach on procurement, in which design decisions towards offsite factory construction must be made at the very onset of the project. The process may require early involvement of the MEP subcontractors to work together with the main contractor and the project design consultants. Input from the MEP subcontractors can then be seamlessly incorporated into the design to attain a more effective and holistic technical solution, thereby avoiding additional costs and time due to late design changes, in particular changes in building layouts and MEP accommodation. In some projects, a leading subcontractor coordinating different MEP services may be required.

Early contractor involvement (ECI) refers to the involvement of a contractor at an early stage of project development, to work together with the client and/or project design consultant in partnership, mainly to assist in planning and buildability (Rahman & Alhassan, 2012). The contractor in the ECI approach can be engaged through various methods. In moving towards the early involvement of the MEP subcontractors, it will include the early appointment of MEP subcontractors as nominated subcontractors or having the main contractor to team up with MEP subcontractors to tender for the project. If the client may have reservation of early release of project information to specific contractors, then at the inception/concept stages, the input knowledge on DfMA would largely rely on the experience and competence of in-house or consultant designer. The ECI approach for DfMA in MEP works is illustrated in Figure 3.6. The need to appoint an MEP specialist will depend on the experience and competent of the in-house or consultants appointed by the client at the inception/concept stages of the project.

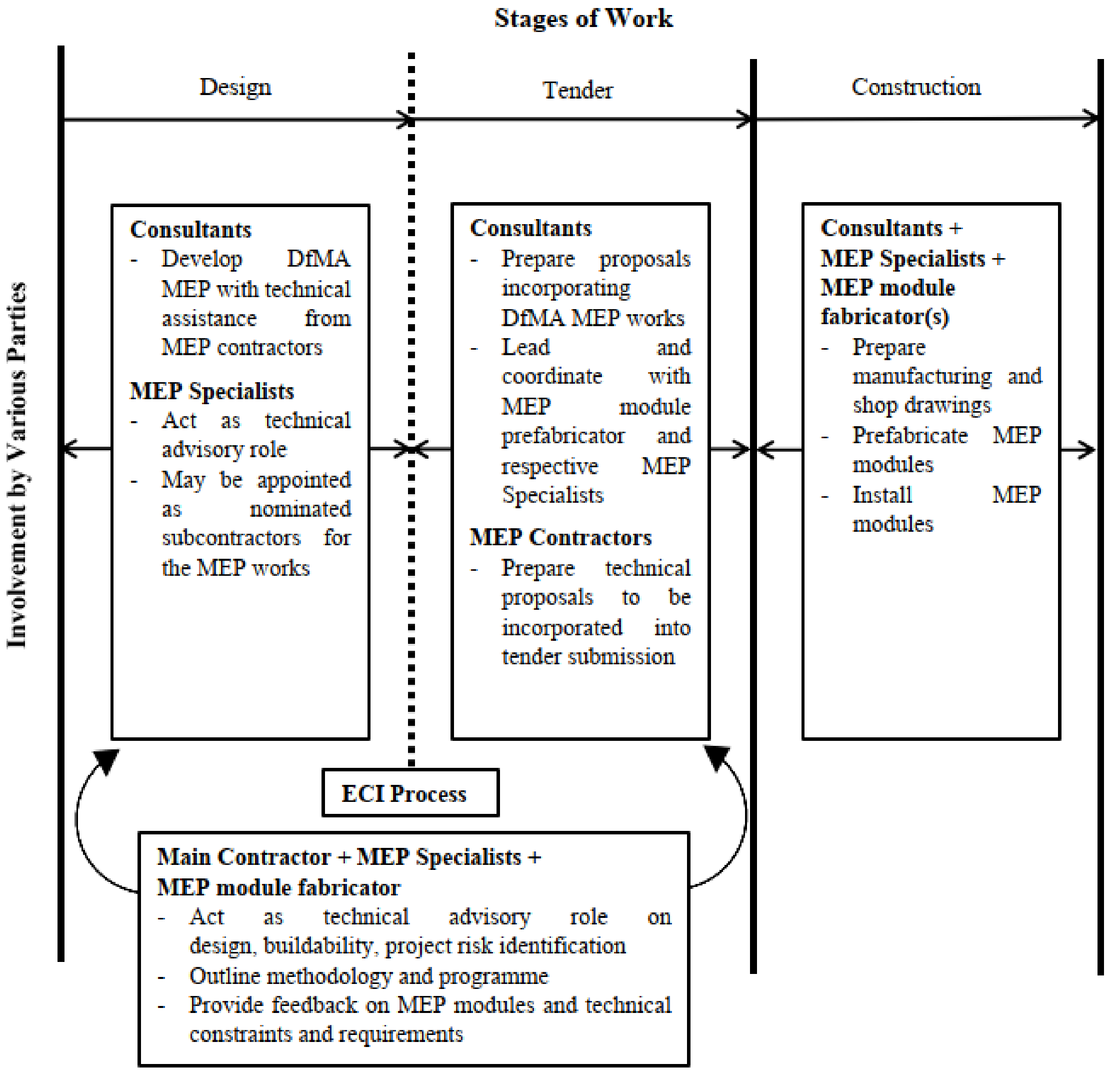


Figure 3.6 Early Contractor Involvement (ECI) approach for DfMA MEP works
[Adapted from Boon & Doig (2019)]

If ECI is considered as beneficial to the project, there may be various options as described in the 4.4.2 Collaborative Procurement of this Guidebook to be appropriately chosen against the project specific situations.

3.4.2 Procurement Strategy

The procurement strategy should include strategies for supervision for both offsite prefabrication and onsite construction, taking into account the level of offsite prefabrication adopted in the design (The consultant team could be instructed to incorporate into the design with the recommendation on construction staging and packaging of the works contract(s), and the tendering strategy for letting out the works contract(s)). The responsibilities for various parties will follow the strategies and pro forma established in the previous stages which are explained in the Design Framework for Building Services (Churcher, Ronceray and Sands, 2018). The established procurement strategy and task lists may be updated for holistic considerations for steps and tasks to be taken by various parties as relevant for this stage.

If necessary, research & development may be initiated and duly allowed in the construction strategy and procurement strategy to integrate into the project in a timely manner to facilitate the wider adoption of beneficial DfMA innovations. For instance, early involvement of MEP subcontractors is essential to ensure all DfMA options can be considered during the concept design.

The consultant team could be instructed to incorporate into the design with the recommendation on construction staging

4. Detailed Design

Detailed design stage is also known as developed design or spatial coordination (Stage 3) in the RIBA Plan of Work (RIBA, 2016 & 2020). It is the process of taking on and developing the approved concept design. During this stage, the concept design is further developed and the design work is progressed until the spatial coordination exercises have been completed between the main design disciplines (architectural, building services and structural).

4.1 Core Objectives

The core objectives at this stage are to prepare detailed or developed design including spatially coordinated and updated proposals for architectural, structural and building services systems, outline specifications and updated cost plan and project strategies in accordance with the design programme. Table 4.1 shows the expected deliverables at this stage.

Table 4.1 Expected deliverables at the detailed design stage

General aspects: • Statutory approval & compliance including items requiring modification or exemption • Finalised layout plans showing detailed design intent & services coordination • Proposed building materials, systems and equipment for tender • Revised project estimates & confirmation of contract strategy • BIM models showing design coordination • Updated information on sustainability strategy (e.g. BEAM Plus assessment), buildability evaluation, universal accessibility design & innovative designs
MEP aspects: • MEP schematic diagrams, layout, detailed design intent, drawings & design report • Detailed planning & drawings of service zones & risers • Detailed list of pre-selected plant and equipment & final builder's work requirements • Weight & dimensions of major plant and equipment • Reliability and maintainability planning report with cost effective analysis • Revised MEP cost estimates & templates for estimation of energy saving

4.2 DfMA Strategies and Considerations

The construction strategy and cost plans will be updated taking into account the selected or potential DfMA opportunities appropriate to the detailed design and coordination activities. A schedule of DfMA components should be prepared and appropriate standards for DfMA should be considered. The buildability issues, including erection sequence, fabrication or manufacturing techniques and tolerances requirement on interfacing, will be considered. The cost information and procurement route will be refined taking into account discussions with potential contractors, specialist subcontractors and suppliers. Also, the risk assessment, health

& safety and maintenance & operational strategies established in the previous stages will be updated taking into account DfMA considerations. Table 4.2 indicates the important DfMA planning issues for detailed design stage.

Table 4.2 Important DfMA planning issues for detailed design stage

Issue	Description
Market research	It can be carried out to gain a good understanding of what products, systems and supplier capabilities exist. Proactive engagement with manufacturers will be needed to ensure products and technologies are readily available in the market to comply with the proposed project timelines.
Define interfaces	Defining inputs & outputs, touch points and dimensional tolerances will require a collaborative approach. Crossover zones/space may be allocated for systems and services, to provide ventilation and working space; and ways of isolating noise and vibration passing between areas should be considered. Particular attention is needed for interfaces between onsite and offsite elements and their associated dimensional tolerances. Configuration management of these interfaces should be established from the start and clearly defined.
Define work packages	Define the facility in terms of form and function to maximise potential and scope so that suppliers can determine how they could best meet the brief. Define work packages that can be delivered in multiple ways, including offsite elements by referring to the interface definitions and extending configuration management to the package definitions.
Benchmark for lean construction	Select the optimum mix of onsite and offsite elements in a holistic way so that the interaction of options is understood. For examples, heavy plant in the basement or on the ground floor could enable a lower performance requirement and cost of the superstructure or roof. Consider the client's drivers & project KPIs and identify ways of delivering increased value and create performance benchmarks for the project. There should be a benchmark for lean construction methodology optimised with respect to onsite and offsite activities and most likely will be a hybrid of the two.
Design documentation	The detailed design development should be documented to serve as integrated production information to be produced on a package basis with limited risk of changes to primary coordination.
Maintainability	System/equipment isolation, disassembly sequence of the equipment/service run/supporting frame of the module and the delivery route shall be developed at detailed design stage to ensure the feasibility and safety of the repairing and replacement works.

Coordination of elements designed with DfMA and prefabrication in mind, particularly within a federated BIM model, and the increased use of multi-functional components can eliminate duplication and reduce costs. BIM, Common Data Environment and digital data exchange between different contract parties should be covered in the BIM execution plan in Work Stage 0/1 and the BIM model should be developed sufficiently in the reference design in a design & build contract (or the detailed design in a design-bid-build contract) to ensure that critical information is given to the tenderers during the tendering process.

Early procurement of factory-manufactured prototypes and mock-ups can help the design team to refine designs before mass production commences, eliminating any details that are tricky to install onsite and allowing the visual aspects to be fine-tuned. Detailed design stage should comprise the generation of design-intent information from the design team and the follow-on development of fabrication information (drawings or models) for approval. Examples of templates for DfMA MEP are shown in Appendix 6.

When developing the detailed design, adequate access points, inspection pits and accessible recesses for concealed installations should be provided and indicated on the drawings to facilitate future inspection and maintenance. Also, adequate space should be considered and provided at congested positions such as ceiling voids of the corridors.

4.2.1 MEP Offsite Strategies and Principles

The MEP offsite strategies should be developed and agreed during this stage to incorporate practical advice from specialist subcontractors and contractors accordingly. It is also necessary to consider programme implications related to multi-service modules with additional supports or serviced walls. For example, the design for the MEP services may need to be further advanced than traditionally. The need to incorporate fixings or elements within earlier delivered packages, such as structure, means that this needs to be carefully aligned across all design disciplines. The lead designer should have experience in this respect and the main contractor or specialist subcontractors may assist with detailed programme information. Furthermore, a specialist subcontractor may be required to optimise with computer design software for the supporting rack arrangements, and provide consideration on structural suitability, thermal insulation, fire resistance, corrosion & sound/vibration isolation, BIM information with interface details, logistic plan, planning for onsite works (e.g. cutting, kitting, pre-assembly), customised delivery schedule, method statement on installation and sequence, and staff training. Table 4.3 explains the important design principles for MEP offsite strategies.

Figures 4.1 shows examples of installation systems supporting the technical equipment for building services such as pipes, conduits and cables. Further information can be found in the relevant European standard (EOTA, 2018).

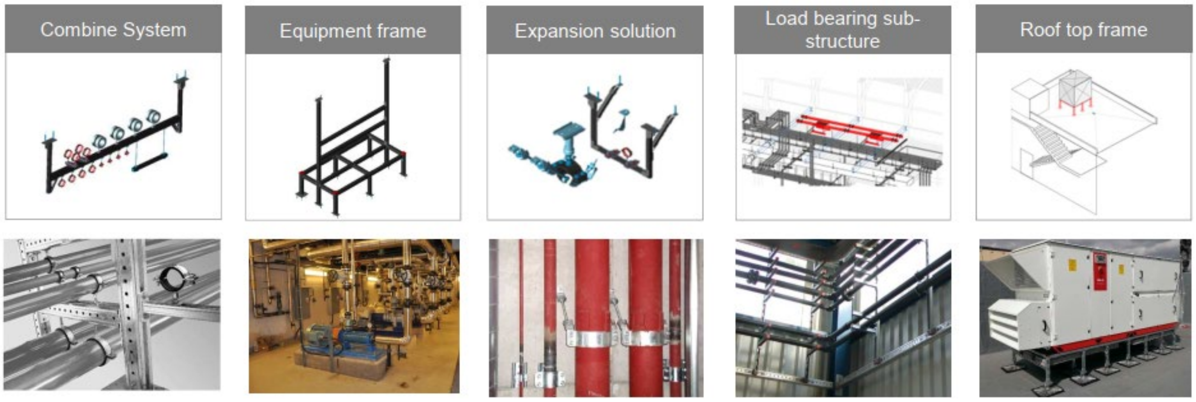


Figure 4.1 Examples of MEP modular installation support systems (Courtesy of Hilti)

Table 4.3 Important design principles for MEP offsite strategies

Structural requirements & analysis: • The weight of MEP modules & their dynamic loading should be provided to determine the building structural requirements • Structural analysis of modules should be done (may be generic from project to project) to comply with codes & other specified design standards • Since modules impose loading on structure differently, if compared to onsite assembled MEP systems, it is essential to ensure that the structure is detailed for the ease of installation of fixing points, e.g. cast-in channels, which can take point loads in both temporary and final positions • Consider base plate design for skid mounted assemblies & plantrooms to spread the load evenly • Consider imposed point loads & numbers of fixings required for suspended modules as the cost of upgrading capacities of slabs can be significant • Additional loads for steel frame should be considered by the structural engineer • Expansion & contraction arrangements with modules may be differently imposed on the structure due to module frames and these should be detailed at this stage • The modular frame for supporting multiple services subassemblies and/or fully integrated assembles will require structural consideration to withstand the stress encountered during the transit and operation conditions
Supporting system of MEP modules: • Structural design of supports should utilise standard strut components & hardware, with all mechanical connections & bridging from the modules, as much as possible • The supporting frame should allow a certain level of flexibility for adjustment and adequate space to be provided between services for future maintenance and modification • The support system should be as lightweight as possible for easy of lifting and installation • If welded connections are used in the assembly, measures to prevent corrosion to the welded connections should be provided, e.g. cold galvanizing paint with zinc • The overhead components should be independently supported & modules can be linked in tandem for a continuous service run • The supporting systems should be robustly designed against the anticipated loading by professional structural engineers and appropriately incorporated throughout the design and construction process, as well as statutory approval as necessary
Interface & field connection: • Where services are incorporated into other elements (e.g. a serviced wall), the services design should be completed in sufficiently advance in programme, otherwise, strategy should be set out in the concept design stage to make the service design independent to these elements • Detailed design shall incorporate field connections & equipment such as electrical connectors or controls outstations. They should be mounted on distribution or terminal modules within the factory as many as possible

4.2.2 Detailed Design of MEP Modules

To facilitate offsite strategies, prefabricated MEP modules can be used and they are divided into three main types: horizontal ceiling module, vertical riser module and plant module (BCA, 2017 & 2018). Other modules commonly adopted by the local industry include panelised electrical modules, integrated AHUs and modular condensing pipework system. Table 4.4 presents the major design considerations for prefabricated MEP modules, with examples by an offsite manufacturer given in Figure 4.1. Figure 4.2 shows an example of access space provided between vertical tiers within a module. If a proprietary system is adopted, the possible constraints and requirements should be identified and included in the detailed design. For the modular grouping, engineering calculations should be carried out based on the agreed modular approach (e.g. for cable sizing, assume a radial rather than ring circuit, systems grouped and routed according to the concept strategy).

Table 4.4 Major design considerations for prefabricated MEP modules

Horizontal ceiling modules: • A ceiling module should aim to include most if not all of the MEP services • The design should consider the potential risk of undesirable water leakages & fire safety • The distance between vertical tiers of the module should be at least 100 mm to allow access for further works • The modules should include components that allow adjustment to the level of services to cater for required gradient and construction tolerance
Vertical riser modules: • The module comprising ducts and pipes can be constructed horizontally at the factory • A riser module can be installed prior and independent to the erection of block walls of the riser shaft • Another method of installation is to lower the modules into the riser shaft through designated openings at the top floor. Therefore, lifting lugs and bracketry should be incorporated in the design of vertical riser modules
Plant modules: • Prefabricated MEP plant modules are fully pre-assembled with control panels, internal wiring and instruments mounted on skids with lifting eyes for piping connections & valves, cable termination for power supply, interfaces for building automation system and fire alarm system, where applicable • Two or more modules can be combined using flexible connections onsite to complete the installation in a plantroom

Figure 4.2 Access space provided between vertical tiers within a module (Courtesy of Hilti)

4.3 BIM Tasks

The design stage model should be handed over to the contractor to develop the shop drawing model. Contractual liability to take over the design model is required to be resolved (see also Section 4.4.2). Where BIM is being used, during this stage, the project information model is developed based upon generic representations with approximate quantities, size, shape, location, tolerances, and so on. Specification properties and attributes are developed so that the selection of systems and products is possible. Structural and architectural information should be developed in detail, and MEP design may include generic information about sizes, capacity and control systems. The model development should involve early contractor engagement and preliminary construction sequence.

The BIM model and components together with other digital coordination technologies should be further developed to an appropriate level of details set out in the design responsibility matrix and validated against the client's brief. The project is also likely to have a BIM library containing client-specific designs and standard products along with generic representations of the building services and systems.

4.3.1 Detailed Design Model and Clash Evaluation

The BIM detailed design model should include the extent of building services systems and the services treatments for each individual space with the relevant information on performance and spatial requirements. Approximate locations of horizontal and vertical services runs should be shown and the BIM model should convey maximum space requirements for expected plant and distribution systems, taking account of falls, coordination, tolerances, installation, maintenance and removal. The model could also indicate designs for repeatable areas (e.g. standard room types) to identify key principles.

Tolerances for detailed design models, in terms of absolute values, percentage variance, in relation to volume, area, length, weight or some other properties, should be agreed between the client or approval unit and the designer before commencement of detailed design. BIM objects are linked together into systems and typical object parameters will be added and further developed. Figure 4.3 shows an example of 3D view for a developed design model.

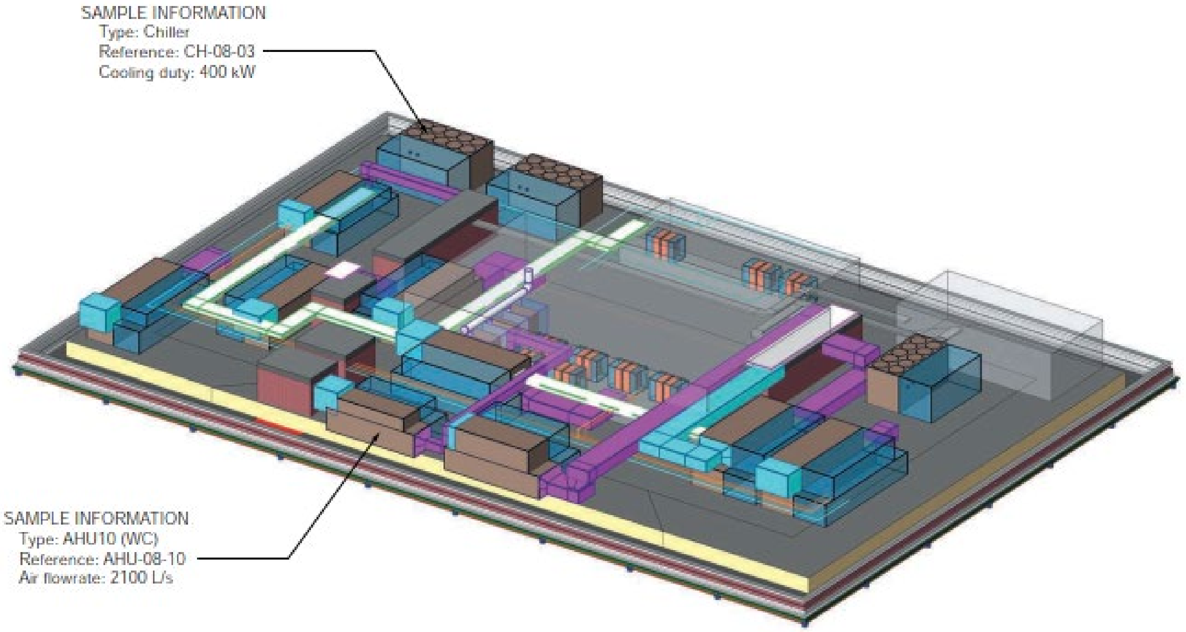


Figure 4.3 Developed design model 3D view (Churcher, Ronceray and Sands, 2018)

With the BIM model, the design coordination should continue based on the responsibility matrix. Typical uses of the model at this stage include:

- Analysis for the approximate nominal capacities of plant and distribution systems
- Costing based on approximate quantities and sizes on plan
- Programme estimate on timing of installation of the building services systems

Also, the design coordination should continue to eliminate the clashes along the framework laid down in the previous stage. While a clash-free model would be ideal, some types of clashes may be resolved at a later stage as defined in Table 4.5 to optimise the efficient use of modelling resources. Figures 4.4 and Table 4.6 show different types of clash and the clash evaluation for MEP elements.

Table 4.5 Descriptions of acceptable clash types (Churcher, Ronceray and Sands, 2018)

Types of clash	**Description**
Critical	Major clash – must be resolved at this stage
Moderate	Easily resolvable – does not have a major impact on ongoing design. Can be resolved at a future design stage
Allowable	Acceptable clash – resolution not required in the design model

4.3.2 MEP Design Information

For mechanical services, principal ductwork (within risers and from risers to local plant) could be shown as 3D objects to demonstrate that the routes indicated are feasible. Ductwork from local plant to terminal units and pipework may be represented by centrelines, but should also detail routes to and from secondary area.

For electrical services, distribution boards should indicate numbers of ways and proposed loads. Electrical containment can be represented by line diagrams unless it is similar in size to the principal ductwork when 3D objects should be used. Lighting detail is typically at scheme design level, but layouts should be provided in sensitive areas.

For plumbing and drainage services, stack locations, float pipe locations and letter box space allocations for pipe falls along drainage runs should be shown.

Definition of the term "clash": Two distinct elements occupying the same space. Space for access, installation and maintenance must also be allowed for.

		Examples					
		Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
Critical	Major clash - must be resolved at this stage	If a plant height requirement exceeds the SSL to soffit height	Main plant equipment or access zone clashes with structural or building fabric elements, or other main plant equipment. Primary distribution services clashing with anything such as to require major re-routing. Insufficient spatial allocation for distribution and terminals	Any services (other than final connections to terminals) clashing with services or with other construction elements	All clashes resolved to allow installation without rework	Not applicable at this stage	Not applicable at this stage
Moderate	Easily resolvable - does not have major impact on ongoing design. Can be resolved at a future design stage	If a column clashes with a plant zone but services can be coordinated within, or column re-arranged; Riser zones clashing with slabs and walls	Cable trays clashing with ductwork within ceiling void, provided sufficient space is demonstrated	Not applicable at this stage	Not applicable at this stage	Not applicable at this stage	Not applicable at this stage
Allowable	Acceptable clash. Resolution not required in the design model	Not applicable at this stage as the level of detail is not sufficiently advanced	Not applicable at this stage as the level of detail is not sufficiently advanced	Small pipework / conduit runouts to equipment / final circuits where space is proven to be sufficient	Not applicable at this stage	Not applicable at this stage	Not applicable at this stage
Recommended Coordination Activities:			Model typical transfer zones; Typical ceiling voids in corridors & above rooms	See section 2.4			

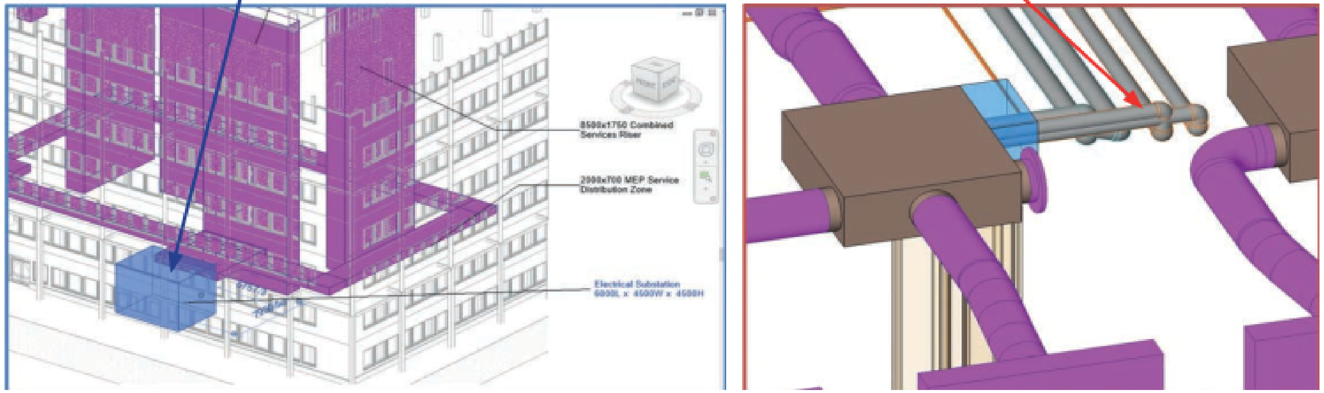
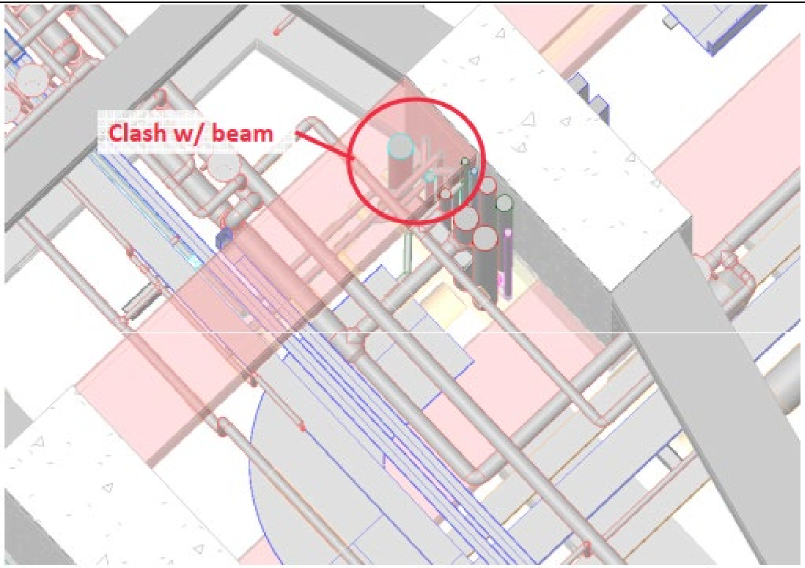
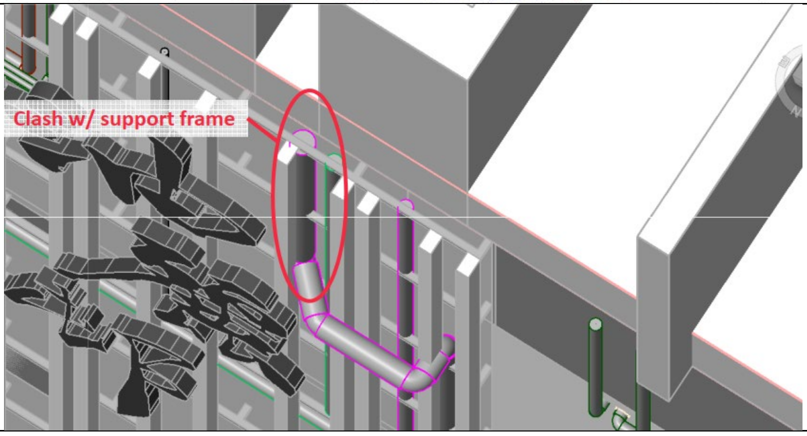
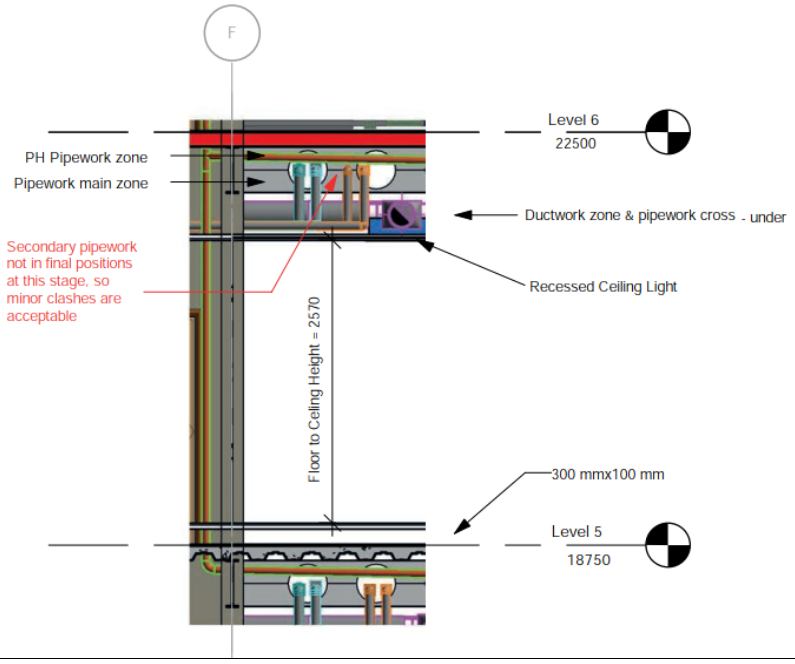


Figure 4.4 Types of clash and their applicability (Churcher, Ronceray and Sands, 2018)

Table 4.6 Examples of clash evaluation for MEP elements

Critical – Pipe risers clash with structural beam (Photo courtesy of Vircon)	
Moderate – Drain pipe clashes with architectural frame, where space is proven to be sufficient (Photo courtesy of Vircon)	
Allowable – Pipework clashes with structural beam, where space is proven to be sufficient [Photo extracted from Churcher, Ronceray and Sands (2018)]	

4.4 Procurement Tasks

There will be further discussions with contractors and specialist subcontractors relevant to the procurement route to test DfMA components and coordination exercises set out in this stage with updating of the construction strategy. A collaborative procurement model and digital technologies may be applied to assist engagement and coordination exercises.

4.4.1 Contractor Design Portion (CDP)

The Contractor Designed Portion (CDP) is a contractual arrangement whereby the building services contractor is required to carry out the detailed design of specific elements of the works. Examples of elements where CDP engagement is typically applied include prefabrication/offsite construction, lifts and escalators, combined heat and power (CHP), controls and building management systems (BMS).

The building services contractor may then engage specialist subcontractors to carry out these works on their behalf. For these elements, the client's designer would normally produce a performance design (including any key requirements and restraints) as part of their duties, and then pass the detailed design responsibility onto the contractor. This type of arrangement typically occurs where the detailed design is normally carried out by the specialist company who will be installing it as the expertise does not reside within the client's design team.

Where CDP is being used, it is important that the interfaces between the scope of design work of the client's designer and that of the contractor are agreed and clearly understood to avoid any potential gaps in design responsibility. This should be done using the allocating model, drawing and information production spreadsheet in Appendix B of the Design Framework for Building Services (Churcher, Ronceray and Sands, 2018). As well as being detailed within the building services specification, the requirement for the contractor to carry out design portions needs to be reflected within the form of contract used for their engagement, and most forms of contract produced by reputable providers have versions which include contractor designed portions. Attention should be given to the structural support design requirements for MEP modules and whether the design responsibility is assigned to the contractor.

4.4.2 Collaborative Procurement

At the detailed design stage, ECI is very useful particular for the detailing and integration of DfMA to other parts of the project. In general, DfMA requires early engagement of contractors and specialist subcontractors in the design phase, depending on complexity of DfMA strategies. Therefore, it is necessary to have a paradigm shift to change the traditional procurement process, in order to bring contractors in earlier, so that the designers and contractors can form a solid business case together using a collaborative procurement model. As a result, payment mechanisms and risk allocations need to be tailored to suit procurement of offsite construction under the DfMA approach. It is believed that by using standard and off-the-shelf components as stipulated in DfMA, the purchasing lead time and costs can be reduced.

Unfortunately, at present, there is currently no standard procurement model for DfMA. When applying the DfMA offsite approach, it is necessary to consider best value rather than best price so that the key non-monetary benefits and full lifecycle costing are taken into account. It is believed that developing a collaborative procurement model can best enable the DfMA approach. At present, a pragmatic approach is to identify the responsibilities for various parties by following the current strategies and pro forma as recommended in the Design Framework for Building Services (Churcher, Ronceray and Sands, 2018) or other similar methods. Then, a suitable procurement strategy and task lists can be established and regularly updated for holistic considerations of the steps and tasks to be taken by various parties for DfMA adoption as relevant for this stage.

The following options for contract arrangement may be chosen against the project-specific objectives and target timelines. The project team members should collaborate to choose the best option as an optimised and balanced solution after due considerations of various project factors, such as development objectives, project KPIs, budget, programmes, site constraints, partnering relationship with their potential product and services providers, etc.

- Design and build contract, as often adopted by government on major projects, which enables early commitment and a teamwork environment to consider alternative solutions.
- Management contract, with an early integrator in the example shown with HSBC headquarters project.
- 2-stage tendering, process to enable early input from related specialist subcontractors before the final tender and contract award.
- Partnering arrangement provides an early involvement and a less adversarial environment for the key parties to perform in a team such as the relevant NEC practices with early contractor involvement option.
- Framework agreement for pre-agreed fee and cost framework, when the key suppliers and contractors have been employed by the client for a number of years and for a collection of similar projects, to allow timely involvements by the project team, whilst providing closer contact with the client for his needs and opportunities to apply the benefits of well thought solutions over several similar projects.
- Traditional approach, supplementary with buildability adviser during the design stage.

5. Documentation and Tender

The documentation and tender stage is also known as technical design (Stage 4) in the RIBA Plan of Work (RIBA, 2020). Technical design refers to project activities that take place after the detailed design (or 'developed design' or 'definition') has been completed, but before the construction contract is tendered or construction begins. Increasingly, however, technical design may continue through the preparation of production information and tender documentation and even during construction itself, particularly where aspects of the technical design are undertaken by specialist subcontractors. Regular reviews should be carried out during this stage to assess construction sequencing, buildability, the interfaces (between different elements of the design), and the project programme and risk.

5.1 Core Objectives

The core objectives at this stage are to prepare technical design according to the design programme to include all architectural, structural and building services information, specialist subcontractor design and specification in accordance with the design responsibility matrix and project strategies. The designs of the main disciplines (architectural, building services and structural) are further refined to provide technical definition of the project and the design work of specialist subcontractors is developed and concluded. The level of detail produced by each designer will depend on whether the construction onsite will be built in accordance with the information produced by the design team or based on information developed by a specialist subcontractor. Table 5.1 shows the expected deliverables at this stage.

Table 5.1 Expected deliverables at the documentation and tender (technical design) stage

General aspects: • Site availability, design calculations and detailed drawings • Tender drawings, builder’s work drawings & particular specifications • Material & equipment schedules, draft special conditions of contract • List of prime cost & provisional sums, detailed pre-tender estimates • Tender queries & responses, tender assessment, tender report & recommendations • BIM models showing design coordination (technical design model) • List of contractor’s design items • Updated information for green building assessment (e.g. BEAM Plus)
MEP aspects: • Contract strategy (finalised), MEP tender drawings, specifications & equipment schedules • Demarcation of building services contracts & schedule of the client’s supplied items • MEP design calculations, technical drawings, schematics, coordinated working drawings • Advice on the categories & groupings of subcontractors • Advice on the timing for the tender of nominated subcontractors • Technical design by specialist subcontractors/suppliers

5.2 DfMA Strategies and Considerations

The DfMA components should be more accurately developed by considering the implications of the possible methods of manufacturing or fabrication. More details should be developed on the interfaces and specifications for structural, water/moisture/vapor penetration, and vibration/acoustic issues. This will probably involve the specialist subcontractors in production drawings taking the tender design to a point suitable for manufacture offsite. Also, the construction strategy should be further updated by considering the logistics arrangement (lifting, handling and transportation) and programme for each DfMA component and subassembly. In addition, the risk assessment and health & safety strategies should be updated to consider manufacturing and assembly risks. The commissioning plan should be established for both onsite and offsite works to optimising the use of factory acceptance testing.

5.2.1 Important DfMA Planning Issues

Traditional onsite approach allows specialist consultants/contractors to make minor adjustments to suit site conditions, but this is not possible in a factory environment. The level of detail required will be greater to compensate for this but will have a real benefit of a fully worked through design. At this stage, final framing, commodity components, manufacturer-specific equipment detailing and manufacturing information such as break jointing are finally resolved.

Manufacturing lead times and capacity planning, combined with the reduced ability to modify the design onsite at the erection stage, mean that those aspects of a project's design which interface with the offsite elements need to have their design frozen, prior to manufacturing, planning & ordering the long lead time components and materials. Once the manufacturing procurement process has started and the order received by the supplying factory, the ability to change designs drops rapidly and the cost of change can also increase significantly.

It should be clear on what the applicable codes and standards are and how approvals will be obtained, particularly for statutory approval and inspection requirements of offsite manufacture across the border. In Hong Kong, the documents published by the Construction Industry Council (CIC) on the statutory requirements for MiC projects are useful (CIC, 2020b & 2019). However, it is important to note that the performance of DfMA strategy is not always equivalent to assemble constituent parts traditionally, since each different approach adopted in design, procurement, manufactory, delivery, etc., will create different outcomes.

The essential logistics factors as mentioned in Table 3.4 and developed in the previous stages should be reflected in the tender documents. Construction programmes with a high offsite content can be a lot shorter than traditional methods, even allowing for the factory production lead time. The key to achieving this is to create an overall balance in the flow of assemblies and site works that establishes a repeatable rhythm. The same applies within the offsite factory. A balanced flow-line with short change over times and a flexible multi-skilled workforce combined with a controlled working environment can increase safety, productivity, and quality performance dramatically and help achieve "just in time" manufacture.

In order to ensure high construction performance for the project, the manufacturing method statements and tolerances should be specified and designed carefully. Table 5.2 discusses the important DfMA planning issues for the method statements and tolerances.

Table 5.2 Important DfMA planning issues for the method statements and tolerances

Issue	Description
Method statements	They are becoming very comprehensive but arguably less accessible by the people actually doing the work. Manufacturing method statements bring all of the relevant information for a production stage together in one very visual set of instructions. These may be called "One Point Lessons" or "visual task sheets". They detail everything the operative needs to know about assembling a particular product or family of products, BIM is adding another dimension to this, providing both 3D drawings and the ability to view the model in an interactive way where risks can be highlighted, assembly sequences animated and information such as specifications and test result viewed by simply pointing at the relevant component.
Tolerances & fixing systems	Accuracy of onsite construction will affect the design of MEP offsite design. It is easier to achieve tighter production tolerances in a controlled factory environment than a construction site. It is helpful if designers have an understanding of the tolerances & fixing systems for different product families, materials & production methods. Where a structure has a predictable installed dimensional range and the achievable dimensional tolerance range of an offsite assembly is known, a suitable fixing system that can accommodate the two extremes of these ranges may be used. With a good control over both the structural element & the related MEP element, fixings may be pre-positioned and incorporated into the structure during manufacture. Examples of this being done include threaded sockets included in precast concrete panels or electrical conduits and switch or socket back boxes being incorporated into modular wall panels.

5.2.2 Lean Manufacturing Management for Offsite Elements

Most offsite construction constitutes the assembly of "off the shelf" products and materials, to suit the project-specific dimension and will be purchased directly from the manufacturer with others will be procured through distributors. A principle known as RRS (runners, repeaters and strangers) is commonly adopted in lean manufacturing management to categorise the items and optimise the management of offsite manufacturing elements (https://leanmanufacturingtools.org/). This principle is explained in Table 5.3. As a lean tool, it is typically used for identifying where to concentrate efforts. It could also be used for evaluation of activities such as products, problems, processes or projects, to support decision-making and sequencing of activities.

Table 5.3 Principle of RRS (runners, repeaters and strangers) in lean manufacturing

Item	Description
Runners	Standard items which are carried out frequently, highly predictable, consistent & usually efficient as low value but frequently used components (e.g. fixings & standard brackets, or multiple services support frames of MEP terminal equipment items). They may be supplied by a local company, which replenishes stores next to the assembly line on a regular basis (say weekly), probably using a “2 bin” or Kanban system (Figure 5.1). When the bin closest to the operative is empty it is moved to the back of the rack and a full one pulled forward. The supplier then refills the empty one at the rear.
Repeaters	They are components that are used regularly, predictable but less frequent and efficient (e.g. major and tall riser modules). There is more likely to be minimum economic batch sizes associated with them and inventory management needs to be linked closely to the manufacturing plan.
Strangers	They are highly customised, rarely occurring and often require a high level of resources to undertake (e.g. non-standard equipment or system combinations). They may have a long lead time and require special tooling to be produced and require early identification and procurement. Designers should aim to avoid the need for using “strangers”.

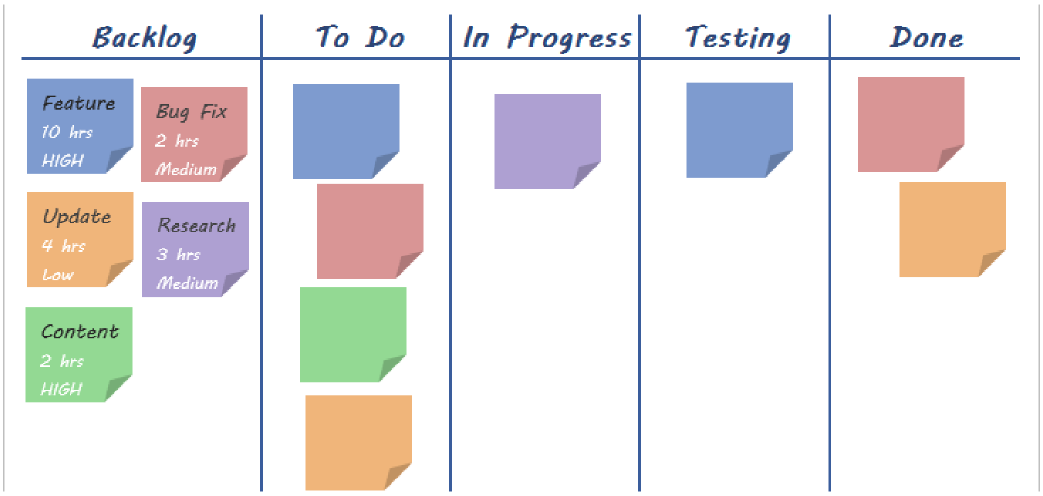
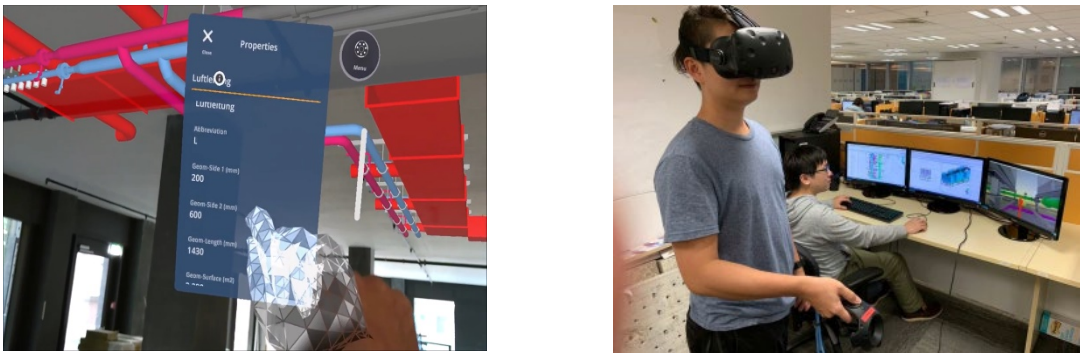


Figure 5.1 Essential elements of a Kanban system (Source: https://legaldbol.com/kanban-card-template-xls/97-the-best-kanban-card-template-xls-maker-with-kanban-card-template-xls/)

5.3 BIM Tasks

At this stage, the BIM model and components will be further developed to the next level of development as set out in the design responsibility matrix and then validated against the client’s information requirements established in previous stages. 4D BIM technologies may be adopted to test and rehearse the installation sequence including every aspect of manufacture, logistics and assembly before work starts onsite. With the advent of BIM and digital tools (Figure 5.2), a lot can be achieved using virtual, digital models. Modelling and simulation now play a major role in the design and efficient delivery of offsite construction.



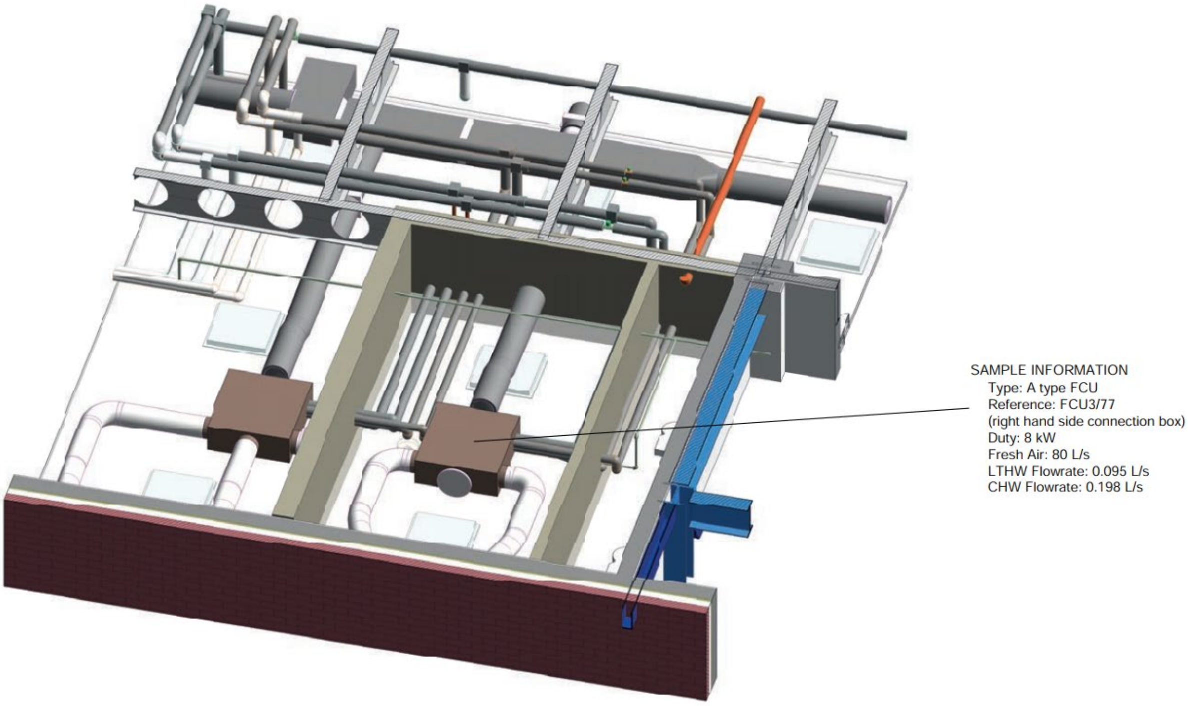
(a) Use of AR to visualise design (Courtesy of Jung BIM-Services)

(b) Use of VR to rehearse the installation (Courtesy of FSE Engineering Ltd.)

Figure 5.2 Use of digital tools to facilitate offsite construction

5.3.1 Technical Design Model

The technical design model can be developed to one or more levels of definition to suit the chosen procurement route. If a client wishes a designer to deliver a coordinated-generic object model but not the preceding feasible-generic object model, then this has to be clearly indicated in the design responsibility matrix. Also, tolerances for technical design models should be agreed between the recipient and the author before technical design starts, with reference to other members of the project team as appropriate. Figure 5.3 shows an example of 3D view for a technical design model.



SAMPLE INFORMATION
Type: A type FCU
Reference: FCU3/77
(right hand side connection box)
Duty: 8 kW
Fresh Air: 80 L/s
LTHW Flowrate: 0.095 L/s
CHW Flowrate: 0.198 L/s

Figure 5.3 Technical design model 3D View (Churcher, Ronceray and Sands, 2018)

5.3.2 Design Coordination

At this stage, the design coordination will continue based on the responsibility matrix agreed to eliminate the clashes along the framework laid down in the previous stage. Figure 5.4 shows two coordinated working drawing sections as an example of design coordination. In order to define and assign the design activities and outputs clearly and systematically, the technical design stage can be divided into three general phases as follows:

- Feasible-generic design: with feasible design using generic objects, it is feasible to provide the design shown, and the model/drawings are created using generic objects.
- Coordinated-generic design: with coordinated design using generic objects, the feasible-generic design has now been coordinated with other disciplines/services.
- Coordinated-specific design: with coordinated design using intended/procured equipment, the coordinated-generic design now uses selected/procured items of equipment.

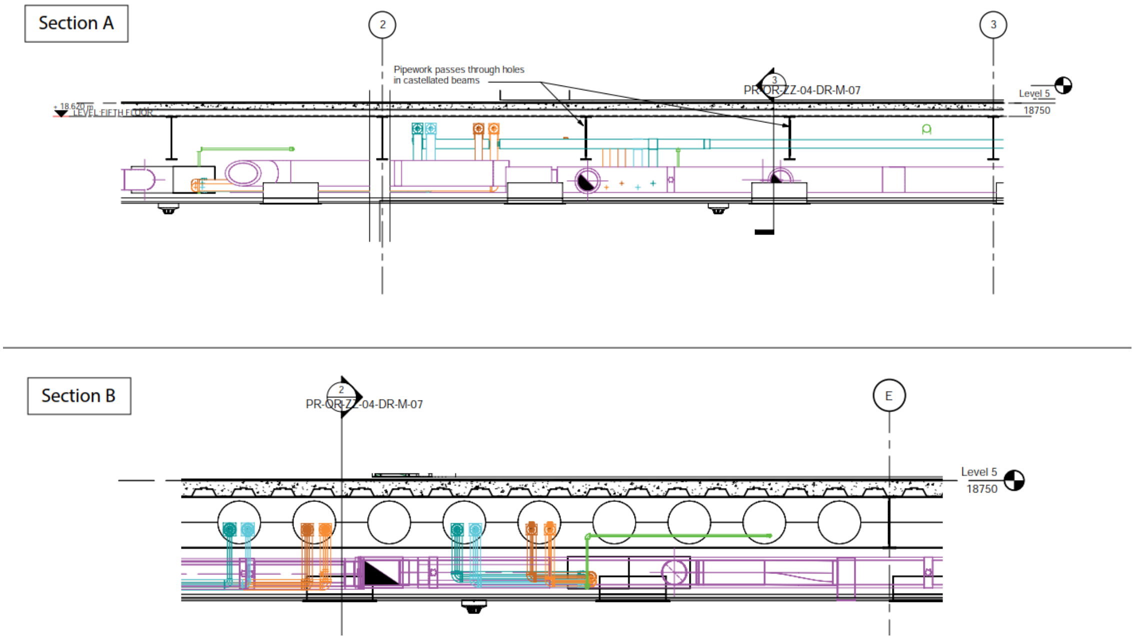


Figure 5.4 Coordinated working drawing sections (Churcher, Ronceray and Sands, 2018)

5.4 Tender Requirements and Arrangements

The requirement to adopt DfMA and offsite prefabricated MEP modules cannot be an afterthought and needs to be incorporated upfront in the tender documents, starting from the project brief. The early decision to adopt MEP modules in the project allows greater continuity of design and can maximise productivity and other performance gains. As a result, the project milestones are different when prefabricated MEP modules are adopted in a project.

5.4.1 Offsite Adoption and MEP Prefabrication

During planning, it is important to allocate sufficient time to consider a range of design options for prefabricated MEP modules with the help of BIM software, and avoid rushing into details which can limit the design options. For example, a detailed design of MEP modules may pre-determine the construction sequence or limit the scope for preassembly. The use of a vertical riser in a frame passing through multiple floors may be more efficient than having a smaller assembly for each floor or fitting components in traditional insitu manner. However, lifting restrictions on the site may prevent this option from being used. As various design options require inputs across the construction value chain, the client should allow adequate time for design in BIM software and collaboration among its consultants, builder, MEP trade specialist subcontractors and prefabricator of MEP modules, before onsite construction starts. To facilitate smooth administration, suitable terms and standard forms of building contract should be used for the MEP works.

Once prefabrication is completed, only minor changes are allowed. Any design changes or re-routing would cause a lot of disruption. Hence, it is important that the designs of the MEP services are confirmed early. Since all modules are manufactured based on BIM coordinated models, the process of approving the shop drawings is critical and must be robust. The CSD needs to be endorsed by all relevant project parties, i.e. the client, consultants, builder and relevant MEP trade specialist subcontractors, according to a pre-agreed schedule. Clients are also encouraged to require the main contractor and MEP specialist subcontractors to provide more detailed BIM drawings to facilitate offsite prefabrication of MEP modules.

5.4.2 Inspection and Approval of Materials and Mock-ups Prior to Mass Production

Unlike insitu construction works where there is a sequence for materials to arrive onsite, upfront material planning is critical for prefabricated MEP modules as all materials are needed at the same time for prefabrication. The client is required to approve the materials used early, so that prefabrication of modules can proceed on schedule. Mock-ups of the most typical prefabricated MEP modules used in the development should also be produced for the client's approval, prior to mass production of the modules in the factory.

To ensure the smooth installation of the modules onsite, the tender should include requirements for training and competent assessment for workers in the factory to carry out the safety- and quality-critical tasks, and to rectify defects found in the modules installed onsite. To minimise defects in the modules due to poor workmanship, an Engineer's Representative or AP/RSE Representative should be engaged to inspect/check/audit the critical elements of works done in the factory. This person must be an independent party from the prefabricator, main contractor and specialist subcontractors to avoid conflict of interest. As the prefabrication factory or site is sometimes located outside Hong Kong, independent inspection in another jurisdiction may be needed to support offsite completed modules payment.

5.4.3 Lead Coordinator and Payment Arrangement

Clients can specify to engage firms with the relevant expertise and track record experience as the first-level subcontractor to coordinate the installation of prefabricated MEP works. In addition, the tender should specify a dedicate firm or person to lead and direct the coordination among various trades onsite and in the factory. The lead coordinator is preferably the builder or out from the leading MEP specialist subcontractors who is well placed to coordinate logistics and activities of all trades onsite.

With a different work sequence, the contractor's pricing methodology will change and the consultants' payment certification methodology and the bill of quantity, or schedule of works in the case of a lump sum contract will also have to be tailored accordingly. For example, if the main contractor or an MEP subcontractor is also the prefabricator of MEP modules, he can claim part of the contract amount for the modules completed in the factory, before the installation of these modules onsite. To facilitate offsite payment, the standard conditions of contract may need to be amended.

6. Construction

Construction refers to Stage 5 of RIBA Plan of Work. In the RIBA Plan of Work 2020, it was replaced by ‘Manufacturing and Construction’ which reflects the increasing prevalence of manufactured systems and components and volumetric construction (RIBA, 2020). This stage comprises the manufacturing and construction of the building systems in accordance with the construction programme agreed in the building contract. Increasingly, digital technologies are being used to facilitate different construction activities, allowing Stage 5 to be faster, safer and more reliable in achieving the built quality required.

6.1 Core Objectives

This stage is for offsite manufacturing and onsite construction in accordance with the construction programme and resolution of design queries from site as they arise. As the construction industry moves towards greater uptake of offsite manufacturing, greater emphasis is also placed on the logistics of getting materials and large-scale components to site on time, and on the management of supply chain partners. Table 6.1 indicates the key deliverables at this stage.

Table 6.1 Key deliverables at the construction stage

General aspects: • Construction drawings, final construction programme & subcontractor management plan • Financial statements, interim payment certificates & contractual claim reports • Operation & maintenance guides/manuals • Completion certificate, as-built drawings • BIM installation & as-built models
MEP aspects: • Installation drawings, builder’s work drawings, manufacturers’ drawings & records • Testing & commissioning (T&C) schedules & reports • Progress, financial management & completion reports • List of approved materials/equipment • Handover & defect lists, user’s manual for operators

6.2 DfMA Strategies and Considerations

Strategically, impacts of DfMA implementation on the construction programme should be well considered to avoid difficulties during the construction and handover stage. The construction strategy will be updated with appropriate logistics plan so that the building can be progressively completed and captured with the as-built information. The completed building systems will be commissioned progressively to capture the as-constructed information in a manner that will assist the future in-use stage including the consideration for addition and alternation of the building and disassembly of its MEP facilities.

6.2.1 Lean Construction Methods

Lean is defined as a set of management practices to improve efficiency and effectiveness by eliminating waste. The core principle of lean is to reduce and eliminate non-value adding activities and waste, ultimately making the activities more efficient and productive. Lean construction borrows the idea from the manufacturing approach developed by Toyota after World War II. A primary goal of lean construction is eliminating or minimising waste at every opportunity. In practice, lean construction targets to minimise eight major types of waste: (a) defects, (b) overproduction, (c) waiting, (d) not utilising talent, (e) transport, (f) inventory, (g) motion, and (h) over processing.

The ideal state of a lean construction project is a continuous, uninterrupted workflow that is reliable and predictable. As the sequence is key in construction, clear communication between all parties is essential to achieve the desire workflow. When one part of the project becomes behind or ahead of schedule, it is essential to let everyone know so that adjustments can be made to avoid the wastes of waiting, motion, and excess inventory. Creating reliable workflows depends on work being released based on downstream demand. Lean construction recognises that this is best done by those performing the work, often subcontractors. Participants communicate and collaborate closely with each other to determine the schedule of tasks.

During the construction stage, the offsite and onsite activities should be seamlessly dovetailed by the application of lean construction methods to create a smoother workflow, with less waste, greater predictability, lower cost and a focus upon continuous improvement, delivering increased value to the client in terms of cost, time, quality and other aspects which represent value in that context. In general, the five principles of lean construction may be summarised as:

- Value: understanding what the client values
- Value Stream: how the value is created, and waste eliminated
- Flow: a balanced flow of work
- Pull: demand created by the needs of the next customer in the process
- Perfection: the goal of continuous improvement

Value stream mapping (VSM), also known as material- and information-flow mapping, is one of the effective lean tools that has been used to analyse and design the process workflow of resources and information required to deliver a product to the customer. The VSM process allows people to create a detailed visualisation of all steps in the work process and it is a representation of the flow of goods from the supplier to the customer through the organisation. The primary purpose of creating a VSM is to show the places where managers can improve the process by visualising both its value-adding and wasteful steps.

6.2.2 Offsite Manufacturing

As shown in Table 1.1, DfMA consists of two design methodologies: Design for Assembly (DFA) and Design for Manufacture (DFM). The DFM methodology aims to simplify components to be easier and efficient to produce, for a lower cost. When applying the DFM methodology in construction and MEP works, there are four key principles as shown in Table 6.2 (BESA, 2015).

Table 6.2 Four key principles of Design for Manufacture (DFM)

Principle	Description
Design for productivity	• Determine the required site installation rate & assess the best way to divide up the design of the building/facility to optimise the manufacturing process • Design the layout of the offsite facility to ensure that work content at each workstation matches the required rate of output from the assembly facility • Establish a "pull" mechanism from site to trigger assembly & ensure nothing is assembled unless this mechanism is activated • Design the facility elements for logistics & productivity • Use in-process inspection & acceptance • Use simple visual management techniques of material & tooling locations that can be easily understood by all personnel working in the area
Design to be modular	May adopt six modularity types (component sharing, component swapping, cut-to-fit, mix, bus & sectional) to create an efficient solution that meets the client's requirements for form, fitness for purpose & function. This minimises the number of variants early in the design process, giving benefits to lead time, stock levels, repeatability of process (and therefore quality) but still allows customisation within pre-defined parameters
Design to make manufacture easy	Allow early engagement of the manufacturers to consider advice on reduced complexity & ease of manufacture of the components to maximise the offsite benefits
Use common parts & materials	Use configuration management in association with a defined part numbering system to control & optimise the number of parts, so as to reap the benefit of designing once for multiple repeated usage

Production scheduling should reflect the site delivery requirements in order not to lose efficiencies gained in the factory by that wasted onsite. For example, a complex system may have simple straight modules in a mix of more complex to manufacture curved or other irregularly shaped elements, which may be on the critical path to affect the process even though the other standard elements can be installed fast. The batch size and production schedule should be flexibly designed to be more responsive to changes to the construction sequence onsite. Excessively large batch production may lead to large and inefficient inventories held ahead of site requirements and these may contain quality or coordination issues that only become evident once onsite and leading to costly and disruptive rework.

All suppliers should understand which dimensions are critical and that they have a robust, quality assurance process in place to deliver them. Such processes should include demonstrating that processes and measurement systems can do what is required to get the outputs right first time every time, using the six sigma concept (Figure 6.1) for other quality control methodologies. Before production commences, detailed manufacturing drawings for each module are produced and finalised by all key parties. After the MEP modules have been produced in the factory, the manufacturing drawing should be passed on the respective modules and the services labelled accordingly for reference by other trades. The labels should be positioned accordingly at the location of ceiling access panels or maintenance panels, according to the ceiling plan. Radio frequency identification (RFID) or a barcode system can also be used to track the modules in the factory and facilitate installation onsite.

Figure 6.1 Lean six sigma (6σ) concept (Courtesy of AECOM)

During the prefabrication process of the modules in factory, regular supervision should be conducted and proper records in the inspection log sheet should be maintained for easy checking. After the delivery of the MEP modules to the construction site, final checking and inspection should be carried out on the modules before the onsite assembly process for quality assurance. All the checking should be properly recorded for easy checking.

6.2.3 Design for Assembly

The concept of DFA or design for efficient assembly aims for an efficient combination of components, reducing the overall number of them incorporated into the product. For MEP works, components may provide value in more than one conventional discipline. For instance, a panel that supports an assembly of pre-installed building services equipment may also be a structural element of the building and may have to respect tighter dimensional tolerances and incorporate pre-drilled holes to receive fixings, etc. Another example is designing a structure to include flat soffits to facilitate the installation of frames carrying a range of services, cable trays, etc. Whilst it may consequently add cost to one component, it may save substantially more in the overall context. When applying the DFA methodology in construction and MEP works, six key principles can be identified as follows (BESA, 2015):

- Minimise and manage interfaces
- Simplify and reduce subassemblies and component parts
- Reduce assembly risks
- Make assembly easy
- Design for easy handling
- Use efficient methods of jointing

6.2.4 Delivery to Site and Project Management

Before delivery of MEP modules to the construction site, the following preparation work should be considered:

- To ensure smooth installation onsite, a template or jig could be used when lining up the modules in the factory to check for proper alignment (see Figure 6.2).
- Modules should be covered with shrink wrap, tarp, etc. to protect them against exposure to weather. Alternatively, the modules can always be kept in a sheltered condition.
- To ease transport and handling, modules can be pre-installed with castor wheels that can be taken off after installation. Equipment such as pallet jacks and forklifts also facilitate the manoeuvring and lifting of modules in the factory and onsite.
- To facilitate the installation of MEP modules in tight working spaces, the builder and prefabricator can work together to integrate other works into the MEP modules. For

example, part of a partition wall can be integrated with the MEP modules, as shown Figure 6.3.

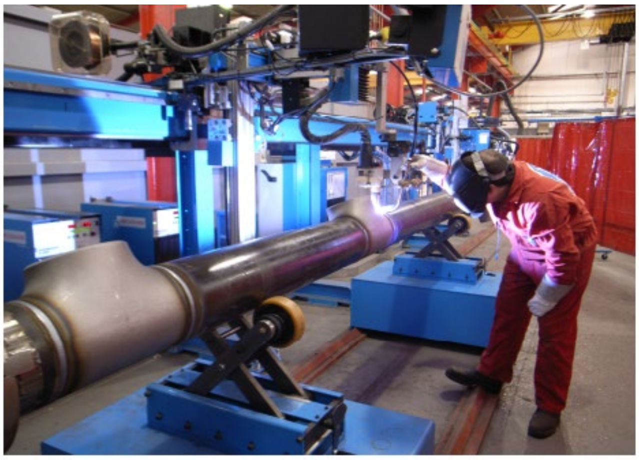


Figure 6.2 Jig for welding pipes (Courtesy of Laing O'Rourke)

Figure 6.3 Horizontal module integrated with partition wall
(Courtesy of BYME Engineering (H.K.) Ltd.)

The main contractor should coordinate with nominated subcontractors and specialist contractors on the provision for logistics (such as tower cranes, hoists, loading and unloading platforms, access, temporary openings, etc.) and for the storage of offsite prefabricated building components throughout the construction period. A small works area within the project site may be allocated for handling the MEP modules and their assembly/installation works. Close collaboration between the onsite project manager and offsite factory manager is essential to minimise the conflict of interest as the project manager's interest will be about delivering change, whereas the factory manager aspires to predictability of schedule and maximising the utilisation of their equipment. Onsite project managers need to have good awareness of lean construction principles and the different characteristics of offsite procurement to get the most out of offsite manufacture and supply. Increasingly project management will need to embrace systems integration as suppliers deliver more assemblies and subassemblies to site and managing interfaces between them becomes more significant.

6.2.5 Just in Time (JIT) Concept

By adopting a just-in-time (JIT) concept, MEP modules are delivered according to the construction sequence to eliminate congestion in the factory and minimise damages to the modules onsite. BIM can be used to simulate the actual onsite installation to identify potential problems in the access route. Close coordination between parties at the project site and factory is critical to ensure a smooth supply of modules to the site and minimise downtime due to missing modules onsite. As large modules are unable to be stored onsite, a JIT installation (see Figure 6.4) could prove to be efficient and productive.

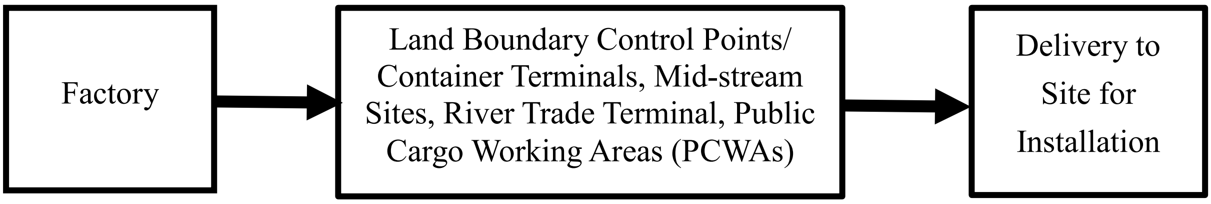


Figure 6.4 Just-in-Time (JIT) installation for prefabricated modules

The rate of installation must be determined for a smoother JIT operation. Modules supplier can further employ systems such as traffic monitoring and global positioning system (GPS) for prime movers to better facilitate deliveries. This will in turn make JIT operation smoother and more predictable. Also, it is advisable to have space for unloading and storage in the event where JIT installation is not possible, e.g. during inclement weather, etc. Trailers with heavy cargo pose potential hazards upon entering while navigating the site. Traffic controller must be employed to ensure smooth traffic management within the site. Figure 6.5 shows the workflow for prefabricated building services modules with typical steps indicated. At this stage, the essential logistics factors as mentioned in Table 3.4 should be verified and feasible solutions should be confirmed during construction.

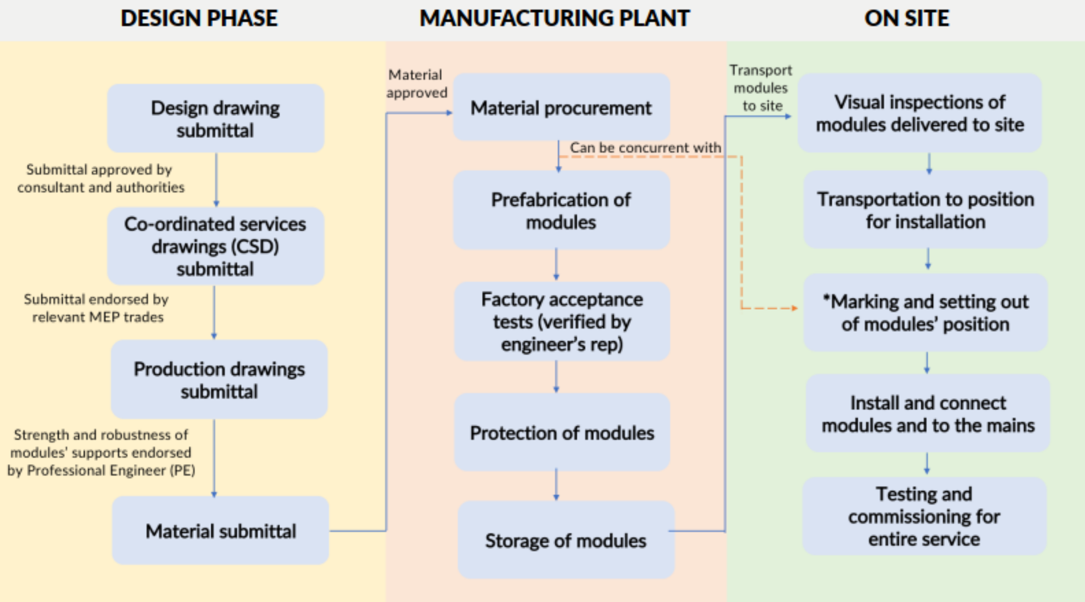


Figure 6.5 Workflow for prefabricated building services modules (BCA, 2018)

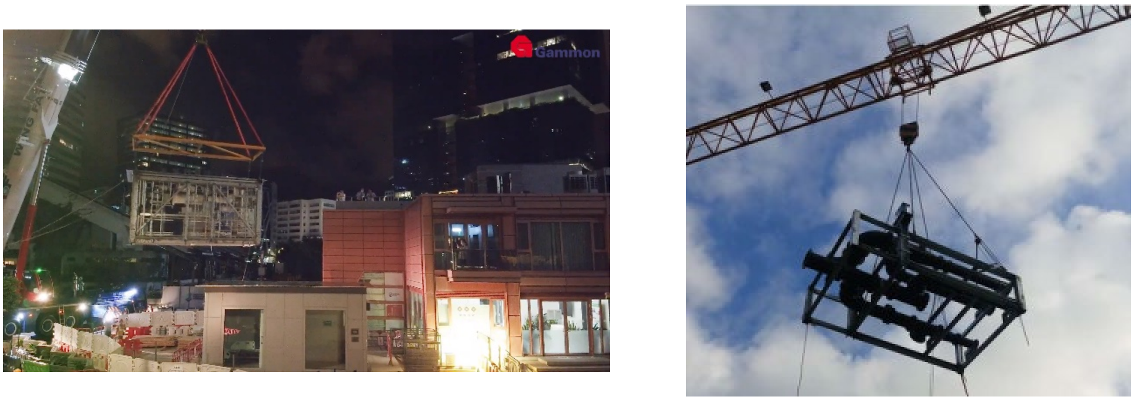
6.2.6 Lifting and Positioning

At the project construction site, the craneage, hoist and module lifting strategy should be developed as part of the early construction advice input. The forces involved are different if a module is lifted in a horizontal or vertical orientation. Centres of gravity can be calculated in BIM and lifting fixtures positioned accordingly to facilitate work at this point, particularly with crane use. Occupational health and safety considerations should determine a safe lifting system option with repeatable and capable processes at the design stage. For example, a scissor lift can be positioned under an assembling, transporting and installation frame (ATIF) (Figure 6.6) for lifting modules to be hung from soffits or installed inside ceilings. After installation of the modules, the ATIF can be returned to manufacturing centre for re-use.

(a) in BIM model (b) in reality

Figure 6.6 Assembling, transporting and installation frame (ATIF)
(Courtesy of Crown House Engineering)

Final positioning can be a critical aspect in achieving the critical dimensional tolerances. The design may have incorporated positioning guides (e.g. cones or tapered components). The lifting system may have adjustable fine-tuning screws that control the last few centimetres. The floor plate may have dropped down levels to receive modules that contain their own floor (e.g. bathroom pods). A clearly documented methods statement should be worked out for each type of operation. The tower crane capacity is often on the critical path for multiple work packages. The crane employed must be able to handle the weight of the large modules, but at the same time be able to provide enough coverage for the intended block. Figure 6.7 shows two examples of lifting of modules for onsite installation.



(a) Lifting of MEP service module by mobile crane (Photo courtesy of Gammon Construction Limited)

(b) Lifting of pipe module by tower crane (Photo courtesy of FSE Engineering Group Ltd.)

Figure 6.7 Lifting of modules for installation

Figure 6.8 shows examples of construction tools, which have been supported under the Construction Innovation and Technology Fund (CITF) to enhance construction productivity, safety and sustainability. They can offer useful ideas to plan the lifting and positioning strategy for offsite modules and onsite construction works.

(a) Laser scanner to facilitate offsite fabrication

(b) Lifting crane with safe load indicator

(c) Working platform working on sloped terrain

(d) Remotely controlled material lifting machine to minimise the use of eye bolts and chain blocks

(e) Remotely controlled transportation machine

Figure 6.8 Examples of pre-approved Advanced Construction Technology (ACT) products (From CITF website: http://www.citf.cic.hk/?route=search)

6.3 BIM Tasks

BIM will be used to support the construction and to train site operatives. In conjunction with other digital technologies, BIM animation will be implemented to enhance the traceability, productivity, safety and sustainability, and minimise human errors in installation and quality assurance. Digital technologies may be adopted to track each step of the manufacturing, packaging, logistics and delivery process (e.g. factory acceptance test, shipment, arrival onsite, delivery to the floor, final positioning, assembly, testing and commissioning). The complete history and location of every component will be recorded for feedback, future use and learning. The BIM components will be linked to assembly manuals, method statements and quality records including identifying any aspects of the design which may be reused for future projects, particularly for those components/subassemblies/modules related to DfMA development. The handover of the building and conclusion of the building contract may also be supported by BIM and other digital technologies.

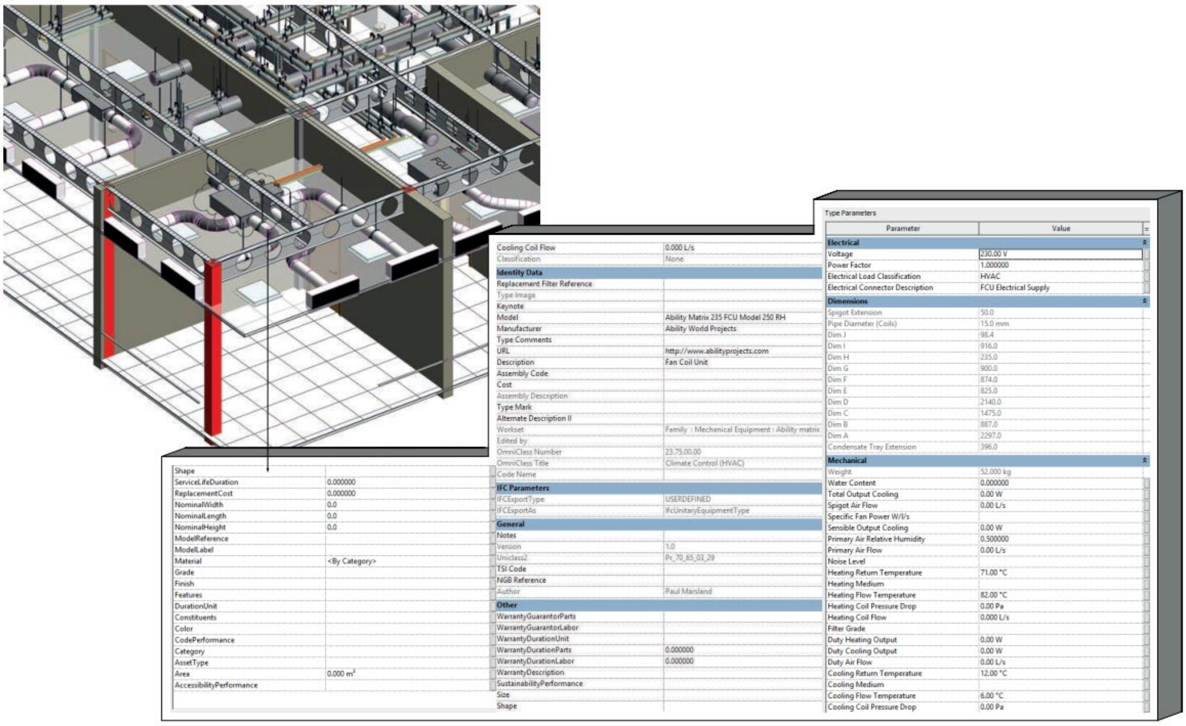
6.3.1 Installation Model

The BIM installation model will show all procured equipment and components with their actual sizes and precise locations as well as typical supports and fixings necessary for installation. If the technical design model has not been developed to the coordinated specific level (see Stage 4 technical design or Chapter 5 of this Guidebook), then the installation model will convey this. Typical object parameters to include along with geometry at this stage would include:

- Actual size of object
- Actual weight of object
- Identification of actual item to be installed

Figure 6.9 shows an example of 3D view for an installation model. Typical object parameters from Stage 4 technical design should be substituted with data relating to the installed objects. Typical uses for the model at this stage are:

- <u>Construction</u>: The model elements are virtual representations of the proposed building elements and are suitable for construction.
- <u>Analysis</u>: The model may be analysed for performance of approved selected systems and components by applying specific criteria to the actual model elements.
- <u>Estimating</u>: Costs are based on the actual costs of specific elements at purchase.
- <u>Programme</u>: The model may be used to show the time scale of installation of detailed systems and components, including methods of construction and installation sequences.



Shape	
ServiceLifeDuration	0.000000
ReplacementCost	0.000000
NominalWidth	0.0
NominalLength	0.0
NominalHeight	0.0
ModelReference	
ModelLabel	
Material	<By Category>
Grade	
Finish	
Features	
DurationUnit	
Constituents	
Color	
CodePerformance	
Category	
AssetType	
Area	0.000 m²
AccessibilityPerformance	

Cooling Coil Flow	0.000 L/s
Classification	None
Identity Data	
Replacement Filter Reference	
Type Image	
Keynote	
Model	Ability Matrix 235 FCU Model 250 RH
Manufacturer	Ability World Projects
Type Comments	
URL	http://www.abilityprojects.com
Description	Fan Coil Unit
Assembly Code	
Cost	
Assembly Description	
Type Mark	
Alternate Description II	
Workset	Family : Mechanical Equipment : Ability matrix
Edited by	
OmniClass Number	23.75.00.00
OmniClass Title	Climate Control (HVAC)
Code Name	
IFC Parameters	
IFCExportType	USERDEFINED
IFCExportAs	IfcUnitaryEquipmentType
General	
Notes	
Version	1.0
Uniclass2	Pr_70_65_03_29
TSI Code	
NGB Reference	
Author	Paul Marsland
Other	
WarrantyGuarantorParts	
WarrantyGuarantorLabor	
WarrantyDurationUnit	
WarrantyDurationParts	0.000000
WarrantyDurationLabor	0.000000
WarrantyDescription	
SustainabilityPerformance	
Size	
Shape	

Type Parameters

Parameter	Value
Electrical	
Voltage	230.00 V
Power Factor	1.000000
Electrical Load Classification	HVAC
Electrical Connector Description	FCU Electrical Supply
Dimensions	
Spigot Extension	50.0
Pipe Diameter (Coils)	15.0 mm
Dim J	98.4
Dim I	916.0
Dim H	235.0
Dim G	900.0
Dim F	874.0
Dim E	825.0
Dim D	2140.0
Dim C	1475.0
Dim B	887.0
Dim A	2297.0
Condensate Tray Extension	396.0
Mechanical	
Weight	52.000 kg
Water Content	0.000000
Total Output Cooling	0.00 W
Spigot Air Flow	0.00 L/s
Specific Fan Power W/l/s	
Sensible Output Cooling	0.00 W
Primary Air Relative Humidity	0.500000
Primary Air Flow	0.00 L/s
Noise Level	
Heating Return Temperature	71.00 °C
Heating Medium	
Heating Flow Temperature	82.00 °C
Heating Coil Pressure Drop	0.00 Pa
Heating Coil Flow	0.000 L/s
Filter Grade	
Duty Heating Output	0.00 W
Duty Cooling Output	0.00 W
Duty Air Flow	0.00 L/s
Cooling Return Temperature	12.00 °C
Cooling Medium	
Cooling Flow Temperature	6.00 °C
Cooling Coil Pressure Drop	0.00 Pa

Figure 6.9 Installation model 3D view (Churcher, Ronceray and Sands, 2018)

6.3.2 As-built Model

The as-built model should show all as-built engineering systems, components and equipment. All pipes, ducts and cable objects should contain data about their sizes, flow rates, flow direction, voltages (as appropriate), etc. The model should include access information for equipment maintenance and replacement. It is analogous to the level of detail in record drawings.

Tolerances for as-built models should be agreed between the recipient and the author before installation starts, with reference to other members of the project team as appropriate. Different tolerances might be agreed for visible and hidden components. Typical object parameters to include along with geometry at this stage would include:

- Model numbers and serial numbers of actual components and equipment installed
- Results from commissioning works (flow rates or sent points for all control equipment)
- Links to stored plant and equipment details (specification, manufacturers details, operation and maintenance information)
- End of life considerations

The model may be used for maintaining, altering and expanding the building, within the terms of any license agreement agreed with the model originator(s).

6.4 Procurement Tasks

For the construction stage, opportunities are still available for contractor's involvement in refining the DfMA process, if contract clauses allowed contractor's proposed alternative design for portion of works adopting DfMA. The integration with BIM would be a useful tool to demonstrate the relevant benefit to enable the acceptance of the contractor's proposal.

During the construction stage, lessons learned may be captured for feedback to improve the procurement strategy of future projects. At present, it is believed that the procurement strategy should be tailored for each project based on the relationship between the offsite manufacturer and its supply chain and site needs. The constructed information relating to DfMA development should be captured into the client's in-house BIM object library. In addition, feedback will be noted on the capabilities and performance of specialist subcontractors or manufacturers involved in the DfMA deliverables. In longer term, it is hoped that the procurement strategy for DfMA can be standardised in order to create a critical mass and generate economy of scale.

Upon satisfactory completion, the project team's priorities will be facilitating the successful handover of the building in line with the project programme. Subsequently, the project team will also be concluding all aspects of the building contract, including the inspection of defects as they are rectified, or the production of certification required by the building contract. Other services may also be required during this period, as dictated by project-specific schedules of services, which should be aligned with the procurement and handover strategies.

7. Handover and Post-Handover Services

This stage includes the “handover / handover and close out” (Stage 6) and “use / in use” (Stage 7) of the RIBA Plan of Work (RIBA, 2020 & 2016). On the majority of projects, the design team and construction team will have no Stage 7 duties to undertake in accordance with the schedule of services. This stage will acknowledge the potential benefits of harnessing the project design information to assist with the successful operation and use of the building. While the end of a building’s life might be considered at this stage, it is more likely that commencement of the follow-on project or refurbishment would deal with these aspects as part of strategically defining the future of the building.

7.1 Core Objectives

Stage 6 “handover” refers to handover of building and conclusion of building contract including updating ‘as-constructed’ information, commissioning and training, and may sometimes include post-occupancy evaluation. Presumably the stage also includes tasks associated with the defects liability period and issuing the final certificate, although these are not described. Stage 7 “use” includes post-occupancy evaluation and post-project review as well as other services that can be undertaken during the “in-use” period of a building.

Crucial at this stage is recording the ‘as-constructed’ information for the building, including decisions made onsite, allowing high-quality information to be available during the building’s life for those who use and maintain it. This information can be diverse and might incorporate a wide range of manufacturer and DfMA information, including how the building might be disassembled. It is essential that clients consider their project outcomes at the early stages and include them in the various professional services and building contracts.

7.2 DfMA Strategies and Considerations

The DfMA strategies at this stage are given in Table 7.1 (RIBA, 2016).

Table 7.1 DfMA strategies for handover and post-handover services

Handover: • Consider how to capture commissioning & ‘as-constructed’ information in a manner that will assist the in-use stage including the potential disassembly of the building
Post-handover (Use): • Consider any feedback during the in-use stage necessary to inform future projects • Monitor the performance of standardised components, including maintenance & replacement and provide feedback • Monitor disassembly or potential reuse of materials during demolition at the end of the stage & provide feedback

For MEP, each system should be considered both individually as well as at the interfaces so that it should be possible to replace each system or each component on an individual basis. It is important to consider the different design life of MEP modules and how these can be safely decommissioned and replaced/disassembled independently. Even before the design life has expired there may be the need to replace individual systems and/or components. Each component and assembly need to be designed for both installation and disassembly (i.e. design for disassembly). Considerations should include size, sequencing, fixing, interfaces and the possibility of re-use of entire systems, components and/or materials.

Reasonable physical access should be considered for removal of large items for replacement due to defects or end of life. Items that are not easy or safe to be taken apart will need to be safely removed. Information about safe disassembly and removal should be provided to the building owner as part of the operation and maintenance (O&M) manuals and/or BIM model.

Information should be available for replacement of items and systems in the O&M manuals and/or BIM model. This information will include elements provided by the consultants as well as the manufacturers and will need to be coordinated. As early as possible, the relevant parties should agree how this information is going to be compiled, coordinated and communicated. Responsibilities should be agreed as soon as possible to allow enough budget cost and other resources.

7.3 BIM Tasks

After the handover, the BIM model should be taken care of by the facility management team of the building. Appropriate configuration management techniques may be adopted to maintain an updated BIM model record of the building. It is important to ensure that all relevant documentation relating to DfMA components or modules (e.g. approved as-built general building plans (GBPs) and fire service installation (FSI) drawings, design calculations for FSI, FSI equipment/material certificates, annual inspection records and FSI certificates) is linked to the BIM model for feedback, including lessons learned and potential repurposing. It is also necessary to consider configuration management techniques to maintain an up-to-date record (BIM model) of the building. The established BIM model and other digital technologies will continue to support the operation and maintenance of the MEP services such as monitoring of the performance of the components and modules, monitoring disassembly or potential re-use of demolished materials, and updating of the records of the various installations.

To enhance asset management, the technical documents, drawings, approved building plans, reports, T&C records, inspection records and certificates relevant to MEP systems should be incorporated into the BIM model.

7.4 Procurement Tasks

The procurement strategy should ensure that ‘as-constructed’ information relating to DfMA products has been delivered including feedback on information to be incorporated into the client’s in-house BIM object library. It is also necessary to provide feedback on the capability and performance of specialist subcontractors who delivered DfMA aspects. The information could be useful in facility management of the building or in future projects.

8. MiMEP

A new idea known as Multitrade integrated Mechanical, Electrical and Plumbing (MiMEP) has come up in Hong Kong recently and is being strongly supported by the government authorities. This term MiMEP, is coined at the CIC-HKFEMC joint conference held during the DfMA MiMEP Tradeshow in March 2021 (http://mimep.hk). At the conference, the Permanent Secretary for Development (Works) of the Development Bureau of HKSAR Government promulgated to the industry to develop the MiMEP concept for MEP works as a continuity of recent success of Modular integrated Construction (MiC) for the local construction industry. It is believed that this development will enable wider adoption of the DfMA approach to enhance productivity, quality and safety for the construction industry.

8.1 Basic Concepts

To understand better the nature and characteristics of this emerging trend, the basic concepts of DfMA, MiC and MiMEP are highlighted in Table 8.1. As indicated in Chapter 1, DfMA focuses on design process management to facilitate the optimisation of all manufacture and assembly functions. In practice, MiC and MiMEP provide the product deliverable methods for implementing the DfMA mindset and thinking in an effective way.

Table 8.1 Basic concepts of DfMA, MiC and MiMEP

Term	Meaning
Design for Manufacture and Assembly (DfMA) 面向製造和裝配的設計	A design approach that focuses on ease of manufacture and efficiency of assembly of construction components
Modular Integrated Construction (MiC) 組裝合成建築法	An innovative construction method whereby free-standing integrated modules (completed with finishes, fixtures and fittings) are manufactured in a prefabrication factory and then transported to site for installation in a building
Multitrade integrated Mechanical, Electrical and Plumbing (MiMEP) 機電裝備合成法技術	A construction method whereby mechanical, electrical and Plumbing (MEP) components and equipment are integrated into a sub-assembly offsite and then deliver to and installed onsite

Traditionally, as MEP installation is always the last stage in a construction project, there is enormous time pressure in completing the works. With adoption of the MiMEP approach, MEP components and equipment can be integrated effectively into modules or sub-assemblies which are prefabricated in an offsite factory before transporting to the construction site for assembly and installation as well as final testing and commissioning. With MEP prefabrication undertaken simultaneously with construction work, it can greatly enhance productivity, work efficiency and quality. However, it should be noted that the application of DfMA and MiMEP is more than just a collection of procedures for prefabrication works, but a comprehensive holistic approach as described in the previous Chapters of this Guidebook. To make them successful, much more careful and early planning works are needed in the activity chain and project work stages, with the support of new suitable project management and delivery methods.

It is expected that, as a new idea and an emerging innovation, the MiMEP approach will be further developed and elaborated in the coming future. Very often, the key issue is to design the MEP systems so that they can be fitted in each module with minimal external connections. Using the BIM technology, the works in the factory and offsite prefabrication of MEP systems can be well coordinated to enable seamless assembly or installation of different modules at the construction site. Also, completed modules are inspected for quality and statutory compliance before transporting to the site for assembly and installation. At present, three core design principles are identified for MiMEP as shown below.

(a) Offsite prefabrication
(b) Multi-trade integration and module maximisation (imply volumetric assembly with multi-trades integration)
(c) Plug and play (minimise onsite installation works)

Based on the above interpretation, MiMEP can be considered as a construction method for MEP works that employs well-coordinated modules of having significant volumetric contents (integrating MEP, builder's works and other non-MEP work elements etc.) manufactured offsite and then transported to site for assembly. Therefore, MiMEP would be the highest end category for DfMA application on MEP works with higher level of integration and in form of volumetric modules. This idea is similar to the category of Integrated Assemblies as described in the DfMA MEP guidebook of Singapore (BCA, 2018).

8.2 Practical Examples

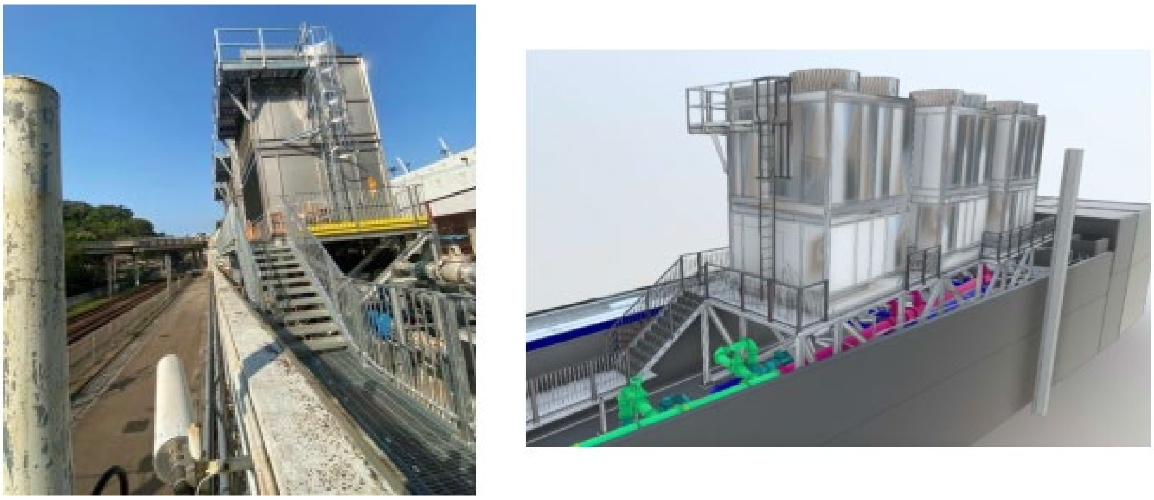
As mentioned in Section 1.5, the idea of modular MEP elements and prefabricated construction is not completely new in Hong Kong as it has been applied in the 1980s for a landmark bank building in Central (see Figure 1.4). Nowadays, the MiMEP approach has evolved with the support of BIM, offsite construction and many other advanced manufacturing technologies. To illustrate the current applications of MiMEP in Hong Kong, some practical examples were identified as shown below.

(a) Cooling tower modules completed with access platform and ladders as in the MTR Ho Tung Lau Depot (Figure 8.1)
(b) Pump room modules in a government project (Figure 8.2)
(c) Plant room modules for an isolation ward in a hospital (Figure 8.3)

Some interesting examples of MiMEP applications with varying complexities from other countries are given as follows:

(a) IT rack modules for data centre (Figure 8.4)
(b) Utility cupboards for apartment buildings in the United Kingdom (Figure 8.5)
(c) MEP modules integrating builder's works (Figure 8.6)

It is anticipated that more and more good examples of MiMEP will be developed and completed in the future. After reaching a certain successful level of maturity, an industry-wide quantitative benchmark can be established to evaluate the performance.



(a) As-fitted module (b) BIM Model

Figure 8.1 Prefabricated cooling tower modules with maintenance access provisions (Photo courtesy of JEC Engineering)

(a) Pump room modules (b) Bird's eye view of pump room modules with architectural features

Figure 8.2 Pump room modules with fibreglass water tanks, pumps, pneumatic vessels, controls and other accessories (Photo courtesy of the Architectural Services Department)

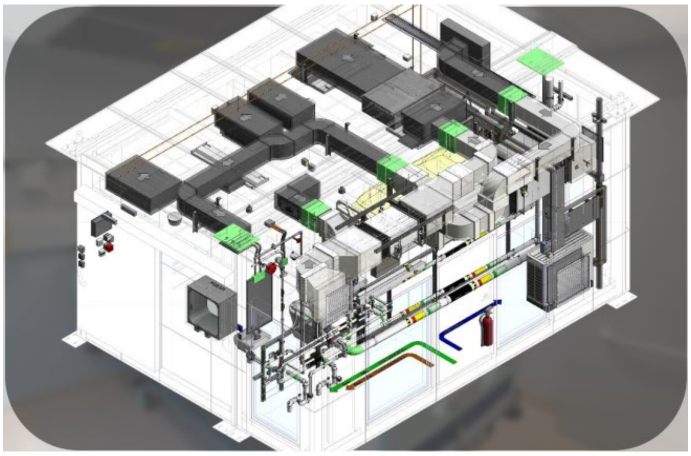


Figure 8.3 Prefabricated plant room modules for a negative pressure isolation ward (mock-up) (Photo courtesy of Gammon Construction Limited)

Figure 8.4 IT rack module, which integrates in-row cooling, Uninterruptible Power Supply (UPS) and the aisle containment (Photo courtesy of BYME Engineering (H.K.) Limited)

(a) Utility cupboard completed with underfloor heating components with a washing machine etc.

(b) Utility cupboard completed with electrical installations and underfloor heating components etc.

Figure 8.5 Examples of utility cupboards
(Photo courtesy of SES Engineering Services Limited, UK)

(a) Horizontal MEP modules with false ceiling panels and frames

(b) Horizontal MEP modules completed with Firestop board

Figure 8.6 Horizontal MEP modules integrating various builder's works
(Photo courtesy of SES Engineering Services Limited, UK)

8.3 Application to Alterations and Additions (A&A) Projects

Apart from the application for new projects, MiMEP may also be applied to A&A and minor works in existing buildings. It is hoped that in the coming future more detailed information on DfMA application process for existing buildings can be developed. At present, one example on renovation of toilet modules for the Hong Kong International Airport is identified and shown below (Figure 8.7). Considering a typical toilet revamp project in the operational environment of an existing building, it is undesirable to carry out prolonged construction works since it requires closure of multiple toilets which causes interruption to normal operation. DfMA can shorten the onsite construction time, but the major difficulty is the low flexibility of the existing buildings with logistic and site constraints.

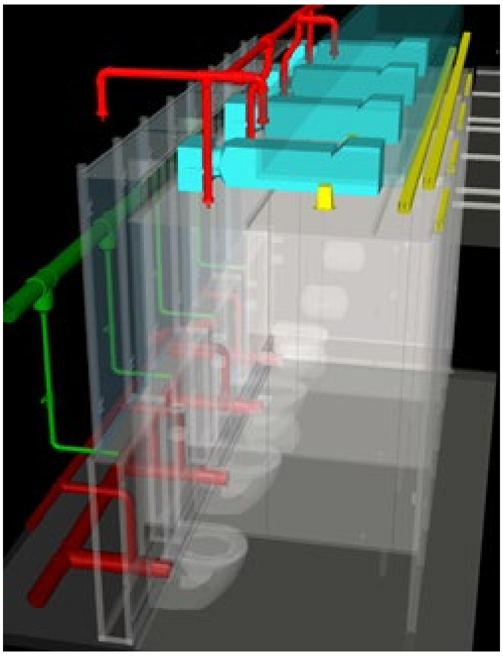
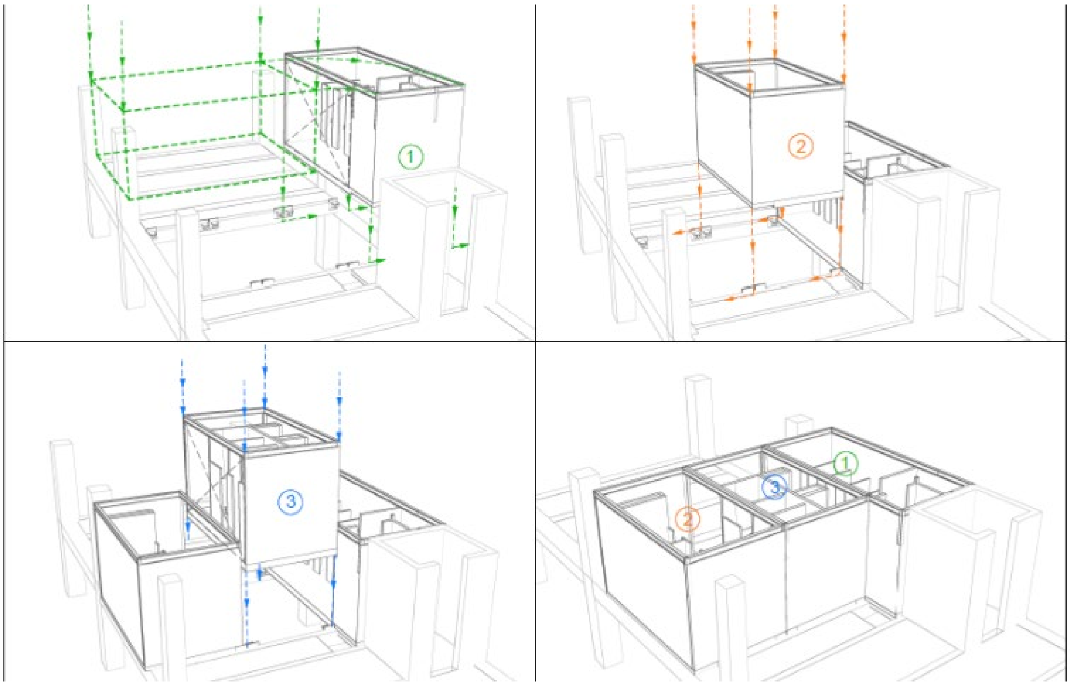


Figure 8.7 Standardised MEP provision for each toilet cubicle
(Photo courtesy of the Hong Kong International Airport)

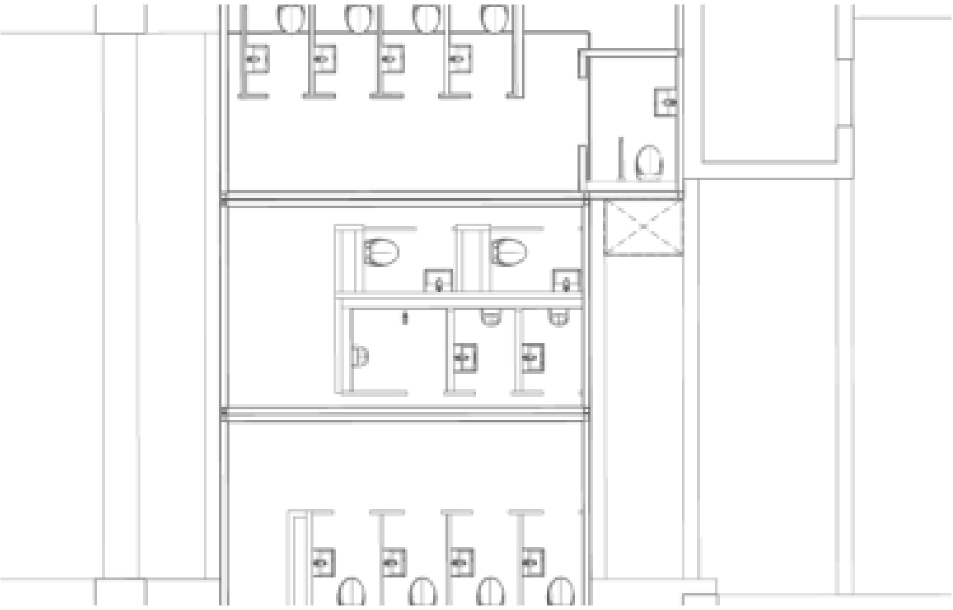
The major considerations for successful implementation of DfMA and MiMEP in this project are described as follows:

a. Sufficient and suitable interface shall be provided between the MiMEP modules, new architectural and structural elements. Also, developing a proper supporting system between the MiMEP modules and the existing building should be included, since it is critical to facilitate onsite assembly of the modules in the existing buildings.

b. Compared with new buildings, the site condition of existing buildings is more congested with different services and structures. The construction sequence should be well-planned in concept design stage to allow sufficient space for onsite installation (Figure 8.8) and connection between modules of different trades of services (Figure 8.9).



(a) Installation sequence



(b) Toilet layout plan

Figure 8.8 Installation sequence planning for the toilet modules
(Photo courtesy of BYME Engineering (H.K.) Limited)

c. Maximisation of the benefits can be effected by the adoption of 3D modelling for A&A works in the existing building. With the use of three-dimensional space scanning tools, point cloud data can be generated to ascertain the existing condition of the toilet envelopes and the remaining building services (Figure 8.10). Such point cloud data can be imported into and overlaid with the BIM models for clash analysis in order to enhance precision of prefabrication elements and compatibility between the existing site conditions and the new works at detailed design stage.

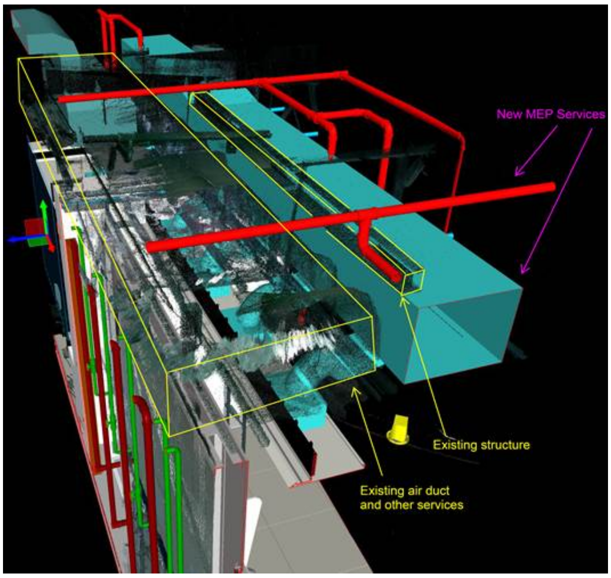


Figure 8.9 Visualization of site constraints with 3D point cloud scanning
(Photo courtesy of the Hong Kong International Airport)

8.4 Specifications for MiMEP

To apply the MiMEP process effectively, it is important to prepare specifications for the building services systems to be included in the MiMEP modules. An example of typical specifications for MiMEP is given in Appendix 7 for general reference (with the courtesy of the Building Services Branch of the ArchSD) as starting point. With the complexity of the combination of MEP and non-MEP contents within the modules, it is apparent that each project specification may have top up from this starting point to encompass more elements tallying with the project KPIs and project strategies. The procurement strategy also needs to be tailored accordingly.

9. Conclusions

Offsite methods such as prefabrication and modular construction are experiencing a significant expansion of interest and use as the construction industry seeks to improve productivity, quality, cost, schedule, safety and sustainability performance while continuing to face workforce shortages, cost uncertainties and other challenges. It is believed that DfMA can help enable offsite methods and related design solutions to be implemented more effectively.

DfMA is one of the key enablers for industrialised construction (IC). When applied in MEP works, DfMA implementation requires a change in the relationship between design and construction. The design should focus on the methods by which the project is to be delivered, using offsite manufactured components where possible and planning for efficient logistics and easy assembly of these components onsite. The core characteristic of DfMA is its component-driven, modularisation and standardisation approach.

The DfMA approach offers a wide spectrum of solutions. Selection of the level of DfMA adoption should be in response to project-specific drivers including sector category, client's values and KPIs, supply chain capability, degree of repeatability possible, site/logistics constraints, etc. In general, the higher level of DfMA adoption, the greater the onsite productivity/onsite manpower savings that are possible. The four main categories of DfMA offsite construction are:

- Component manufacture & subassembly
- Non-volumetric preassembly
- Volumetric preassembly
- Modular systems or buildings

A key technology to facilitate DfMA is BIM, which is now close to being universally accepted as the essential norm. The synergies of BIM, DfMA and lean principles will continue to grow and will bring up new changes in technology, processes and people for design and construction. It should be noted that DfMA and lean principles are more than simply a set of tools; it is a philosophy and design approach that are shared throughout a value stream for organisational transformation and collaborative strategy. For future development and integration of DfMA thinking in construction and MEP works, it is important to enhance the awareness, education and training within the local construction industry on DfMA, lean principles and value stream.

MEP elements constitute a crucial segment in the construction industry for their high cost content, importance for time certainty, environmental impact and safety and health reasons. Wider adoption of DfMA in MEP will play an important role to support construction industry transformation as raised up in the Construction 2.0 and related government initiative. To effectively transform the current fragmented traditional MEP practice into an industrialised practice, Hong Kong requires a robust ecosystem for DfMA in MEP systems, consisting of three important pillars:

- A sustainable demand to be perceived by the stakeholders;
- A high quality and cost-effective supply chain capability compatible with the demand; and
- Strong industry capabilities with good people skills for the new approaches.

Figure 9.1 shows the basic concept of practical strategies for driving DfMA adoption so as to nurture a robust ecosystem to overcome the barriers to secure the opportunities and benefits. It starts with the general awareness, generation of demand, enhancement of supply chain and build-up of people skills.

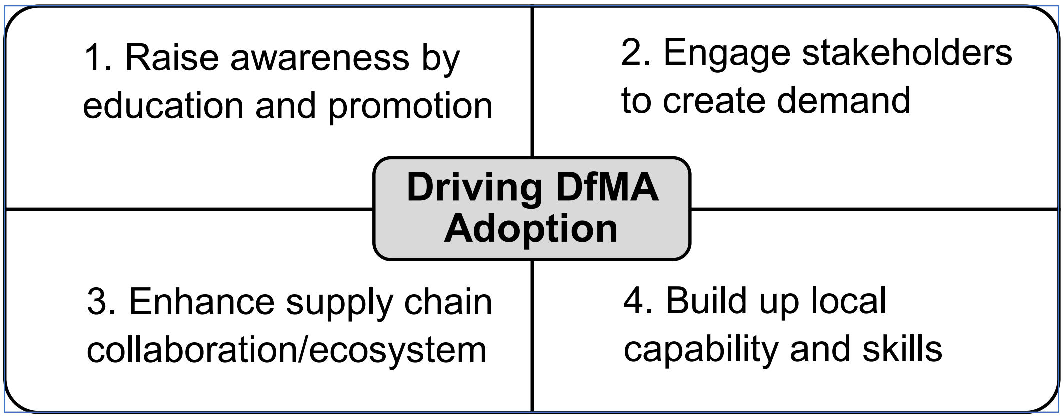


Figure 9.1 Basic concepts of practical strategies for driving DfMA adoption

In addition, the various strategies to nurture a sustainable and robust ecosystem as indicated above will require continuous supporting efforts from various stakeholders as depicted in Figures 9.2 to 9.6. Hopefully this Guidebook would serve as a starting seed as well as a living document to support the adoption and subsequent implementation of the various strategies.

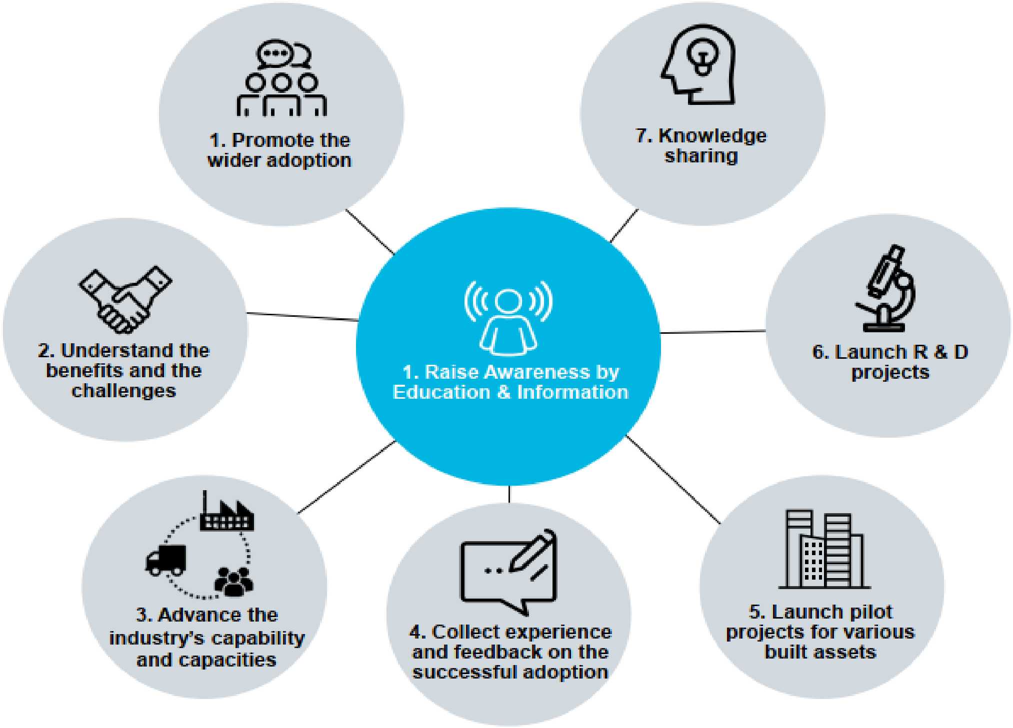


Figure 9.2 Strategies to raise awareness by education and information

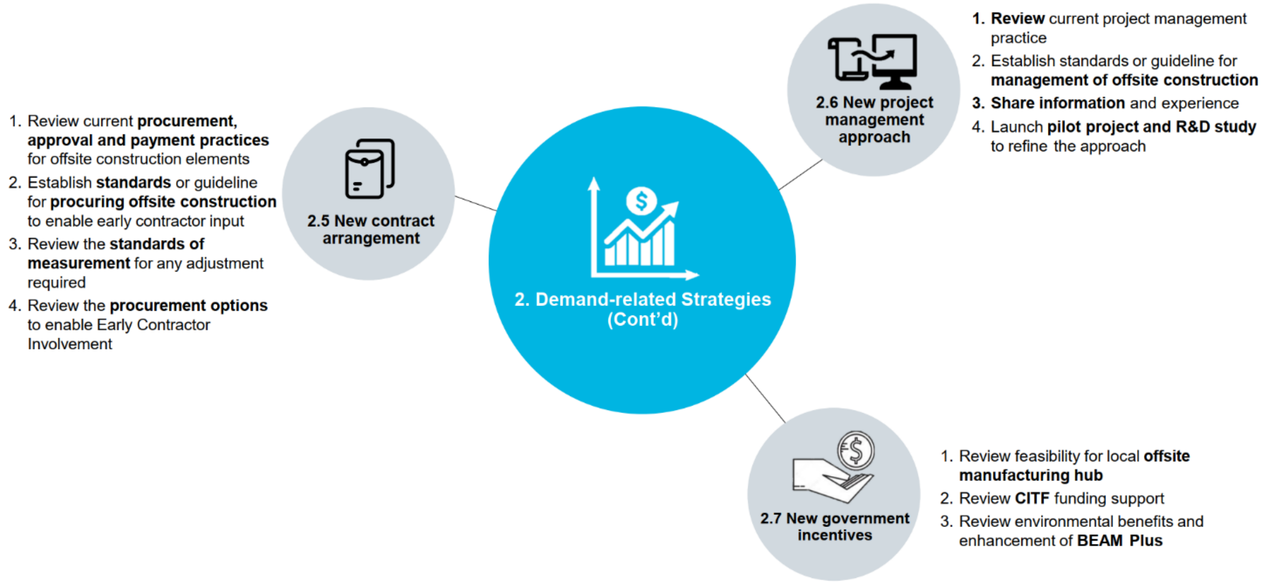
1. **Top management** to understand the benefits and transform their organisations
2. Judge project outcome with **new KPIs**
3. Launch **pilot project** to show benefits and form database for quantification
4. Establish **framework** for the new KPIs

1. Establish **new quality standards** for MEP elements, e.g. multi-service supports
2. Establish **wider standardisation** for economy of scale
3. **Harmonise** the manufacturing standards for more choice
4. **Bridge the HK standards** and share practices with regional practitioners

1. Define **a road map** for buildability & productivity
2. Progressive **development** for wider MEP **spectrum**
3. **In the short term**, adoption of **MEP equipment**-based integration in plantrooms
4. **In the mid and long term**, adoption of services **sub-assemblies** and integration with **architecture**
5. Establish a **reference document** on standard, methodology and the required level of details
6. Establish **BIM templates** and **BIM object libraries**

1. Review the regulatory mechanism for **works executed across the border**
2. Establish a robust and efficient regulatory mechanism

Figure 9.3 Demand-related strategies (1 of 2)



2. Demand-related Strategies (Cont'd)

2.5 New contract arrangement

1. Review current **procurement, approval and payment practices** for offsite construction elements
2. Establish **standards** or guideline for **procuring offsite construction** to enable early contractor input
3. Review the **standards of measurement** for any adjustment required
4. Review the **procurement options** to enable Early Contractor Involvement

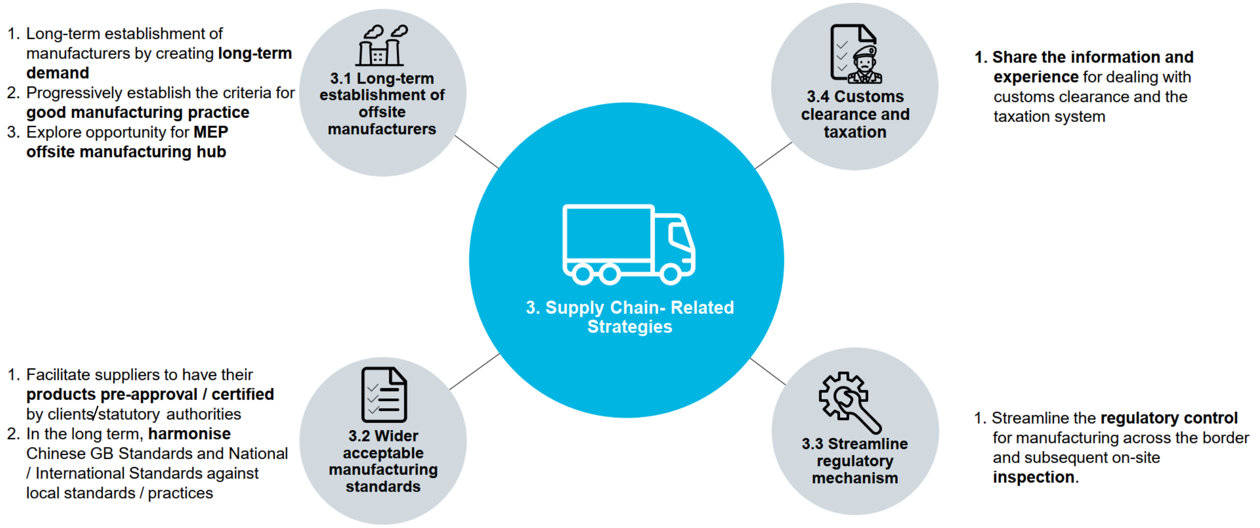
2.6 New project management approach

1. **Review** current project management practice
2. Establish standards or guideline for **management of offsite construction**
3. **Share information** and experience
4. Launch **pilot project and R&D study** to refine the approach

2.7 New government incentives

1. Review feasibility for local **offsite manufacturing hub**
2. Review **CITF** funding support
3. Review environmental benefits and enhancement of **BEAM Plus**

Figure 9.4 Demand-related strategies (2 of 2)



3. Supply Chain- Related Strategies

3.1 Long-term establishment of offsite manufacturers

1. Long-term establishment of manufacturers by creating **long-term demand**
2. Progressively establish the criteria for **good manufacturing practice**
3. Explore opportunity for **MEP offsite manufacturing hub**

3.2 Wider acceptable manufacturing standards

1. Facilitate suppliers to have their **products pre-approval / certified** by clients/statutory authorities
2. In the long term, **harmonise** Chinese GB Standards and National / International Standards against local standards / practices

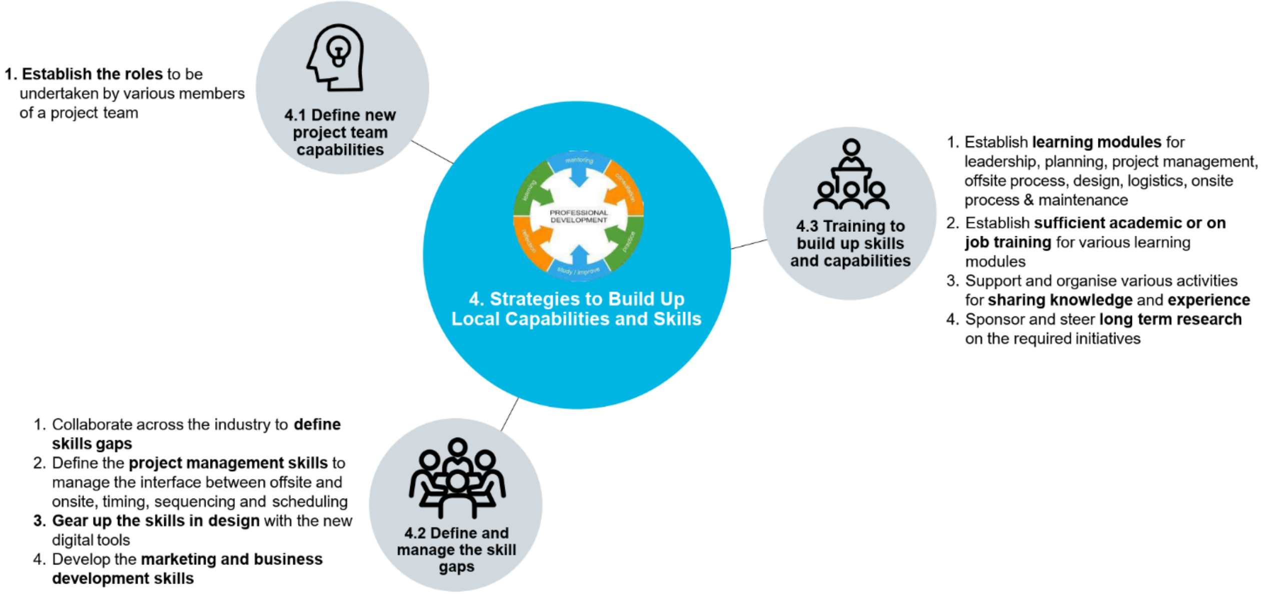
3.4 Customs clearance and taxation

1. **Share the information and experience** for dealing with customs clearance and the taxation system

3.3 Streamline regulatory mechanism

1. Streamline the **regulatory control** for manufacturing across the border and subsequent on-site **inspection**.

Figure 9.5 Supply chain-related strategies



4. Strategies to Build Up Local Capabilities and Skills

4.1 Define new project team capabilities

1. **Establish the roles** to be undertaken by various members of a project team

4.2 Define and manage the skill gaps

1. Collaborate across the industry to **define skills gaps**
2. Define the **project management skills** to manage the interface between offsite and onsite, timing, sequencing and scheduling
3. **Gear up the skills in design** with the new digital tools
4. Develop the **marketing and business development skills**

4.3 Training to build up skills and capabilities

1. Establish **learning modules** for leadership, planning, project management, offsite process, design, logistics, onsite process & maintenance
2. Establish **sufficient academic or on job training** for various learning modules
3. Support and organise various activities for **sharing knowledge** and **experience**
4. Sponsor and steer **long term research** on the required initiatives

Figure 9.6 Strategies to build up local capabilities and skills

References

ACRA, 2020. DfMA in Air Conditioning, *ACRA Newsletter*, Winter 2020, page 8-12, Hong Kong Air Conditioning and Refrigeration Association Ltd. (ACRA), Hong Kong.

Arif M., Bendi D., Sawhney A. & Iyer K. C., 2012. State of offsite construction in India-Drivers and barriers, *Journal of Physics: Conference Series*, 364: 12109.

Banks C., Kotecha R., Curtis J., Dee C., Pitt N. & Papworth R., 2018. Enhancing high-rise residential construction through design for manufacture and assembly – a UK case study, *Proceedings of the Institution of Civil Engineers - Management, Procurement and Law*, 171 (4) 164-175.

BCA, 2016. *BIM for DfMA (Design for Manufacturing and Assembly) Essential Guide*, Building and Construction Authority (BCA), Singapore.

BCA, 2018. *Design for Manufacturing and Assembly (DfMA): Prefabricated Mechanical, Electrical and Plumbing (MEP) Systems*, Building and Construction Authority (BCA), Singapore.

BCA, 2019. *Design for Maintainability Guide (Non-residential)*, Version 1.0, Building and Construction Authority (BCA), Singapore.

BDI, 2018. *DFMA Design for Manufacture & Assembly: Reduce Costs Increase Profits*, a White Paper for Corporate Management, Boothroyd Dewhurst, Inc. (BDI), Wakefield, RI. https://www.dfma.com/resources/dfmawp.asp

BESA, 2015. *An Offsite Guide for the Building and Engineering Services Sector*, Building and Engineering Services Association (BESA), London. https://www.buildoffsite.com/content/uploads/2016/01/OffsiteGuide.pdf

Bogue R., 2012. Design for manufacture and assembly: background, capabilities and applications, *Assembly Automation*, 32 (2) 112-118.

Boon K. S. & Doig L., 2019. DFMA for prefabricated Mechanical, Electrical and Plumbing (MEP) systems, *Arcadis Insights*, Issue 2/2019 - March 2019.

Boothroyd G., Dewhurst P., Knight W. A. & Anthony W., 2011. *Product Design for Manufacture and Assembly*, 3rd ed, CRC Press, Boca Raton, FL.

BSI, 2013. *PAS 1192-2:2013 Specification for information management for the capital/delivery phase of construction projects using building information modelling*, British Standards Institution (BSI), London.

BSI, 2019a. *BS EN ISO 19650-1:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM). Information management using building information modelling. Concepts and principles*, British Standards Institution (BSI), London.

BSI, 2019b. *BS EN ISO 19650-2:2018 Organization and digitization of information about* *buildings and civil engineering works, including building information modelling (BIM). Information management using building information modelling. Delivery phase of the assets*, British Standards Institution (BSI), London.

BSI, 2020a. *BS EN ISO 19650-3:2020 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM). Information management using building information modelling. Operational phase of the assets*, British Standards Institution (BSI), London.

BSI, 2020b. *BS EN ISO 19650-5:2020 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM). Information management using building information modelling. Security-minded approach to information management*, British Standards Institution (BSI), London.

Chen K. & Lu W., 2018. Design for manufacture and assembly oriented design approach to a curtain wall system: a case study of a commercial building in Wuhan, China, *Sustainability*, 10 (7) 2211.

Churcher D., Ronceray M. and Sands J., 2018. *Design Framework for Building Services*, 5th ed., BG 6/2018, Building Services Research and Information Association, Bracknell, Berkshire, England.

CIC, 2018. *Potential Utilisation of Prefabrication Yards and Prefabricated Components in Hong Kong - Feasibility Report*, Construction Industry Council (CIC), Hong Kong.

CIC, 2020a. *Reference Material on Logistics and Transport for Modular Integrated Construction Projects*, Construction Industry Council (CIC), Hong Kong.

CIC, 2020b. *Reference Material on the Statutory Requirements For Modular Integrated Construction Projects*, Construction Industry Council (CIC), Hong Kong.

Dewhurst N. P., 2019. Design for Manufacture and Assembly: History, an overview, and a design story, presentation at the *2019 International Forum on DFMA*, Boothroyd Dewhurst, Inc., Providence, RI. https://www.dfma.com/forum/2019pdf/dewhurstpres.pdf

DEVB, 2020. Modular Integrated Construction (MiC), Development Bureau Technical Circular (Works) No. 2/2020, Development Bureau (DEVB), Hong Kong. https://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/375/1/C-2020-02-01.pdf

Drigo R. & Deadman J., 2019. DfMA Building Services: What have we done and where are we going?, *CIBSE ANZ Technical Seminar: Piecing It All Together – Prefabrication and Modular Construction*, Sydney, Australia.

Dwyer T., 2019. Module 154: Offsite prefabrication driven by DfMA, CIBSE Journal CPD Programme. https://www.cibsejournal.com/cpd/modules/2019-11-dma/

EOTA, 2018. *Products Relating to Installation Systems Supporting Technical Equipment for Building Services such as Pipes, Conduits and Cables*, European Assessment Document (EAD) 280016-00-0602, European Organisation for Technical Assessment (EOTA). https://www.hilti.ch/content/dam/documents/pdf/global/EAD%20280016-00-0602.pdf

Gao S., Jin R. & Lu W., 2020. Design for manufacture and assembly in construction: a review, *Building Research & Information*, 48 (5) 538-550.

Gbadamosi A.-Q., Mahamadu A.-M., Oyedele L. O., Akinade O. O., Manu P., Mahdjoubi L. & Aigbavboa C., 2019. Offsite construction: Developing a BIM-Based optimizer for assembly, *Journal of Cleaner Production*, 215: 1180-1190.

Gibb A. G. F., 1999. *Off-site Fabrication: Prefabrication, Pre-assembly and Modularisation*, Whittles Pub., Latheronwheel.

Hui S. C. M. & Or G. K. C., 2005. Study of prefabricated building services components for residential buildings in Hong Kong, In *Proceedings of the Hubei-Hong Kong Joint Symposium 2005*, 1-2 July 2005, Wuhan, China, pp. 88-97. (in English with a Chinese abstract) http://ibse.hk/cmhui/hubei2005.pdf

Keung J., 2019. Changing the Way We Build Through Innovation Adoption – the DfMA Story, presentation at *2019 Construction Innovation Expo*, Hong Kong. https://ciexpo.cic.hk/Content/files/DFMA_AM_KEUNG.pdf

Laing O'Rourke, 2013. The future of DfMA is the future of construction, *Engineering Excellence Journal (EEJ)*, 2013 edition, Laing O'Rourke (LOR), UK. http://www.laingorourke.com/~/media/lor/files/lor-engineering-excellence-journal-2013.pdf

Liu G., Nzige J. H. & Li K., 2019. Trending topics and themes in offsite construction (OSC) research, *Construction Innovation*, 19 (3) 343-366.

Lu W., Tan T., Xu J., Wang J., Chen K., Gao S. & Xue F., 2020. Design for manufacture and assembly (DfMA) in construction: the old and the new, *Architectural Engineering and Design Management*, in press. https://doi.org/10.1080/17452007.2020.1768505.

McKinsey Global Institute, 2017. *Reinveting Construction: A Route to Higher Productivity*, McKinsey & Company.

Meeker D. G. & Rousmaniere A., 1996. *DFMA and Its Role in the Integrated Product Development Process*, MIT, June.

Molloy O., 1998. *Design for Manufacturing and Assembly: Concepts, Architectures and Implementation*, Chapman & Hall, London & New York.

Pan W., Zhang Z., Xie M. & Ping T., 2020. *Modular Integrated Construction for High-rises: Measured Success*, Centre for Innovation in Construction and Infrastructure Development (CICID), Department of Civil Engineering, The University of Hong Kong, Hong Kong.

Rahman M. & Alhassan A., 2012. A contractor's perception on early contractor involvement, *Built Environment Project and Asset Management*, 2 (2) 217-233.

RIBA, 2016. *RIBA Plan of Work 2013: Designing for Manufacture and Assembly*, RIBA Publishing, Newcastle upon Tyne, UK.

RIBA, 2020. *RIBA Plan of Work 2020 Overview*, Royal Institute of British Architects (RIBA), London. http://www.ribaplanofwork.com

Sands, J., 2019. *Offsite Construction for Building Services*, Topic Guide TG 17/2019, Building Services Research and Information Association (BSRIA), Bracknell, Berkshire, UK.

Wilson D. G., Smith M. H. & Deal J., 1999a. *Prefabrication and Preassembly: Applying the Techniques to Building Engineering Services*, Advanced Construction Techniques ACT 1/99, Building Services Research and Information Association (BSRIA), Bracknell, Berkshire, UK.

Wilson D. G., Smith M. H. & Deal J., 1999b. *Prefabrication and Preassembly: Successful Application in Building Engineering Services*, Advanced Construction Techniques ACT 2/99, Building Services Research and Information Association (BSRIA), Bracknell, Berkshire, UK.

List of Appendices

Appendix 1 Glossary

This glossary was compiled partly from the terms defined in the publications by the Royal Institute of British Architects (Sinclair et al., 2016) (denoted by '#') and the Building and Engineering Services Association/ Buildoffsite (Fraser et al., 2015) (denoted by '^'). Terms that are unique to Hong Kong or not defined in these two publications are defined accordingly.

Term	**Definition**
Assembly (noun)	An item formed by aggregating or combining different components or elements in part (subassembly) or in full (assembly).
Assembly (verb)	The act of construction of a building through the combining and securing of manufactured components on site, generally in a planned, tested and carefully controlled sequence.
Buildability/ Constructability	A project management technique to review construction processes from start to finish during the pre-construction phase. Its purpose is to identify obstacles before a project is actually built in order to reduce or prevent errors, delays and cost overruns.
Building Information Modelling (BIM)	A process involving the generation and management of digital representations of physical and functional characteristics of places. A BIM model is a digital representation of the physical and functional characteristics of a facility.
Collaborative design#	DfMA requires collaborative interaction between designers, contractors, subcontractors (including specialist subcontractors), product suppliers and trades to encourage innovation in design-to-construction processes.
Component	A manufactured individual building element, which may include other prefabricated elements.
Component libraries#	Many design team members are developing their own BIM libraries, to help them reuse information from one project to the next. Increasingly, these libraries are based on modules or assemblies that utilise DfMA processes. Manufacturers are also increasingly providing BIM objects to represent their products, either directly or through libraries. BIMobject, BIMstore, the (RIBA/NBS) National BIM Library and CIC's BIM Objects Library (to name a few) provide objects, families and system files for use with major BIM and CAD software platforms. BIM software will also include a wide range of generic BIM objects. Component libraries are a core aspect of continuous improvement processes and standardisation.

Concurrent engineering	An approach that brings together in a team both design and manufacturing engineers throughout the design sequence. The product and the manufacturing process are engineered at the same time and adequate attention to all important design objectives, including DFM, is facilitated. The approach can also speed up the product realisation cycle.
Construction Industrialisation#	The development and improvement of construction work through the use of mechanisation and automation. The industrialisation of construction has several purposes: increase productivity, replace manual labour with machines, accelerate the pace of construction, put new projects into operation more quickly, reduce costs and improve quality.
Design and Build (D&B)	A procurement route in which the main contractor is appointed to design and construct the works, as opposed to a traditional contract where the client appoints consultants to design the development and then a contractor is appointed separately to construct the works.
Design Bid Build (DBB)	A project delivery method in which the agency or owner contracts with separate entities for the design and construction of a project. (Also known as a Design–tender (or "design/tender") traditional method or hard bid).
Design for Assembly (DFA)	Design of parts and products for easy assembly. Product design aimed specifically at simplifying a product and its overall assembly.
Design for Manufacture/ Manufacturability (DFM)	In a broad sense, DFM includes any step, method, or system for providing a product design that eases the task of manufacturing and lowers manufacturing cost. In a more specific sense, DFM is primarily a knowledge-based technique that invokes a series of guidelines, principles, recommendations, or rules of thumb for designing a product which is easy to make.
Design for Safety#	The process whereby designers influence construction safety by making appropriate choices in the design and planning stages of a project; for example, by eliminating the need to work at height, or the need for hot works on site, such as welding.
Design for Manufacture and Assembly (DfMA or DFMA)	A design approach that focuses on ease of manufacture and efficiency of assembly. By simplifying the design of a product, it is possible to manufacture and assemble it more efficiently, in the minimum time and at a lower cost. DfMA is a proactive and concurrent design and engineering process that focuses on meeting customer requirements while balancing cost, quality and performance. DFMA is also the name of the integrated set

	of software products from Boothroyd Dewhurst, Inc. that are used by companies to implement the DFMA methodology. DFMA is a registered trademark of Boothroyd Dewhurst, Inc.
Distribution module^	Volumetric services preassembly for vertical risers or horizontal distribution which can be subdivided into heavy or light categories depending largely on the construction method and size/complexity/number of services they contain.
Design for Excellence (DFX)	A knowledge-based approach that is intended to provide the designer with a means to achieve all desirable objectives. The "X" represents any factor related to the problem to be solved, such as quality and reliability, safety, serviceability, user friendliness, environmental friendliness, and short time-to-market design.
Digital Engineering#	Digital engineering refers to the digital interactions between design, construction, manufacturing and engineering, including Building Information Modelling (BIM): the digital modelling of a building or asset through design, construction and use.
Fabrication	A manufacturing process, generally taking place at a specialised facility, in which various materials are joined to form a component part of the final installation.
Field factory#/ Flying factory	A factory facility set up near the construction site. A field factory might manufacture modules from scratch or might preassemble flat-pack components before assembly on site. Field factories minimise the logistics associated with transporting modules and also enable larger modules to be manufactured due to the removal of transportation constraints.
Industrialised Building System (IBS)	A construction system where components are manufactured at factories on or offsite, transported, and then assembled into a structure with minimum work.
Industrialised Construction (IC)	An approach that promotes the advancement of construction processes by employing mechanisation and automation. It is a construction system that uses more innovative and integrated techniques to connect the design-to-make process.
Integrated Project Delivery (IPD)	A construction project delivery method that seeks efficiency and involvement of all participants and elements/components (people, systems, business structures and practices) through all phases of design, fabrication, and construction. IPD combines ideas from integrated practice and lean construction.
Just-in-time (JIT) Delivery#	JIT logistics involve receiving raw materials, products and parts in the factory and then on site as they are needed, rather

	than days or weeks earlier. This allows businesses to reduce inventory costs by having fewer unnecessary supplies on hand, and fewer materials to store and handle. Where buffer stocks are considered necessary (e.g. as a result of a risk analysis), they are specified in terms of time periods linked to the assembly plan (e.g. one day ahead of manufacturing).
Kit of Parts#	A term used to describe the process of organising the individual parts of a building into assemblies that are capable of being manufactured off site, and which are conceived in a way that allows them to be efficiently assembled on site. Developing a Kit of Parts concept in detail involves considering standard, easy-to-manufacture and assemble components and ensuring they are sized for convenient handling or according to shipping and transportation constraints. The use of flying factories may allow the kit to contain larger components, although this will require early consideration.
Lean#	A term used in many ways, but it is essentially about removing waste from any design or construction process. As design and construction becomes more efficient, lean principles will be applied increasingly to design-to-construction processes.
Lean construction	A combination of operational research and practical development in design and construction with an adaption of lean manufacturing principles and practices to the end-to-end design and construction process. Unlike manufacturing, construction is a project-based production process.
Manufacturing	The production of a building element (components, assemblies or modules) in a commoditised manner, typically in a factory environment located remotely from the construction site.
Mass customisation^	The benefits of mass production creatively combined with systems that offer greater choice for the individual customer, improved control of the total construction process, and flexibility of assembly options.
Modern Method of Construction (MMC)	A term used by the United Kingdom government to describe a number of innovations in the housing sector including prefabrication, offsite assembly and various forms of supply chain specifications.
Module^	A volumetric building module where the units form the structure of the building as well as enclosing useable space. The term is also sometimes used to describe room modules, which do not incorporate their own superstructure.

Modular building	A building formed of modular units (also commonly referred to as pods). Similar to volumetric preassembly, modular buildings may be brought to site with completed internal and external finishes, services, and in some cases even furnishing.
Modular co-ordination^	The discipline of designing buildings and structures using a specific module (e.g. one with a specified dimension of 100 mm) where all the elements and components are described as multiples of the module.
Modular integrated Construction (MiC)	A construction method that employs the technique of having freestanding volumetric modules (with finishes, fixtures, fittings, building services installations, etc.) manufactured offsite and then transported to site for assembly.
Modular units	Large modules used in volumetric construction. Units such as hotel rooms can be wholly constructed in the factory as large modules that form the structure of the building as well as enclosing useable space. Units may be fully finished internally in the factory, including many aspects of finishes, furnishings and equipment. Increasingly, external cladding, particularly glazing systems, are also installed in the factory, although in some instances finishes such as brickwork are applied on site.
Multi-purpose riser^	A multiple service vertical distribution module usually constructed from hot-rolled or hollow section primed or galvanised mild steel and incorporating appropriate building services which may or may not be lagged (insulated). The modules are often transported in 3-floor assemblies, typically 12m to 16m long x 3.5m high x 3.5m wide to avoid transportation difficulties. Modules can carry single or combined mechanical and electrical services. Maximum weight is dependent on contents but 4 to 8 tonnes is the usual range.
Non-volumetric preassembly^	Units that are preassembled, but "non-volumetric" in that they do not enclose usable space.
Offsite	Manufacture and preassembly of components, elements or modules before installation into the final location.
Offsite Construction (OSC)/ Offsite Manufacturing (OSM) / Offsite Production (OSP)^	Largely interchangeable terms referring to the part of the construction process that is carried out away from the building site. This can be in a factory or sometimes in specially-created temporary production facilities close to the construction site (or field/flying factories). Common alternative spellings for offsite are off-site or off site.

Offsite fabrication	A process which incorporates prefabrication and preassembly of units or modules remote from the work site and their installation to form the permanent works at the work site. In its fullest sense, offsite fabrication requires a project strategy that will change the orientation of the project process from construction to manufacture and installation.
Plant room module (preassembled)^	Packaged or skid-mounted preassembled plant rooms prefinished in the factory and ready for direct connection to mains services onsite. Can include complete plant room areas including AHUs, fans, chillers, boilers, pumps and pressurisation units, together with elements of the building envelope. Typical sizes 16m x 3.5m x 3.5m, and weigh 25 tonnes, although plant rooms on roofs are often lighter due to limited crane capacity available.
Preassembly	The manufacture and assembly of a complex unit comprising several components prior to the unit's installation on site.
Prefabricated Prefinished Volumetric Construction (PPVC)	Assembly of whole rooms, modules or apartment units complete with internal finishes and fixtures that are prefabricated offsite and installed on site to form modular apartments.
Prefabrication (Prefab)	Offsite construction of building elements and assemblies in a factory, which are then transported to a site for assembly and installation.
Process control and monitoring#	The use of well-documented controls and procedures to ensure a repeatable process is used from design through to construction, enabling the production of consistent buildings from project to project.
Pump module (skid mounted)^	Supplies water for domestic, heating and chilled water, incorporating all pumps, valves, pipework and accessories usually pre-insulated and can contain all electrical and control components on a common base frame. Size and weight varies widely dependent on duty.
Risers (preassembled)^	Preassembled electrical and/or mechanical vertical distribution modules designed either to be self-standing structures or fixed to walls.
Service walls^	Preassembled dry lined internal walls incorporating small bore pipework and electrical services such as controls and small power.
Skids^	Transportable frames for carrying standardised preassembled products, mainly building services, e.g. pump skids, boiler skids, etc. The term is sometimes used as 'skid-mounted

	boiler', etc. Larger sizes may include flooring and access provision, smaller sizes usually connected to services from the perimeter. Smaller size skids are often used in retrofit projects to allow access via existing door openings.
Standardisation#	The use of modules, assemblies, components, interfaces, methods or processes that are repeated through a project and from project to project. Standardisation benefits from the use of continuous improvement processes.
Subassembly^	An assembly of components brought together either at a site or in a factory to form completed systems or volumetric assemblies.
Supply chain#	Everyone involved in the design, construction and, potentially, maintenance of a building, including the design team, contractor, subcontractors (including specialist subcontractors) and suppliers of materials and other aspects.
Supply Chain Integration (SCI)#	SCI involves everyone in the supply chain working cooperatively and collaboratively, so that the collective effort effectively delivers the client's requirements and avoids unnecessary work. SCI is about adding value to design and construction processes, improving time, cost, quality, health and safety and other outcomes.
Terminal module^	A module containing a room terminal unit, e.g. a Fan Coil Unit complete with valves, controls, pipework, ductwork and wiring, etc. Typical size of a fan coil terminal module is 1.8m x 4.2m x 500mm deep, and weigh 200kg.
Value engineering (VE)	A systematic, organised approach to providing necessary functions in a project at the lowest cost. Value engineering promotes the substitution of materials and methods with less expensive alternatives, without sacrificing functionality.
Value management (VM)	A combination of planning tools and methods to find the optimum balance of project benefits in relation to project costs and risks. It is the process of planning, assessing and developing the project in order to make correct decisions about the optimised balance of the benefits, risks and costs.
Valve assemblies (preassembled)^	Valve assemblies prefabricated to individual specification, which reduces onsite installation time, site storage requirements and purchase orders. Some valve manufacturers offer the assemblies as an additional service with sizes and weights available from catalogues.

Volumetric preassembly	Units that enclose useable space, but do not of themselves constitute the whole building. Examples are toilet pods, plant room units, modular lift shifts, etc.

Appendix 2 Statutory, Standards and Quality Assurance Issues

2.1 Statutory Requirements in Hong Kong

The Construction Industry Council has published a comprehensive guide entitled *Reference Material on the Statutory Requirements for Modular Integrated Construction Projects (September 2020),* which provides information on the statutory requirements imposed by the respective regulatory bodies in Hong Kong. The information is considered relevant to DfMA MEP works.

The following is a non-exhaustive list of statutory requirements for DfMA MEP works:

Buildings Department (2019)
Practice Notes for Authorized Persons (PNAP) ADV-36 Modular Integrated Construction
https://www.bd.gov.hk/doc/en/resources/codes-and-references/practice-notes-and-circular-letters/pnap/ADV/ADV036.pdf

Electrical and Mechanical Services Department (EMSD) (2019)
Guidance Note on Fixed Electrical Installations with Modular Integrated Construction Method (June 2019)
https://www.emsd.gov.hk/filemanager/en/content_444/GN_FEI_Modular_Integrated_Construction_Method.pdf

Electrical and Mechanical Services Department (EMSD) (2019)
Guidance Note on Household Electrical Products with Modular Integrated Construction Method (June 2019)
https://www.emsd.gov.hk/filemanager/en/content_444/GN_FEI_Modular_Integrated_Construction_Method.pdf

Electrical and Mechanical Services Department (EMSD) (2019)
Guidance Note on Supply of Energy Label Prescribed Products at MiC Projects (June 2019)
http://www.emsd.gov.hk/energylabel/en/doc/Guidance%20Note%20on%20Supply%20of%20Prescribed%20Products%20at%20MiC%20Projects_ENG(201906).pdf

Electrical and Mechanical Services Department (EMSD) (2020)
Guidance Note on Gas Supply Installations (September 2020)
https://www.emsd.gov.hk/filemanager/en/content_287/Guidance%20Note%20on%20Gas%20Supply%20Installations%20202009_ENG.pdf

Electrical and Mechanical Services Department (EMSD) (2020)
Code of Practice for the Electricity (Wiring) Regulations (2020 Edition)
https://www.emsd.gov.hk/filemanager/en/content_443/COP_E_2020.pdf

Electrical and Mechanical Services Department (EMSD) (2021)
Modular Integrated Construction
https://www.emsd.gov.hk/en/supporting_government_initiatives/mic/index.html

Fire Services Department (FSD) (2019)
Circular Letter No. 3/2019 Modular Integrated Construction (MiC)
https://www.hkfsd.gov.hk/eng/source/circular/2019_03_eng_20190327_160959.pdf

Water Supplies Department (2020)
Guide to Application for Water Supply (November 2020)
https://www.wsd.gov.hk/en/plumbing-engineering/requirements-for-plumbing-installation/guide-to-application-for-water-supply/index.html

Water Supplies Department (2020)
Technical Requirements for Plumbing Works in Buildings (November 2020) by the Water Supplies Department
https://www.wsd.gov.hk/en/plumbing-engineering/requirements-for-plumbing-installation/technical-requirements-for-plumging-works-in-bldgs/index.html

Regarding performance requirements for steel frames, the following guideline may serve as a reference:

Buildings Department (2011)
Code of Practice for the Structural Use of Steel 2011
https://www.bd.gov.hk/doc/en/resources/codes-and-references/code-and-design-manuals/SUOS2011.pdf

2.2 Certification Body Accreditation Scheme(s)/ Standard(s)

The following is a certification body accreditation scheme (for accrediting certification bodies) which may be came across when opting for offsite manufacturers based in Mainland China:

- China National Accreditation Service for Conformity Assessment (CNAS), which is a Mutual Recognition Agreement Partner of the Hong Kong Certification Body Accreditation Scheme (HKCAS) operated under the Hong Kong Accreditation Service

To improve collaboration through BIM, the following standards series should be referred to for the management of information and BIM implementation:

- BS EN ISO 19650 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management building information modelling
    - Part 1: Concepts and principles
    - Part 2: Delivery phase of the assets
- CIC BIM Standards, accessible from the CIC BIM Portal (https://www.bim.cic.hk/en/resources/publications?keyword=cic+bim+standards)

2.3 Quality Assurance

The following is a list of quality management certification systems on which an MEP offsite manufacturer can obtain system certification from a recognised certification body:

- ISO 9001 Quality management systems.
- ISO 14001 Environmental management systems.
- ISO 45001 Occupational health and safety management systems
- EN 1090 Structural Steel and Aluminium CE Marking

Appendix 3 Further Reading

1. Publications by the Government of the Hong Kong Special Administrative Region

Development Bureau (2020)
Development Bureau Technical Circular (Works) No. 2/2020 Modular Integrated Construction (MiC)
https://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/375/1/C-2020-02-01.pdf

Development Bureau (2020)
Development Bureau Technical Circular (Works) No. 12/2020 Adoption of Building Information Modelling for Capital Works Projects in Hong Kong
https://www.devb.gov.hk/filemanager/technicalcirculars/en/upload/381/1/TCW%2012-2020.pdf

2. Publications by Institutions in Hong Kong

Construction Industry Council (2019)
CIC BIM Standards for Mechanical, Electrical and Plumbing (August 2019)
https://www.bim.cic.hk/en/resources/publications_detail/66?cate=48&back=%2Fen%2Fresources%2Fpublications%3Fcate%3D48%26keyword%3D&keyword=

Construction Industry Council (2020)
Reference Material on Logistics and Transport for Modular Integrated Construction Projects (September 2020)
https://mic.cic.hk/files/Information/2/File/Logistics_and_Transport_for_MiC_Projects.pdf

Construction Industry Council (2020)
Reference Material on the Statutory Requirements for Modular Integrated Construction Projects (September 2020)
https://mic.cic.hk/files/Information/1/File/Reference_Material_2020.pdf

Construction Industry Council (2020)
Construction CIC BIM Standards – General (with Hong Kong local Annex of ISO 19650-2:2018) Version 2 – December 2020
https://www.bim.cic.hk/en/resources/publications_detail/85?back=%2fen%2fresources%2fpublications

Pan, W., Yang, Y., Zhang, Z. Q. and Chan, Y. S. (2019)
Modularisation for Modernisation: A Strategy Paper Rethinking Hong Kong Construction
The University of Hong Kong
https://www.miclab.hk/mfm

Pan, W., Zhang, Z. Q. and Yang, Y. (2020)
A Glossary of Modular Integrated Construction
The University of Hong Kong
https://www.miclab.hk/glossary

Pan, W., Zhang, Z. Q., Xie, M. C. and Ping, T. Y. (2020)
Modular Integrated Construction for High-rises: Measure Success

The University of Hong Kong
https://www.miclab.hk/success

Pan, W., Zhang, Z. Q., Xie, M. C. and Ping, T. Y. (2020)
Modular Integrated Construction Performance Measurement: Guidebook
The University of Hong Kong
https://www.miclab.hk/guidebook

3. Publications by Institutions in Countries Overseas

3.1 The Building and Construction Authority (BCA), Singapore

The Building and Construction Authority (BCA), Singapore (2016)
Design for Maintainability Checklist (Version 1.3)
https://www1.bca.gov.sg/docs/default-source/docs-corp-buildsg/dm_checklist_2016.pdf?sfvrsn=8c2da349_0

The Building and Construction Authority (BCA), Singapore (2017)
Design for Manufacturing and Assembly (DfMA) Prefabricated Prefinished Volumetric Construction
https://www.bca.gov.sg/Professionals/Technology/others/PPVC_Guidebook.pdf

The Building and Construction Authority (BCA), Singapore (2018)
Design for Manufacturing and Assembly (DfMA) Prefabricated Mechanical, Electrical and Plumbing (MEP) Systems
https://www1.bca.gov.sg/docs/default-source/docs-corp-buildsg/mep_guidebook.pdf?sfvrsn=e8a20354_0

3.2 Building and Engineering Services Association (BESA), the United Kingdom

Fraser, N., Race, G.L., Kelly, R. and Hancock, P. (2015)
TR39: An Offsite Guide for the Building and Engineering Services Sector
The Building and Engineering Services Association (BESA)/ Buildoffsite, the United Kingdom
https://www.buildoffsite.com/content/uploads/2018/06/BuildOffsite-BESA-Guide-new-June-2018.pdf

3.3 Building Services Research and Information Association (BSRIA), the United Kingdom

Michie, A. and Ogle, John. (1982)
Technical Note TN 1/82 Co-ordination of building services – design stage methods
BSRIA, the United Kingdom

Wilson, D.G., Smith, M.H. and Deal, J. (1999)
Advanced Construction Technology ACT 1/99 Prefabrication and Preassembly – applying the techniques to building engineering services
The Building Services Research and information Association (BSRIA), the United Kingdom

David, C., Sands, J. and Ronceray. (2018)
BSRIA Guide BG 6/2018 A Design Framework for Building Services (5th Edition)
BSRIA, the United Kingdom

Sands, J. (2019)
Technical Guide TG 17/2019 Offsite Construction for Building Services
BSRIA, the United Kingdom
https://www.buildoffsite.com/content/uploads/2019/02/BSRIA-report.pdf

3.4 European Organisation for Technical Assessment (EOTA), the European Union (EU)

European Organisation for Technical Assessment (2018)
European Assessment Document EAD 280016-00-0602 Products related to Installation Systems Supporting Technical Equipment for Building Services such as Pipes, Conduits, Ducts and Cables
https://www.hilti.ch/content/dam/documents/pdf/global/EAD%20280016-00-0602.pdf

3.5 The Monash University, Australia

The Monash University, Australia (2017)
Handbook for the Design of Modular Structures
https://www.dropbox.com/s/dvzf0fg3p8lwdsh/Handbook%20for%20the%20Design%20of%20Modular%20Structures.pdf?dl=0

3.6 The Royal Institute of British Architects (RIBA), the United Kingdom

The Royal Institute of British Architects (RIBA) (2016)
RIBA Plan of Work 2013 Designing for Manufacture and Assembly
RIBA Publishing
http://consig.org/wp-content/uploads/2018/10/RIBAPlanofWorkDfMAOverlaypdf.pdf

4. Details of Training Courses provided by Hong Kong/ Overseas Institutions

The BCA Academy, Singapore (2020)
Specialist Diploma in Design for Manufacturing and Assembly (SDDfMA)
https://www.bcaa.edu.sg/what-we-offer/academic-programmes/specialist-diploma?CourseId=563ad5d7-29fb-4fd6-8a03-a53ba0c2e86f

The BCA Academy, Singapore (2020)
Specialist Diploma in MEP Modularisation (SDMM)
https://www.bcaa.edu.sg/what-we-offer/academic-programmes/specialist-diploma?CourseId=ee6ffb63-c5d7-4848-a29f-c26bb3d10798

5. Information regarding NEC Contract and Early Contractor Involvement to Help Establish a Procurement Strategy for MiMEP Works

Ashurst (2019)
Developments in two-stage contracting and early contractor involvement. A UK Perspective
https://www.ashurst.com/en/news-and-insights/insights/two-stage-contracting-and-eci/

Bryan Cave Leighton Paisner (BCLP) (2021)
NEC4 X22: ECI for an Asian context?
https://www.bclplaw.com/en-US/insights/nec4-x22-eci-for-an-asian-context.html

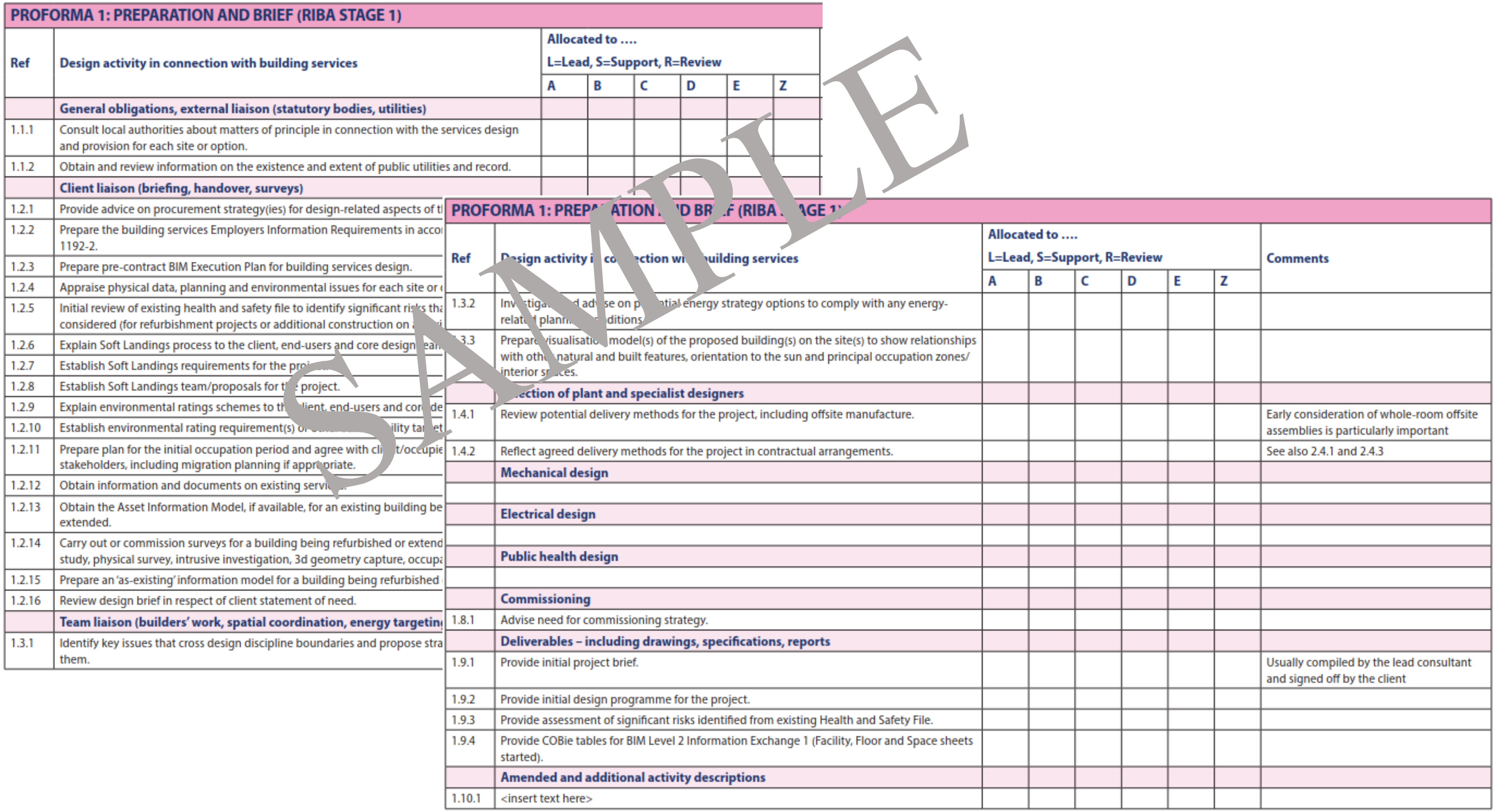
Designing Buildings Wiki (2020)
Two-stage tender
https://www.designingbuildings.co.uk/wiki/Two-stage_tender

Designing Buildings Wiki (2020)
NEC4
https://www.designingbuildings.co.uk/wiki/NEC4

NEC (2019)
Engaging Suppliers Early with NEC4
https://www.neccontract.com/About-NEC/News-and-Media/Engaging-suppliers-early-with-NEC4

Appendix 4 Reference Resources

4.1 Matrix from Appendix A, BG 6/2018 by BSRIA



SAMPLE

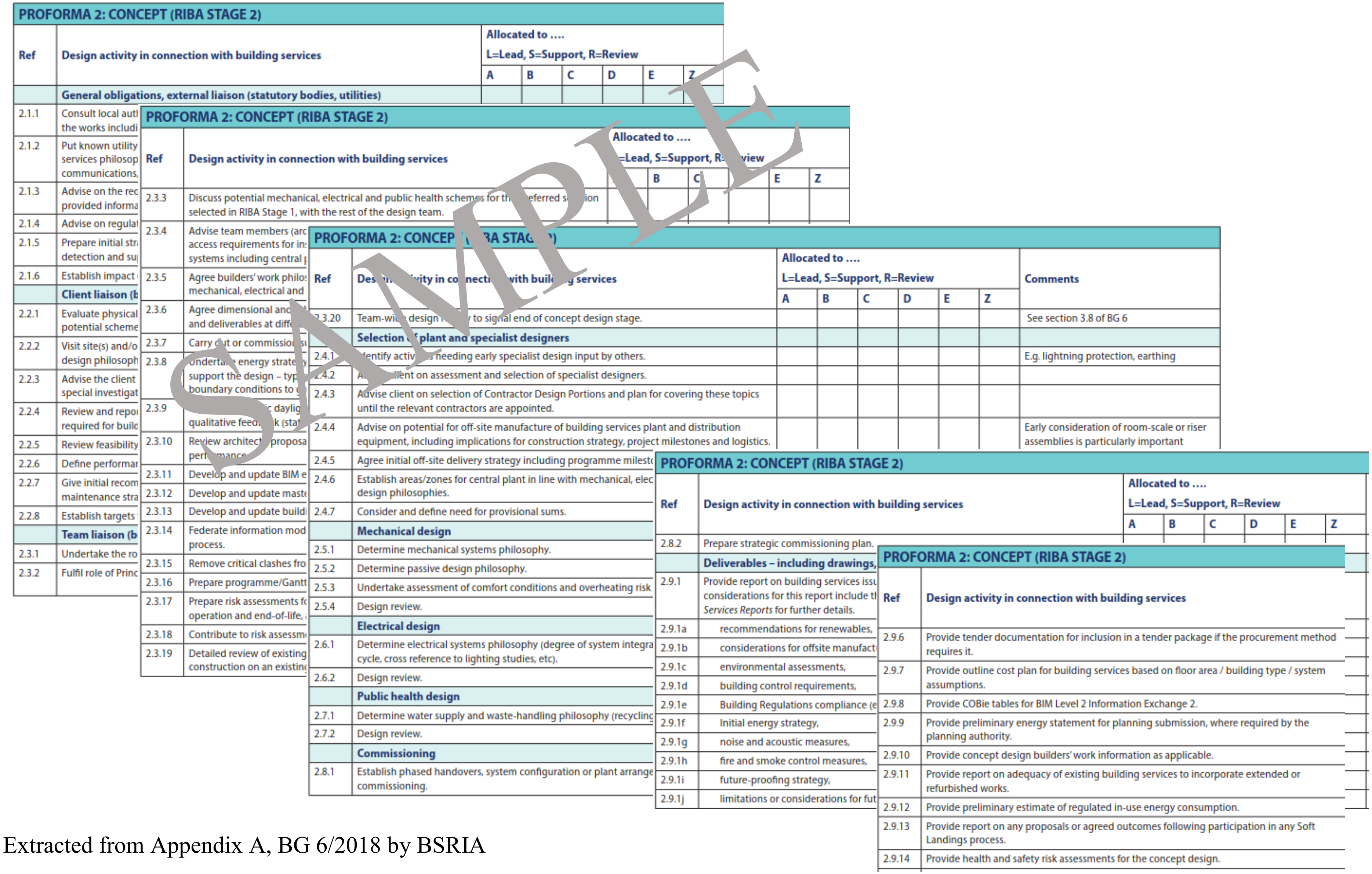
PROFORMA 1: PREPARATION AND BRIEF (RIBA STAGE 1)

Ref	Design activity in connection with building services	Allocated to .... L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
	General obligations, external liaison (statutory bodies, utilities)						
1.1.1	Consult local authorities about matters of principle in connection with the services design and provision for each site or option.						
1.1.2	Obtain and review information on the existence and extent of public utilities and record.						
	Client liaison (briefing, handover, surveys)						
1.2.1	Provide advice on procurement strategy(ies) for design-related aspects of t						
1.2.2	Prepare the building services Employers Information Requirements in accor 1192-2.						
1.2.3	Prepare pre-contract BIM Execution Plan for building services design.						
1.2.4	Appraise physical data, planning and environmental issues for each site or						
1.2.5	Initial review of existing health and safety file to identify significant risks tha considered (for refurbishment projects or additional construction on a						
1.2.6	Explain Soft Landings process to the client, end-users and core design tea						
1.2.7	Establish Soft Landings requirements for the proj						
1.2.8	Establish Soft Landings team/proposals for the project.						
1.2.9	Explain environmental ratings schemes to the client, end-users and core de						
1.2.10	Establish environmental rating requirement(s) or						
1.2.11	Prepare plan for the initial occupation period and agree with client/occupie stakeholders, including migration planning if appropriate.						
1.2.12	Obtain information and documents on existing servi						
1.2.13	Obtain the Asset Information Model, if available, for an existing building be extended.						
1.2.14	Carry out or commission surveys for a building being refurbished or extend study, physical survey, intrusive investigation, 3d geometry capture, occupa						
1.2.15	Prepare an 'as-existing' information model for a building being refurbished						
1.2.16	Review design brief in respect of client statement of need.						
	Team liaison (builders' work, spatial coordination, energy targetin						
1.3.1	Identify key issues that cross design discipline boundaries and propose stra them.						

PROFORMA 1: PREPARATION AND BRIEF (RIBA STAGE 1)

Ref	Design activity in connection with building services	Allocated to .... L=Lead, S=Support, R=Review						Comments
		A	B	C	D	E	Z	
1.3.2	Investigate and advise on potential energy strategy options to comply with any energy-related planning conditions.							
1.3.3	Prepare visualisation model(s) of the proposed building(s) on the site(s) to show relationships with other natural and built features, orientation to the sun and principal occupation zones/ interior spaces.							
	Selection of plant and specialist designers							
1.4.1	Review potential delivery methods for the project, including offsite manufacture.							Early consideration of whole-room offsite assemblies is particularly important
1.4.2	Reflect agreed delivery methods for the project in contractual arrangements.							See also 2.4.1 and 2.4.3
	Mechanical design							
	Electrical design							
	Public health design							
	Commissioning							
1.8.1	Advise need for commissioning strategy.							
	Deliverables – including drawings, specifications, reports							
1.9.1	Provide initial project brief.							Usually compiled by the lead consultant and signed off by the client
1.9.2	Provide initial design programme for the project.							
1.9.3	Provide assessment of significant risks identified from existing Health and Safety File.							
1.9.4	Provide COBie tables for BIM Level 2 Information Exchange 1 (Facility, Floor and Space sheets started).							
	Amended and additional activity descriptions							
1.10.1	<insert text here>							

Extracted from Appendix A, BG 6/2018 by BSRIA



PROFORMA 2: CONCEPT (RIBA STAGE 2)

Ref	Design activity in connection with building services	Allocated to .... L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
	General obligations, external liaison (statutory bodies, utilities)						
2.1.1	Consult local autl the works includi						
2.1.2	Put known utility services philosop communications,						
2.1.3	Advise on the rec provided informa						
2.1.4	Advise on regulat						
2.1.5	Prepare initial str detection and su						
2.1.6	Establish impact						
	Client liaison (b						
2.2.1	Evaluate physical potential scheme						
2.2.2	Visit site(s) and/o design philosoph						
2.2.3	Advise the client special investigat						
2.2.4	Review and repo required for builc						
2.2.5	Review feasibility						
2.2.6	Define performar						
2.2.7	Give initial recom maintenance stra						
2.2.8	Establish targets						
	Team liaison (b						
2.3.1	Undertake the ro						
2.3.2	Fulfil role of Princ						

PROFORMA 2: CONCEPT (RIBA STAGE 2)

Ref	Design activity in connection with building services	Allocated to .... =Lead, S=Support, R= view					
			B	C		E	Z
2.3.3	Discuss potential mechanical, electrical and public health schemes for th eferred s ion selected in RIBA Stage 1, with the rest of the design team.						
2.3.4	Advise team members (arc access requirements for ins systems including central p						
2.3.5	Agree builders' work philos mechanical, electrical and						
2.3.6	Agree dimensional and and deliverables at diffe						
2.3.7	Carry o t or commission su						
2.3.8	Underta energy strate support the design – typ boundary conditions to						
2.3.9	c daylig qualitative feed k (stat						
2.3.10	Review architect proposa perf mance						
2.3.11	Develop and update BIM e						
2.3.12	Develop and update maste						
2.3.13	Develop and update buildi						
2.3.14	Federate information mod process.						
2.3.15	Remove critical clashes fro						
2.3.16	Prepare programme/Gantt						
2.3.17	Prepare risk assessments fo operation and end-of-life,						
2.3.18	Contribute to risk assessm						
2.3.19	Detailed review of existing construction on an existin						

PROFORMA 2: CONCEP A STAG)

Ref	Des ity in co necti with buil g services	Allocated to .... L=Lead, S=Support, R=Review						Comments
		A	B	C	D	E	Z	
2.3.20	Team-wi design to signal end of concept design stage.							See section 3.8 of BG 6
	Selection f plant and specialist designers							
2.4.1	entify activ s needing early specialist design input by others.							E.g. lightning protection, earthing
2.4.2	A ient on assessment and selection of specialist designers.							
2.4.3	Advise client on selection of Contractor Design Portions and plan for covering these topics until the relevant contractors are appointed.							
2.4.4	Advise on potential for off-site manufacture of building services plant and distribution equipment, including implications for construction strategy, project milestones and logistics.							Early consideration of room-scale or riser assemblies is particularly important
2.4.5	Agree initial off-site delivery strategy including programme milesto							
2.4.6	Establish areas/zones for central plant in line with mechanical, elec design philosophies.							
2.4.7	Consider and define need for provisional sums.							
	Mechanical design							
2.5.1	Determine mechanical systems philosophy.							
2.5.2	Determine passive design philosophy.							
2.5.3	Undertake assessment of comfort conditions and overheating risk							
2.5.4	Design review.							
	Electrical design							
2.6.1	Determine electrical systems philosophy (degree of system integra cycle, cross reference to lighting studies, etc).							
2.6.2	Design review.							
	Public health design							
2.7.1	Determine water supply and waste-handling philosophy (recycling							
2.7.2	Design review.							
	Commissioning							
2.8.1	Establish phased handovers, system configuration or plant arrange commissioning.							

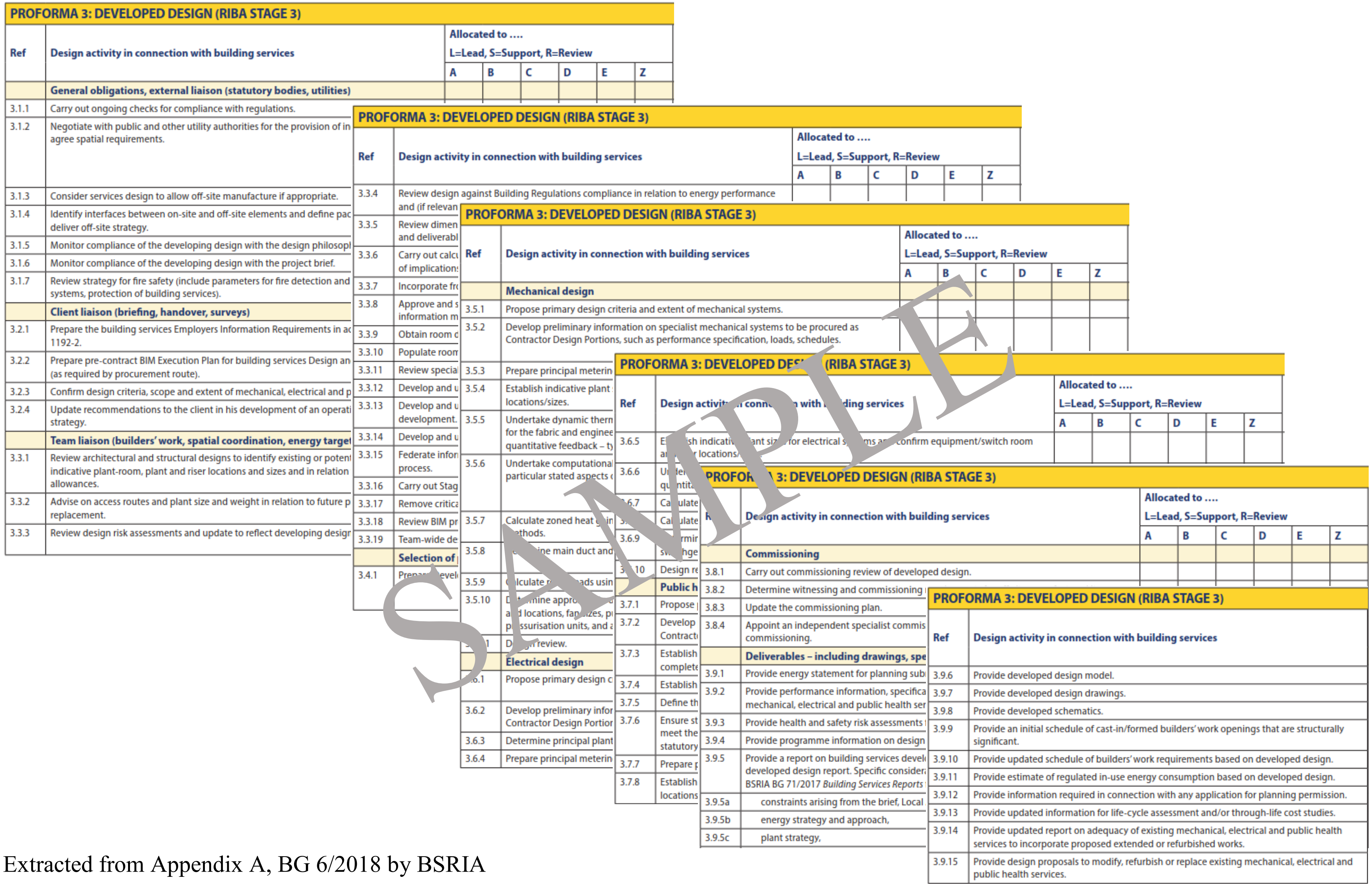
PROFORMA 2: CONCEPT (RIBA STAGE 2)

Ref	Design activity in connection with building services	Allocated to .... L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
2.8.2	Prepare strategic commissioning plan.						
	Deliverables – including drawings,						
2.9.1	Provide report on building services issu considerations for this report include th *Services Reports* for further details.						
2.9.1a	recommendations for renewables,						
2.9.1b	considerations for offsite manufact						
2.9.1c	environmental assessments,						
2.9.1d	building control requirements,						
2.9.1e	Building Regulations compliance (e						
2.9.1f	Initial energy strategy,						
2.9.1g	noise and acoustic measures,						
2.9.1h	fire and smoke control measures,						
2.9.1i	future-proofing strategy,						
2.9.1j	limitations or considerations for fut						

PROFORMA 2: CONCEPT (RIBA STAGE 2)

Ref	Design activity in connection with building services
2.9.6	Provide tender documentation for inclusion in a tender package if the procurement method requires it.
2.9.7	Provide outline cost plan for building services based on floor area / building type / system assumptions.
2.9.8	Provide COBie tables for BIM Level 2 Information Exchange 2.
2.9.9	Provide preliminary energy statement for planning submission, where required by the planning authority.
2.9.10	Provide concept design builders' work information as applicable.
2.9.11	Provide report on adequacy of existing building services to incorporate extended or refurbished works.
2.9.12	Provide preliminary estimate of regulated in-use energy consumption.
2.9.13	Provide report on any proposals or agreed outcomes following participation in any Soft Landings process.
2.9.14	Provide health and safety risk assessments for the concept design.

Extracted from Appendix A, BG 6/2018 by BSRIA



SAMPLE

PROFORMA 3: DEVELOPED DESIGN (RIBA STAGE 3)

Ref	Design activity in connection with building services	Allocated to .... L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
	General obligations, external liaison (statutory bodies, utilities)						
3.1.1	Carry out ongoing checks for compliance with regulations.						
3.1.2	Negotiate with public and other utility authorities for the provision of in agree spatial requirements.						
3.1.3	Consider services design to allow off-site manufacture if appropriate.						
3.1.4	Identify interfaces between on-site and off-site elements and define pac deliver off-site strategy.						
3.1.5	Monitor compliance of the developing design with the design philosopl						
3.1.6	Monitor compliance of the developing design with the project brief.						
3.1.7	Review strategy for fire safety (include parameters for fire detection and systems, protection of building services).						
	Client liaison (briefing, handover, surveys)						
3.2.1	Prepare the building services Employers Information Requirements in ac 1192-2.						
3.2.2	Prepare pre-contract BIM Execution Plan for building services Design an (as required by procurement route).						
3.2.3	Confirm design criteria, scope and extent of mechanical, electrical and p						
3.2.4	Update recommendations to the client in his development of an operati strategy.						
	Team liaison (builders' work, spatial coordination, energy target						
3.3.1	Review architectural and structural designs to identify existing or potent indicative plant-room, plant and riser locations and sizes and in relation allowances.						
3.3.2	Advise on access routes and plant size and weight in relation to future p replacement.						
3.3.3	Review design risk assessments and update to reflect developing design						

PROFORMA 3: DEVELOPED DESIGN (RIBA STAGE 3)

Ref	Design activity in connection with building services	Allocated to .... L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
3.3.4	Review design against Building Regulations compliance in relation to energy performance and (if relevan						
3.3.5	Review dimen and deliverabl						
3.3.6	Carry out calcu of implication						
3.3.7	Incorporate fr						
3.3.8	Approve and s information m						
3.3.9	Obtain room d						
3.3.10	Populate room						
3.3.11	Review special						
3.3.12	Develop and u						
3.3.13	Develop and u development.						
3.3.14	Develop and u						
3.3.15	Federate infor process.						
3.3.16	Carry out Stag						
3.3.17	Remove critica						
3.3.18	Review BIM pr						
3.3.19	Team-wide de						
	Selection of						
3.4.1	Prep evel						

PROFORMA 3: DEVELOPED DESIGN (RIBA STAGE 3)

Ref	Design activity in connection with building services	Allocated to .... L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
	Mechanical design						
3.5.1	Propose primary design criteria and extent of mechanical systems.						
3.5.2	Develop preliminary information on specialist mechanical systems to be procured as Contractor Design Portions, such as performance specification, loads, schedules.						
3.5.3	Prepare principal meterin						
3.5.4	Establish indicative plant locations/sizes.						
3.5.5	Undertake dynamic therm for the fabric and enginee quantitative feedback – ty						
3.5.6	Undertake computational particular stated aspects						
3.5.7	Calculate zoned heat in thods.						
3.5.8	ine main duct and						
3.5.9	lculate ads usin						
3.5.10	D mine appro a d locations, fa izes, p p ssurisation units, and a						
1	D review.						
	Electrical design						
.6.1	Propose primary design c						
3.6.2	Develop preliminary infor Contractor Design Portior						
3.6.3	Determine principal plant						
3.6.4	Prepare principal meterin						

PROFORMA 3: DEVELOPED DES (RIBA STAGE 3)

Ref	Design activit conn with ding services	Allocated to .... L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
3.6.5	E ish indicati ant siz for electrical s ms a confirm equipment/switch room a r locations/						
3.6.6	U de qu ntit						
6.7	Ca ulate						
	Ca ulate						
3.6.9	rmir s hge						
3 10	Design re						
	Public h						
3.7.1	Propose						
3.7.2	Develop Contract						
3.7.3	Establish complete						
3.7.4	Establish						
3.7.5	Define th						
3.7.6	Ensure st meet the statutory						
3.7.7	Prepare p						
3.7.8	Establish locations						

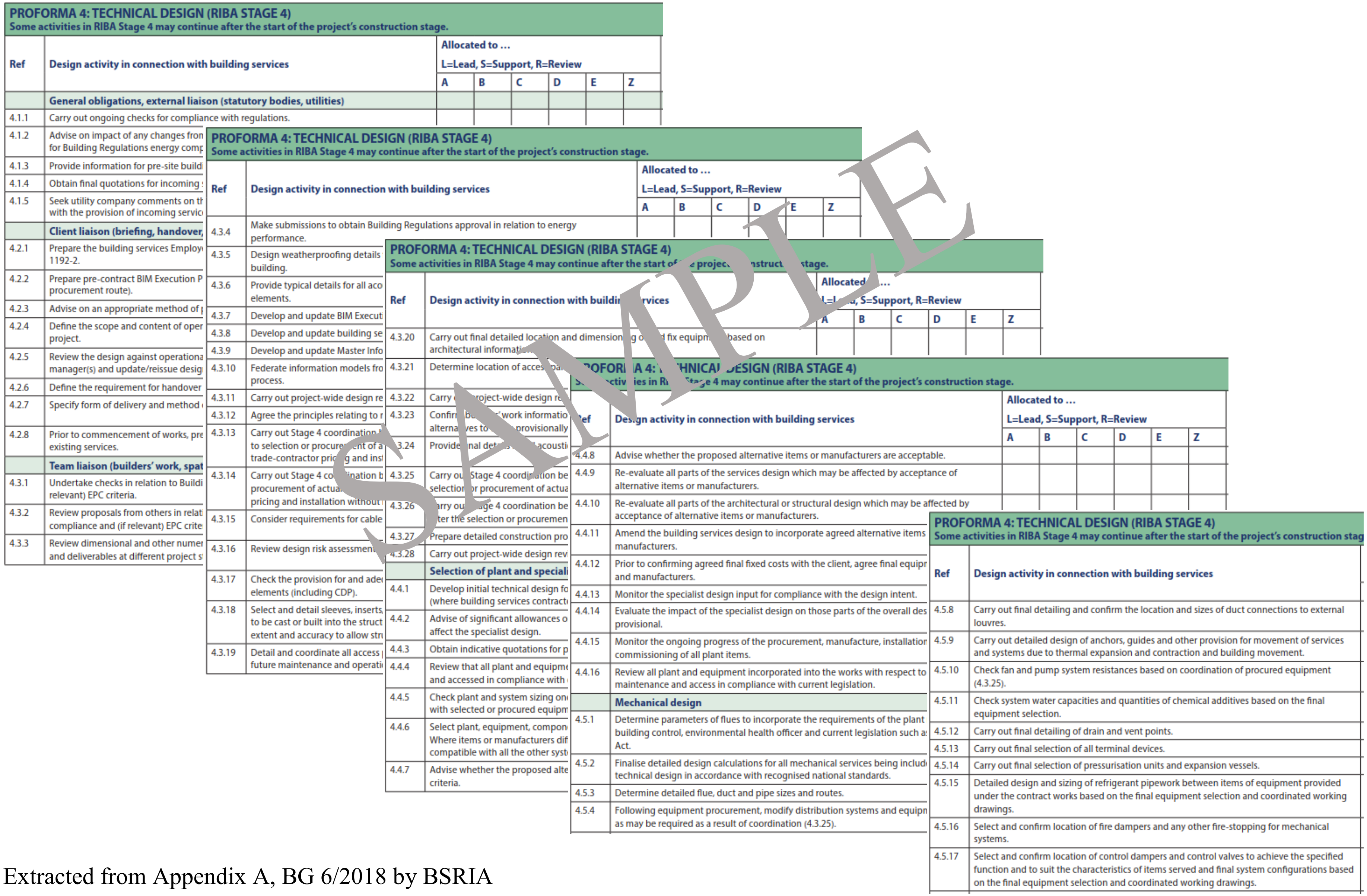
PROFOR 3: DEVELOPED DESIGN (RIBA STAGE 3)

R	De ign activity in connection with building services	Allocated to .... L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
	Commissioning						
3.8.1	Carry out commissioning review of developed design.						
3.8.2	Determine witnessing and commissioning						
3.8.3	Update the commissioning plan.						
3.8.4	Appoint an independent specialist commis commissioning.						
	Deliverables – including drawings, spe						
3.9.1	Provide energy statement for planning sub						
3.9.2	Provide performance information, specifica mechanical, electrical and public health ser						
3.9.3	Provide health and safety risk assessments						
3.9.4	Provide programme information on design						
3.9.5	Provide a report on building services devel developed design report. Specific consider BSRIA BG 71/2017 *Building Services Reports*						
3.9.5a	constraints arising from the brief, Local						
3.9.5b	energy strategy and approach,						
3.9.5c	plant strategy,						

PROFORMA 3: DEVELOPED DESIGN (RIBA STAGE 3)

Ref	Design activity in connection with building services
3.9.6	Provide developed design model.
3.9.7	Provide developed design drawings.
3.9.8	Provide developed schematics.
3.9.9	Provide an initial schedule of cast-in/formed builders' work openings that are structurally significant.
3.9.10	Provide updated schedule of builders' work requirements based on developed design.
3.9.11	Provide estimate of regulated in-use energy consumption based on developed design.
3.9.12	Provide information required in connection with any application for planning permission.
3.9.13	Provide updated information for life-cycle assessment and/or through-life cost studies.
3.9.14	Provide updated report on adequacy of existing mechanical, electrical and public health services to incorporate proposed extended or refurbished works.
3.9.15	Provide design proposals to modify, refurbish or replace existing mechanical, electrical and public health services.

Extracted from Appendix A, BG 6/2018 by BSRIA



PROFORMA 4: TECHNICAL DESIGN (RIBA STAGE 4)
Some activities in RIBA Stage 4 may continue after the start of the project's construction stage.

Ref	Design activity in connection with building services	Allocated to … L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
	General obligations, external liaison (statutory bodies, utilities)						
4.1.1	Carry out ongoing checks for compliance with regulations.						
4.1.2	Advise on impact of any changes fron for Building Regulations energy comp						
4.1.3	Provide information for pre-site buildi						
4.1.4	Obtain final quotations for incoming						
4.1.5	Seek utility company comments on th with the provision of incoming servic						
	Client liaison (briefing, handover,						
4.2.1	Prepare the building services Employ 1192-2.						
4.2.2	Prepare pre-contract BIM Execution P procurement route).						
4.2.3	Advise on an appropriate method of						
4.2.4	Define the scope and content of oper project.						
4.2.5	Review the design against operationa manager(s) and update/reissue desig						
4.2.6	Define the requirement for handover						
4.2.7	Specify form of delivery and method						
4.2.8	Prior to commencement of works, pre existing services.						
	Team liaison (builders' work, spat						
4.3.1	Undertake checks in relation to Buildi relevant) EPC criteria.						
4.3.2	Review proposals from others in relati compliance and (if relevant) EPC crite						
4.3.3	Review dimensional and other numer and deliverables at different project s						

PROFORMA 4: TECHNICAL DESIGN (RIBA STAGE 4)
Some activities in RIBA Stage 4 may continue after the start of the project's construction stage.

Ref	Design activity in connection with building services	Allocated to … L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
4.3.4	Make submissions to obtain Building Regulations approval in relation to energy performance.						
4.3.5	Design weatherproofing details building.						
4.3.6	Provide typical details for all aco elements.						
4.3.7	Develop and update BIM Executi						
4.3.8	Develop and update building se						
4.3.9	Develop and update Master Info						
4.3.10	Federate information models fro process.						
4.3.11	Carry out project-wide design re						
4.3.12	Agree the principles relating to r						
4.3.13	Carry out Stage 4 coordination to selection or procure ent of a trade-contractor pric g and inst						
4.3.14	Carry out Stage 4 co ination b procurement of actua pricing and installation without						
4.3.15	Consider requirements for cable						
4.3.16	Review design risk assessment						
4.3.17	Check the provision for and adeq elements (including CDP).						
4.3.18	Select and detail sleeves, inserts, to be cast or built into the struct extent and accuracy to allow stru						
4.3.19	Detail and coordinate all access future maintenance and operati						

PROFORMA 4: TECHNICAL DESIGN (RIBA STAGE 4)
Some activities in RIBA Stage 4 may continue after the start of e projec nstruct stage.

Ref	Design activity in connection with buildi rvices	Allocated … L=l a, S=Support, R=Review					
		A	B	C	D	E	Z
4.3.20	Carry out final detailed location and dimension g o fix equipm based on architectural informati						
4.3.21	Determine location of acces pa						
4.3.22	Carry roject-wide design re						
4.3.23	Confir bu ' work informatio alterna ves to provisionally						
3.24	Provide nal det acousti						
4.3.25	Carry ou Stage 4 coordi ation be selectio or procurement of actua						
4.3.26	arry ou ge 4 coordination be ter the selection or procuremen						
4.3.27	Prepare detailed construction pro						
4.3.28	Carry out project-wide design revi						
	Selection of plant and speciali						
4.4.1	Develop initial technical design fo (where building services contract						
4.4.2	Advise of significant allowances o affect the specialist design.						
4.4.3	Obtain indicative quotations for p						
4.4.4	Review that all plant and equipme and accessed in compliance with						
4.4.5	Check plant and system sizing on with selected or procured equipm						
4.4.6	Select plant, equipment, compon Where items or manufacturers dif compatible with all the other syst						
4.4.7	Advise whether the proposed alte criteria.						

OFORI A 4: HNICAI DESIGN (RIBA STAGE 4)
S ctiv ies in R tage 4 may continue after the start of the project's construction stage.

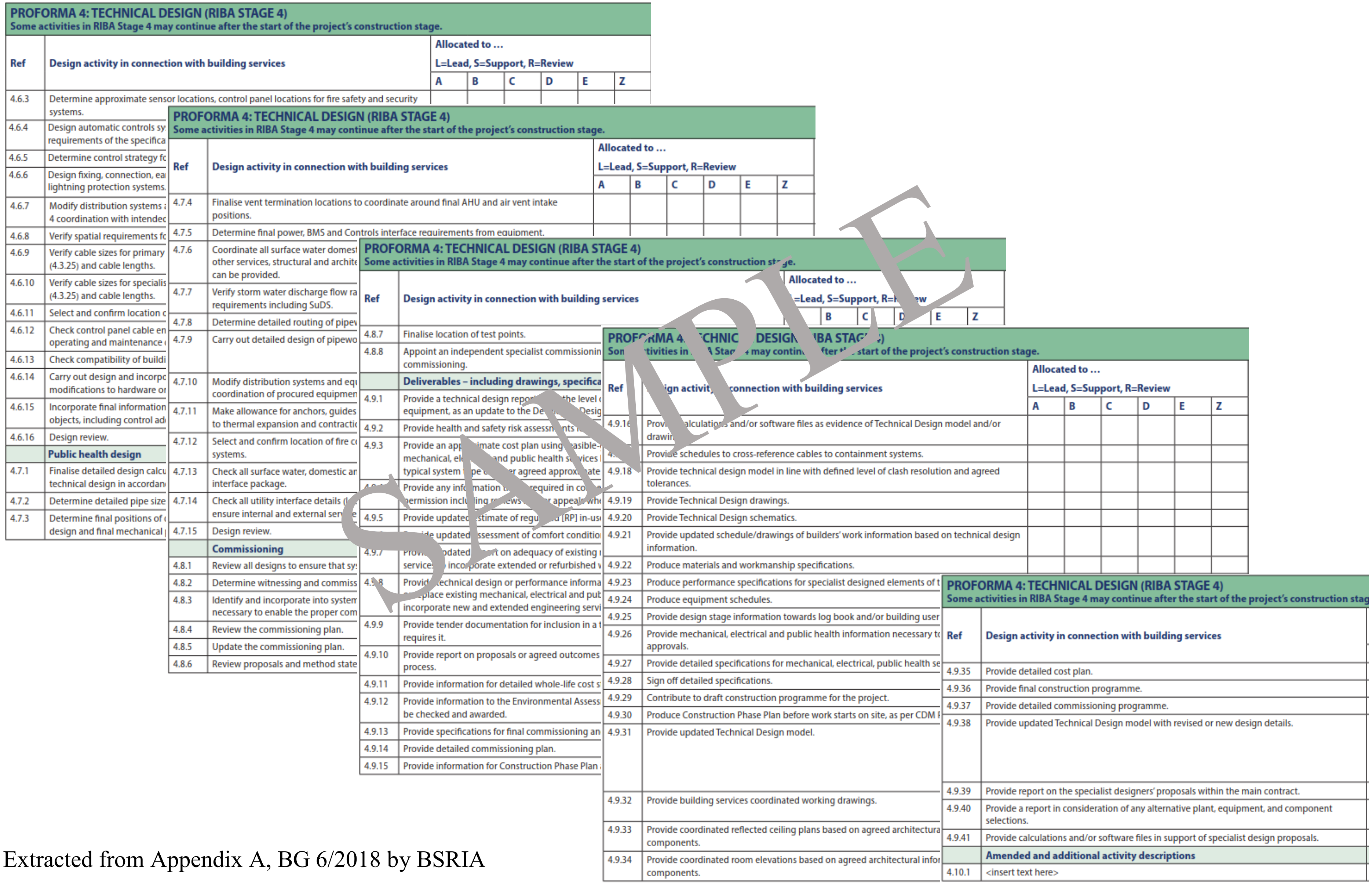
ef	Des gn activity in connection with building services	Allocated to … L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
4.4.8	Advise whether the proposed alternative items or manufacturers are acceptable.						
4.4.9	Re-evaluate all parts of the services design which may be affected by acceptance of alternative items or manufacturers.						
4.4.10	Re-evaluate all parts of the architectural or structural design which may be affected by acceptance of alternative items or manufacturers.						
4.4.11	Amend the building services design to incorporate agreed alternative items manufacturers.						
4.4.12	Prior to confirming agreed final fixed costs with the client, agree final equipr and manufacturers.						
4.4.13	Monitor the specialist design input for compliance with the design intent.						
4.4.14	Evaluate the impact of the specialist design on those parts of the overall des provisional.						
4.4.15	Monitor the ongoing progress of the procurement, manufacture, installation commissioning of all plant items.						
4.4.16	Review all plant and equipment incorporated into the works with respect to maintenance and access in compliance with current legislation.						
	Mechanical design						
4.5.1	Determine parameters of flues to incorporate the requirements of the plant building control, environmental health officer and current legislation such a Act.						
4.5.2	Finalise detailed design calculations for all mechanical services being includ technical design in accordance with recognised national standards.						
4.5.3	Determine detailed flue, duct and pipe sizes and routes.						
4.5.4	Following equipment procurement, modify distribution systems and equipn as may be required as a result of coordination (4.3.25).						

PROFORMA 4: TECHNICAL DESIGN (RIBA STAGE 4)
Some activities in RIBA Stage 4 may continue after the start of the project's construction stag

Ref	Design activity in connection with building services
4.5.8	Carry out final detailing and confirm the location and sizes of duct connections to external louvres.
4.5.9	Carry out detailed design of anchors, guides and other provision for movement of services and systems due to thermal expansion and contraction and building movement.
4.5.10	Check fan and pump system resistances based on coordination of procured equipment (4.3.25).
4.5.11	Check system water capacities and quantities of chemical additives based on the final equipment selection.
4.5.12	Carry out final detailing of drain and vent points.
4.5.13	Carry out final selection of all terminal devices.
4.5.14	Carry out final selection of pressurisation units and expansion vessels.
4.5.15	Detailed design and sizing of refrigerant pipework between items of equipment provided under the contract works based on the final equipment selection and coordinated working drawings.
4.5.16	Select and confirm location of fire dampers and any other fire-stopping for mechanical systems.
4.5.17	Select and confirm location of control dampers and control valves to achieve the specified function and to suit the characteristics of items served and final system configurations based on the final equipment selection and coordinated working drawings.

SAMPLE

Extracted from Appendix A, BG 6/2018 by BSRIA



SAMPLE

PROFORMA 4: TECHNICAL DESIGN (RIBA STAGE 4)
Some activities in RIBA Stage 4 may continue after the start of the project's construction stage.

Ref	Design activity in connection with building services	Allocated to … L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
4.6.3	Determine approximate sensor locations, control panel locations for fire safety and security systems.						
4.6.4	Design automatic controls sy requirements of the specifica						
4.6.5	Determine control strategy fo						
4.6.6	Design fixing, connection, ea lightning protection systems.						
4.6.7	Modify distribution systems a 4 coordination with intendec						
4.6.8	Verify spatial requirements fo						
4.6.9	Verify cable sizes for primary (4.3.25) and cable lengths.						
4.6.10	Verify cable sizes for specialis (4.3.25) and cable lengths.						
4.6.11	Select and confirm location c						
4.6.12	Check control panel cable en operating and maintenance						
4.6.13	Check compatibility of buildi						
4.6.14	Carry out design and incorpo modifications to hardware or						
4.6.15	Incorporate final information objects, including control ad						
4.6.16	Design review.						
	Public health design						
4.7.1	Finalise detailed design calcu technical design in accordan						
4.7.2	Determine detailed pipe size						
4.7.3	Determine final positions of design and final mechanical						

PROFORMA 4: TECHNICAL DESIGN (RIBA STAGE 4)
Some activities in RIBA Stage 4 may continue after the start of the project's construction stage.

Ref	Design activity in connection with building services	Allocated to … L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
4.7.4	Finalise vent termination locations to coordinate around final AHU and air vent intake positions.						
4.7.5	Determine final power, BMS and Controls interface requirements from equipment.						
4.7.6	Coordinate all surface water domest other services, structural and archite can be provided.						
4.7.7	Verify storm water discharge flow ra requirements including SuDS.						
4.7.8	Determine detailed routing of pipev						
4.7.9	Carry out detailed design of pipewo						
4.7.10	Modify distribution systems and equ coordination of procured equipmen						
4.7.11	Make allowance for anchors, guides to thermal expansion and contractic						
4.7.12	Select and confirm location of fire c systems.						
4.7.13	Check all surface water, domestic an interface package.						
4.7.14	Check all utility interface details (ensure internal and external ser						
4.7.15	Design review.						
	Commissioning						
4.8.1	Review all designs to ensure that sys						
4.8.2	Determine witnessing and commiss						
4.8.3	Identify and incorporate into system necessary to enable the proper com						
4.8.4	Review the commissioning plan.						
4.8.5	Update the commissioning plan.						
4.8.6	Review proposals and method state						

PROFORMA 4: TECHNICAL DESIGN (RIBA STAGE 4)
Some activities in RIBA Stage 4 may continue after the start of the project's construction st[illegible]ge.

Ref	Design activity in connection with building services	Allocated to … [illegible]=Lead, S=Support, R=[illegible]ew					
			B	C	D	E	Z
4.8.7	Finalise location of test points.						
4.8.8	Appoint an independent specialist commissionin commissioning.						
	Deliverables – including drawings, specifica						
4.9.1	Provide a technical design repor[illegible] the level equipment, as an update to the De[illegible] Desig						
4.9.2	Provide health and safety risk assessm[illegible]nts						
4.9.3	Provide an app[illegible]imate cost plan using [illegible]asible- mechanical, el[illegible] and public health s[illegible]vices typical system [illegible]pe [illegible]r agreed approx[illegible]ate						
4.[illegible]	Provide any info[illegible]mation [illegible] required in co permission incl[illegible]ing r[illegible]ews [illegible]r appeals whe						
4.9.5	Provide update[illegible] estimate of regu[illegible]d [RP] in-us						
[illegible]	[illegible]de updated [illegible]ssessment of comfort conditio						
4.9.7	Prov[illegible]pdated [illegible]rt on adequacy of existing service[illegible] incorporate extended or refurbished						
4.[illegible]8	Provid[illegible]echnical design or performance informa [illegible]place existing mechanical, electrical and pub incorporate new and extended engineering servi						
4.9.9	Provide tender documentation for inclusion in a t requires it.						
4.9.10	Provide report on proposals or agreed outcomes process.						
4.9.11	Provide information for detailed whole-life cost s						
4.9.12	Provide information to the Environmental Assess be checked and awarded.						
4.9.13	Provide specifications for final commissioning an						
4.9.14	Provide detailed commissioning plan.						
4.9.15	Provide information for Construction Phase Plan						

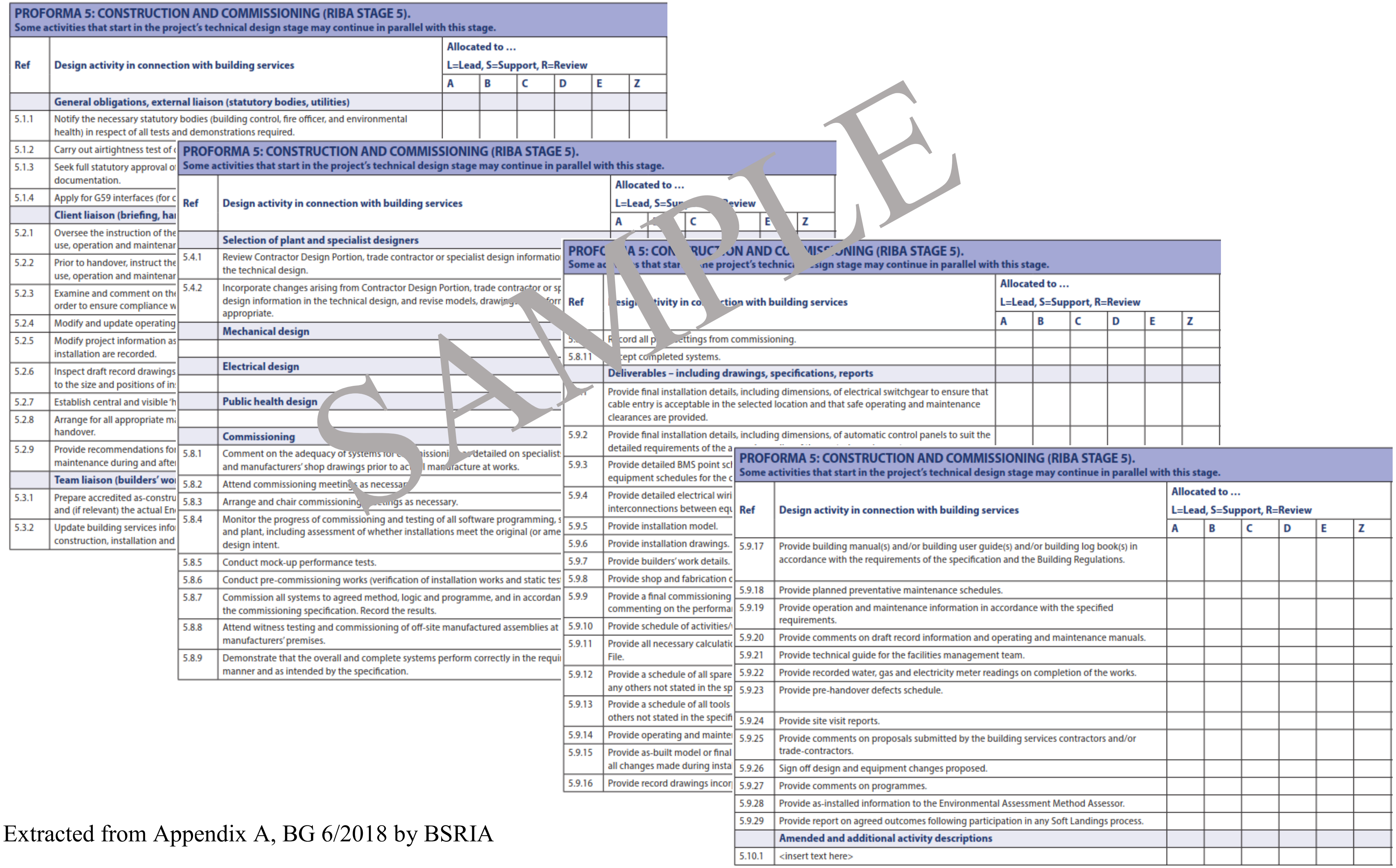
PROF[illegible]RMA 4[illegible]CHNIC[illegible] DESIGN[illegible]BA STAG[illegible])
Son[illegible]tivities in [illegible]A Stag[illegible] may contin[illegible]fter t[illegible] start of the project's construction stage.

Ref	[illegible]ign activity[illegible] connection with building services	Allocated to … L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
4.9.16	Prov[illegible]alculations and/or software files as evidence of Technical Design model and/or drawin						
4.[illegible]	Provi[illegible]e schedules to cross-reference cables to containment systems.						
4.9.18	Provide technical design model in line with defined level of clash resolution and agreed tolerances.						
4.9.19	Provide Technical Design drawings.						
4.9.20	Provide Technical Design schematics.						
4.9.21	Provide updated schedule/drawings of builders' work information based on technical design information.						
4.9.22	Produce materials and workmanship specifications.						
4.9.23	Produce performance specifications for specialist designed elements of t						
4.9.24	Produce equipment schedules.						
4.9.25	Provide design stage information towards log book and/or building user						
4.9.26	Provide mechanical, electrical and public health information necessary t approvals.						
4.9.27	Provide detailed specifications for mechanical, electrical, public health se						
4.9.28	Sign off detailed specifications.						
4.9.29	Contribute to draft construction programme for the project.						
4.9.30	Produce Construction Phase Plan before work starts on site, as per CDM						
4.9.31	Provide updated Technical Design model.						
4.9.32	Provide building services coordinated working drawings.						
4.9.33	Provide coordinated reflected ceiling plans based on agreed architectura components.						
4.9.34	Provide coordinated room elevations based on agreed architectural infor components.						

PROFORMA 4: TECHNICAL DESIGN (RIBA STAGE 4)
Some activities in RIBA Stage 4 may continue after the start of the project's construction stag

Ref	Design activity in connection with building services
4.9.35	Provide detailed cost plan.
4.9.36	Provide final construction programme.
4.9.37	Provide detailed commissioning programme.
4.9.38	Provide updated Technical Design model with revised or new design details.
4.9.39	Provide report on the specialist designers' proposals within the main contract.
4.9.40	Provide a report in consideration of any alternative plant, equipment, and component selections.
4.9.41	Provide calculations and/or software files in support of specialist design proposals.
	Amended and additional activity descriptions
4.10.1	<insert text here>

Extracted from Appendix A, BG 6/2018 by BSRIA



SAMPLE

PROFORMA 5: CONSTRUCTION AND COMMISSIONING (RIBA STAGE 5).
Some activities that start in the project's technical design stage may continue in parallel with this stage.

Ref	Design activity in connection with building services	Allocated to … L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
	General obligations, external liaison (statutory bodies, utilities)						
5.1.1	Notify the necessary statutory bodies (building control, fire officer, and environmental health) in respect of all tests and demonstrations required.						
5.1.2	Carry out airtightness test of						
5.1.3	Seek full statutory approval of documentation.						
5.1.4	Apply for G59 interfaces (for c						
	Client liaison (briefing, ha						
5.2.1	Oversee the instruction of the use, operation and maintenar						
5.2.2	Prior to handover, instruct the use, operation and maintenar						
5.2.3	Examine and comment on the order to ensure compliance w						
5.2.4	Modify and update operating						
5.2.5	Modify project information as installation are recorded.						
5.2.6	Inspect draft record drawings to the size and positions of in						
5.2.7	Establish central and visible 'h						
5.2.8	Arrange for all appropriate m handover.						
5.2.9	Provide recommendations for maintenance during and after						
	Team liaison (builders' wo						
5.3.1	Prepare accredited as-constru and (if relevant) the actual En						
5.3.2	Update building services info construction, installation and						

PROFORMA 5: CONSTRUCTION AND COMMISSIONING (RIBA STAGE 5).
Some activities that start in the project's technical design stage may continue in parallel with this stage.

Ref	Design activity in connection with building services	Allocated to … L=Lead, S=Su eview
	Selection of plant and specialist designers	
5.4.1	Review Contractor Design Portion, trade contractor or specialist design informatio the technical design.	
5.4.2	Incorporate changes arising from Contractor Design Portion, trade contractor or sp design information in the technical design, and revise models, drawin forr appropriate.	
	Mechanical design	
	Electrical design	
	Public health design	
	Commissioning	
5.8.1	Comment on the adequacy of systems for issioni detailed on specialist and manufacturers' shop drawings prior to ac l manufacture at works.	
5.8.2	Attend commissioning meetin as necessar	
5.8.3	Arrange and chair commissioning ings as necessary.	
5.8.4	Monitor the progress of commissioning and testing of all software programming, s and plant, including assessment of whether installations meet the original (or ame design intent.	
5.8.5	Conduct mock-up performance tests.	
5.8.6	Conduct pre-commissioning works (verification of installation works and static tes	
5.8.7	Commission all systems to agreed method, logic and programme, and in accordan the commissioning specification. Record the results.	
5.8.8	Attend witness testing and commissioning of off-site manufactured assemblies at manufacturers' premises.	
5.8.9	Demonstrate that the overall and complete systems perform correctly in the requi manner and as intended by the specification.	

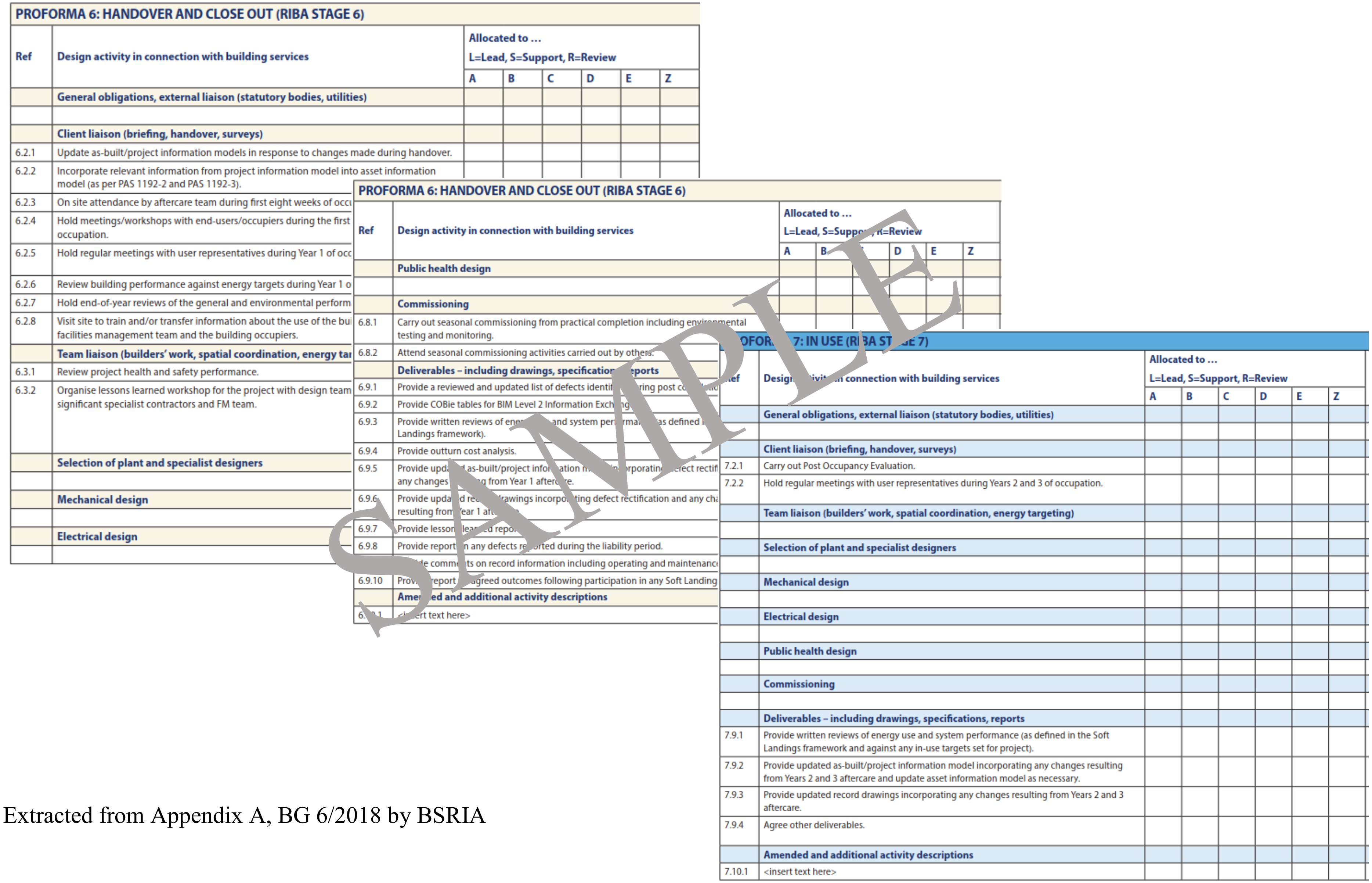
PROFC A 5: CON RUCT ON AND CO MISS ONING (RIBA STAGE 5).
Some ac s that star ne project's technica sign stage may continue in parallel with this stage.

Ref	esig tivity in co ction with building services	Allocated to … L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
5.	R cord all p ettings from commissioning.						
5.8.11	cept completed systems.						
	Deliverables – including drawings, specifications, reports						
	Provide final installation details, including dimensions, of electrical switchgear to ensure that cable entry is acceptable in the selected location and that safe operating and maintenance clearances are provided.						
5.9.2	Provide final installation details, including dimensions, of automatic control panels to suit the detailed requirements of the a						
5.9.3	Provide detailed BMS point sc equipment schedules for the c						
5.9.4	Provide detailed electrical wiri interconnections between equ						
5.9.5	Provide installation model.						
5.9.6	Provide installation drawings.						
5.9.7	Provide builders' work details.						
5.9.8	Provide shop and fabrication c						
5.9.9	Provide a final commissioning commenting on the performa						
5.9.10	Provide schedule of activities/						
5.9.11	Provide all necessary calculatic File.						
5.9.12	Provide a schedule of all spare any others not stated in the sp						
5.9.13	Provide a schedule of all tools others not stated in the specifi						
5.9.14	Provide operating and mainte						
5.9.15	Provide as-built model or final all changes made during insta						
5.9.16	Provide record drawings incor						

PROFORMA 5: CONSTRUCTION AND COMMISSIONING (RIBA STAGE 5).
Some activities that start in the project's technical design stage may continue in parallel with this stage.

Ref	Design activity in connection with building services	Allocated to … L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
5.9.17	Provide building manual(s) and/or building user guide(s) and/or building log book(s) in accordance with the requirements of the specification and the Building Regulations.						
5.9.18	Provide planned preventative maintenance schedules.						
5.9.19	Provide operation and maintenance information in accordance with the specified requirements.						
5.9.20	Provide comments on draft record information and operating and maintenance manuals.						
5.9.21	Provide technical guide for the facilities management team.						
5.9.22	Provide recorded water, gas and electricity meter readings on completion of the works.						
5.9.23	Provide pre-handover defects schedule.						
5.9.24	Provide site visit reports.						
5.9.25	Provide comments on proposals submitted by the building services contractors and/or trade-contractors.						
5.9.26	Sign off design and equipment changes proposed.						
5.9.27	Provide comments on programmes.						
5.9.28	Provide as-installed information to the Environmental Assessment Method Assessor.						
5.9.29	Provide report on agreed outcomes following participation in any Soft Landings process.						
	Amended and additional activity descriptions						
5.10.1	<insert text here>						

Extracted from Appendix A, BG 6/2018 by BSRIA



SAMPLE

PROFORMA 6: HANDOVER AND CLOSE OUT (RIBA STAGE 6)

Ref	Design activity in connection with building services	Allocated to … L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
	General obligations, external liaison (statutory bodies, utilities)						
	Client liaison (briefing, handover, surveys)						
6.2.1	Update as-built/project information models in response to changes made during handover.						
6.2.2	Incorporate relevant information from project information model into asset information model (as per PAS 1192-2 and PAS 1192-3).						
6.2.3	On site attendance by aftercare team during first eight weeks of occu						
6.2.4	Hold meetings/workshops with end-users/occupiers during the first occupation.						
6.2.5	Hold regular meetings with user representatives during Year 1 of occ						
6.2.6	Review building performance against energy targets during Year 1 o						
6.2.7	Hold end-of-year reviews of the general and environmental perform						
6.2.8	Visit site to train and/or transfer information about the use of the bui facilities management team and the building occupiers.						
	Team liaison (builders' work, spatial coordination, energy tar						
6.3.1	Review project health and safety performance.						
6.3.2	Organise lessons learned workshop for the project with design team significant specialist contractors and FM team.						
	Selection of plant and specialist designers						
	Mechanical design						
	Electrical design						

PROFORMA 6: HANDOVER AND CLOSE OUT (RIBA STAGE 6)

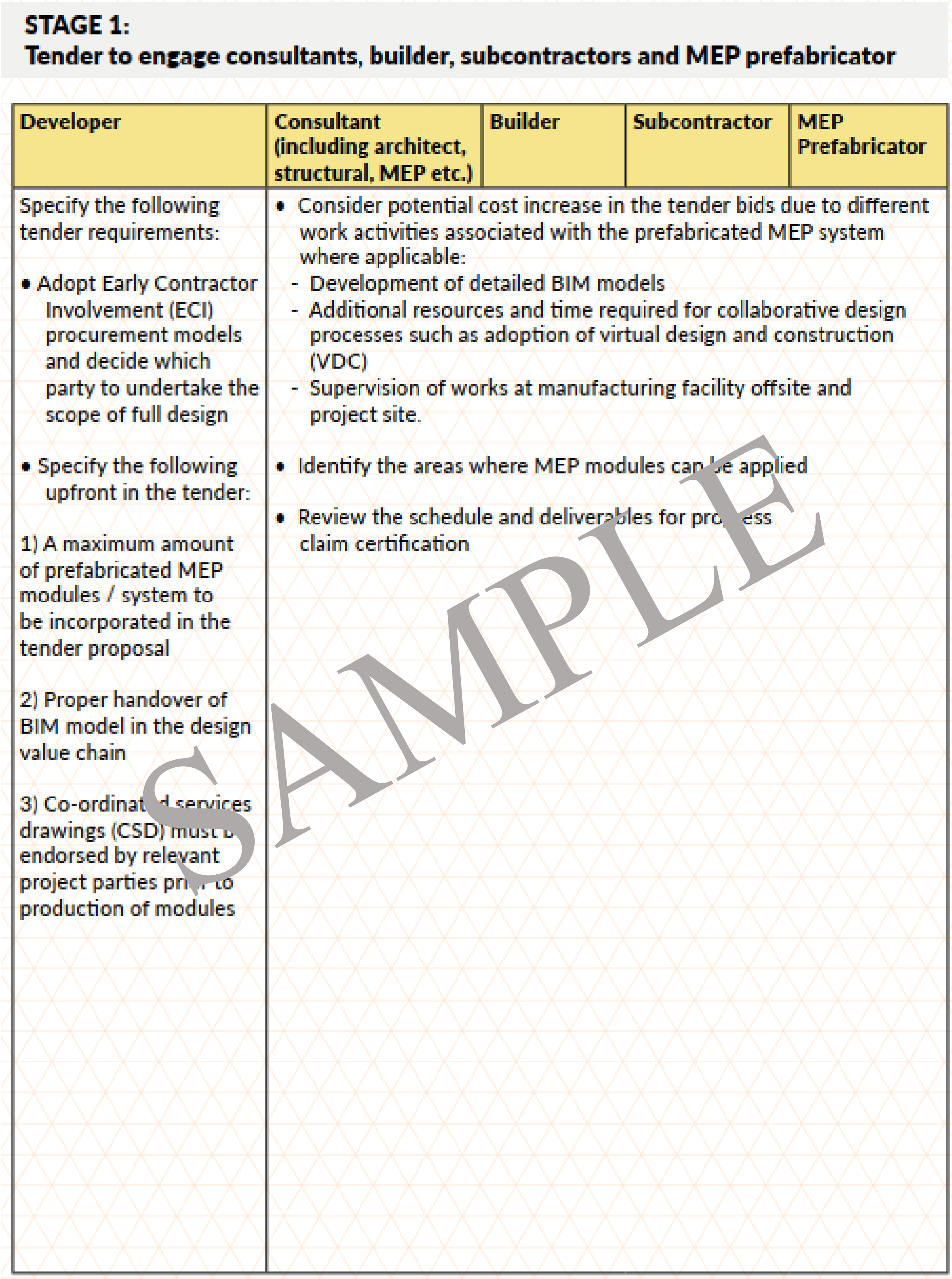
Ref	Design activity in connection with building services	Allocated to … L=Lead, S=Suppo R=Review					
		A	B		D	E	Z
	Public health design						
	Commissioning						
6.8.1	Carry out seasonal commissioning from practical completion including environmental testing and monitoring.						
6.8.2	Attend seasonal commissioning activities carried out by others.						
	Deliverables – including drawings, specification eports						
6.9.1	Provide a reviewed and updated list of defects identif ring post co						
6.9.2	Provide COBie tables for BIM Level 2 Information Exch ng						
6.9.3	Provide written reviews of ene and system per rma as defined Landings framework).						
6.9.4	Provide outturn cost analysis.						
6.9.5	Provide upd as-built/project infor ation m rporatin efect rectif any changes g from Year 1 afterc re.						
6.9.6	Provide upda d re rawings incorpo ting defect rectification and any cha resulting from ear 1 af						
6.9.7	Provide lesson lea d repo						
6.9.8	Provide report n any defects re orted during the liability period.						
	de comm ts on record information including operating and maintenanc						
6.9.10	Prov report greed outcomes following participation in any Soft Landing						
	Amen ed and additional activity descriptions						
6. .1	< ert text here>						

OFOR 7: IN USE (RI BA ST E 7)

ef	Design ivit n connection with building services	Allocated to … L=Lead, S=Support, R=Review					
		A	B	C	D	E	Z
	General obligations, external liaison (statutory bodies, utilities)						
	Client liaison (briefing, handover, surveys)						
7.2.1	Carry out Post Occupancy Evaluation.						
7.2.2	Hold regular meetings with user representatives during Years 2 and 3 of occupation.						
	Team liaison (builders' work, spatial coordination, energy targeting)						
	Selection of plant and specialist designers						
	Mechanical design						
	Electrical design						
	Public health design						
	Commissioning						
	Deliverables – including drawings, specifications, reports						
7.9.1	Provide written reviews of energy use and system performance (as defined in the Soft Landings framework and against any in-use targets set for project).						
7.9.2	Provide updated as-built/project information model incorporating any changes resulting from Years 2 and 3 aftercare and update asset information model as necessary.						
7.9.3	Provide updated record drawings incorporating any changes resulting from Years 2 and 3 aftercare.						
7.9.4	Agree other deliverables.						
	Amended and additional activity descriptions						
7.10.1	<insert text here>						

Extracted from Appendix A, BG 6/2018 by BSRIA

4.2 Recommended Demarcation per Design for Manufacturing and Assembly (DfMA) Prefabricated Mechanical, Electrical and Plumbing (MEP) Systems by BCA, Singapore

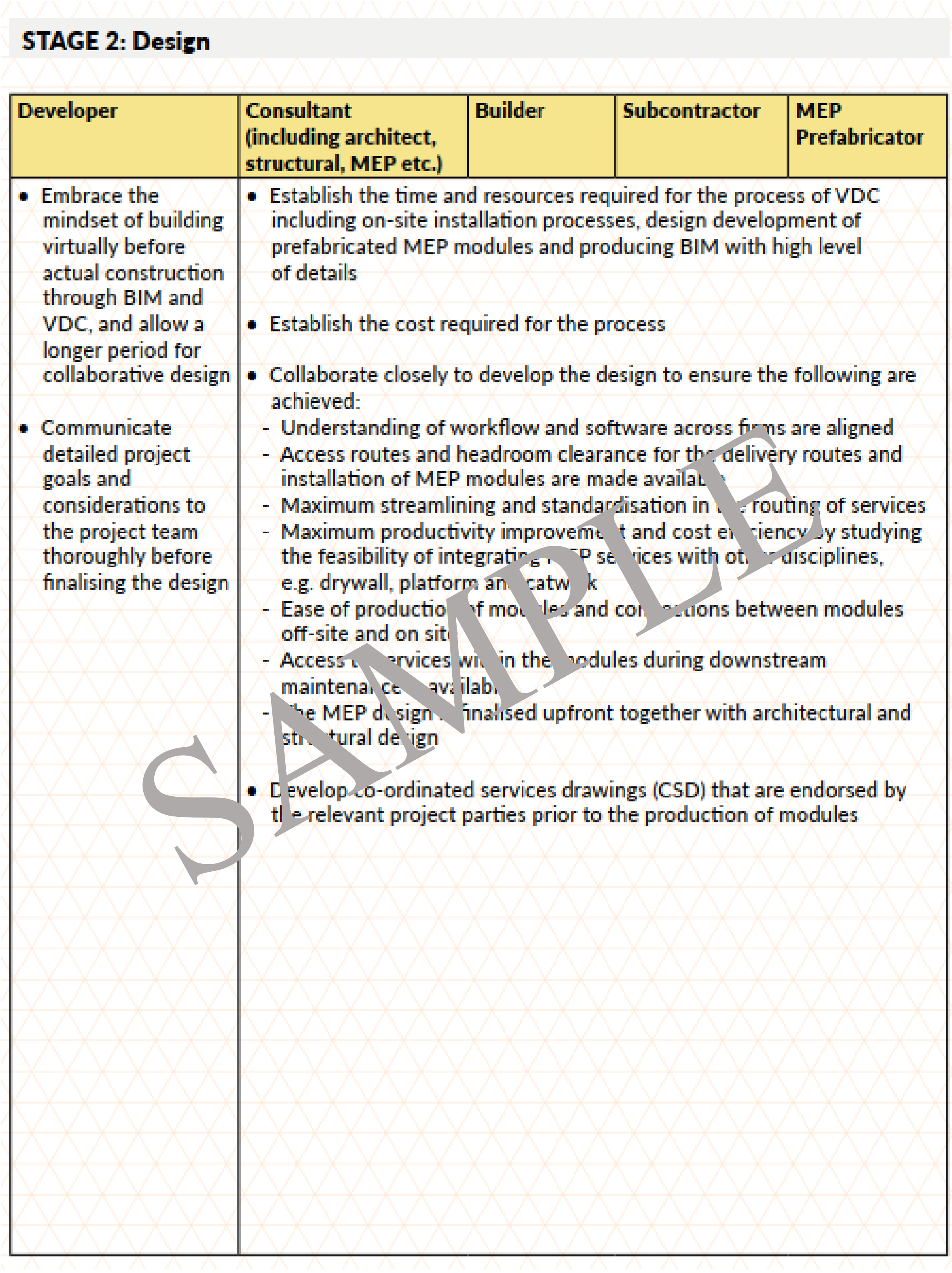


STAGE 1:
Tender to engage consultants, builder, subcontractors and MEP prefabricator

Developer	Consultant (including architect, structural, MEP etc.)	Builder	Subcontractor	MEP Prefabricator
Specify the following tender requirements: • Adopt Early Contractor Involvement (ECI) procurement models and decide which party to undertake the scope of full design • Specify the following upfront in the tender: 1) A maximum amount of prefabricated MEP modules / system to be incorporated in the tender proposal 2) Proper handover of BIM model in the design value chain 3) Co-ordinated services drawings (CSD) must be endorsed by relevant project parties prior to production of modules	• Consider potential cost increase in the tender bids due to different work activities associated with the prefabricated MEP system where applicable: - Development of detailed BIM models - Additional resources and time required for collaborative design processes such as adoption of virtual design and construction (VDC) - Supervision of works at manufacturing facility offsite and project site. • Identify the areas where MEP modules can be applied • Review the schedule and deliverables for progress claim certification			

SAMPLE

(Extracted from Design for Manufacturing and Assembly (DfMA) Prefabricated Mechanical, Electrical and Plumbing (MEP) Systems)

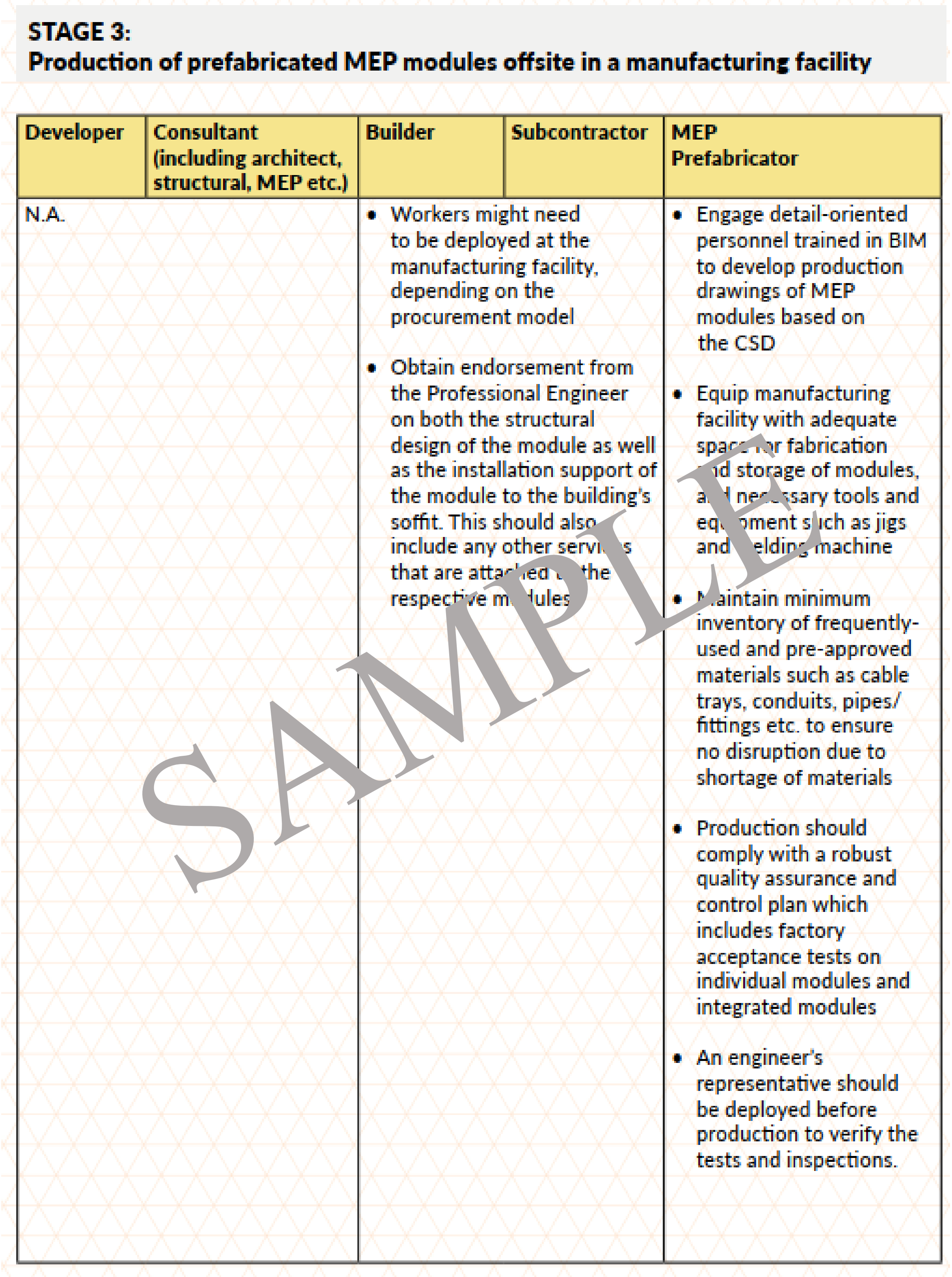


STAGE 2: Design

Developer	Consultant (including architect, structural, MEP etc.)	Builder	Subcontractor	MEP Prefabricator
• Embrace the mindset of building virtually before actual construction through BIM and VDC, and allow a longer period for collaborative design • Communicate detailed project goals and considerations to the project team thoroughly before finalising the design	• Establish the time and resources required for the process of VDC including on-site installation processes, design development of prefabricated MEP modules and producing BIM with high level of details • Establish the cost required for the process • Collaborate closely to develop the design to ensure the following are achieved: - Understanding of workflow and software across firms are aligned - Access routes and headroom clearance for the delivery routes and installation of MEP modules are made available - Maximum streamlining and standardisation in the routing of services - Maximum productivity improvement and cost efficiency by studying the feasibility of integrating MEP services with other disciplines, e.g. drywall, platform and catwalk - Ease of production of modules and connections between modules off-site and on site - Access to services within the modules during downstream maintenance are available - The MEP design is finalised upfront together with architectural and structural design • Develop co-ordinated services drawings (CSD) that are endorsed by the relevant project parties prior to the production of modules			

SAMPLE

(Extracted from Design for Manufacturing and Assembly (DfMA) Prefabricated Mechanical, Electrical and Plumbing (MEP) Systems)

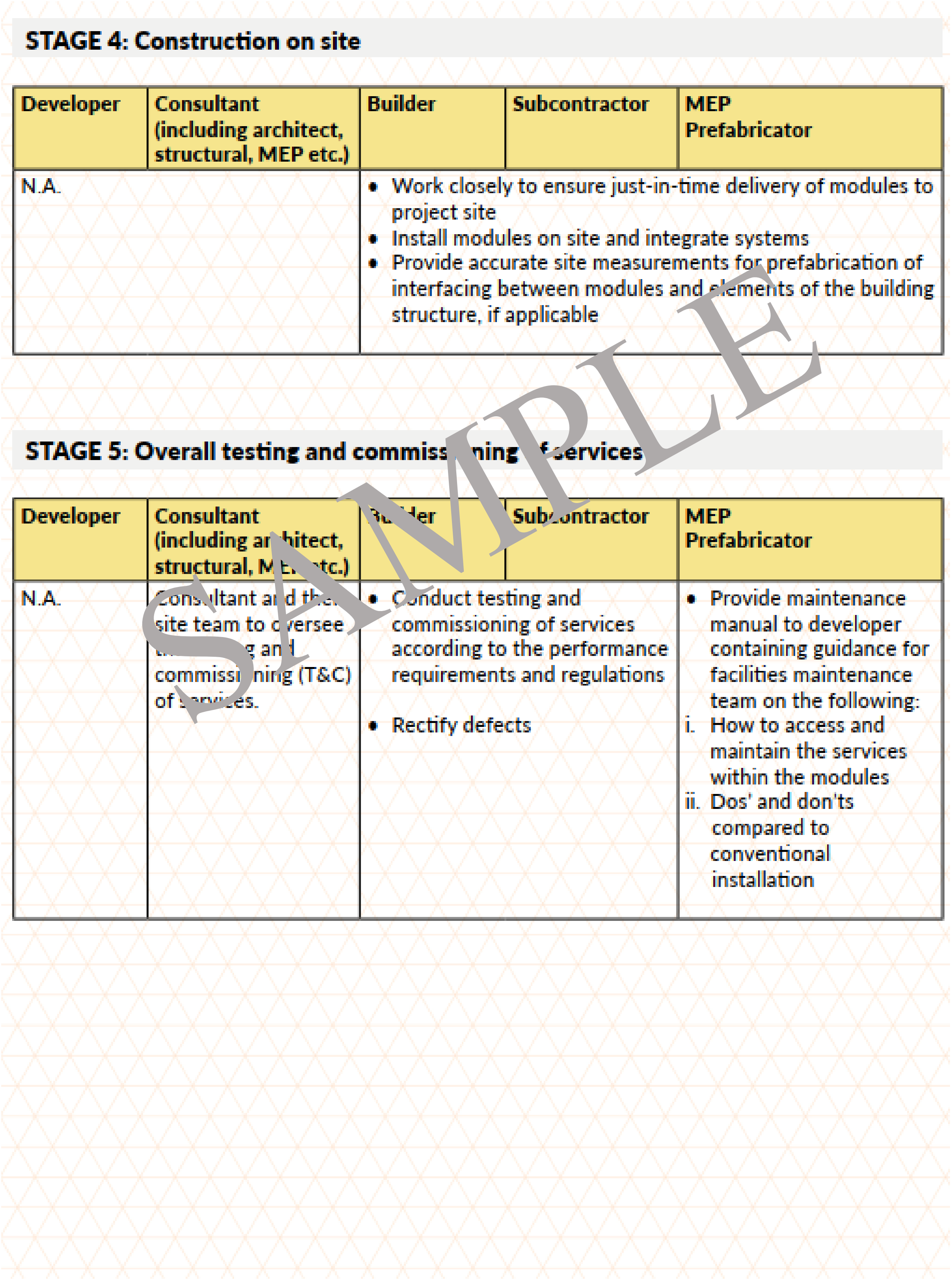


STAGE 3:
Production of prefabricated MEP modules offsite in a manufacturing facility

Developer	Consultant (including architect, structural, MEP etc.)	Builder	Subcontractor	MEP Prefabricator
N.A.		• Workers might need to be deployed at the manufacturing facility, depending on the procurement model • Obtain endorsement from the Professional Engineer on both the structural design of the module as well as the installation support of the module to the building's soffit. This should also include any other services that are attached to the respective modules		• Engage detail-oriented personnel trained in BIM to develop production drawings of MEP modules based on the CSD • Equip manufacturing facility with adequate space for fabrication and storage of modules, and necessary tools and equipment such as jigs and welding machine • Maintain minimum inventory of frequently-used and pre-approved materials such as cable trays, conduits, pipes/ fittings etc. to ensure no disruption due to shortage of materials • Production should comply with a robust quality assurance and control plan which includes factory acceptance tests on individual modules and integrated modules • An engineer's representative should be deployed before production to verify the tests and inspections.

SAMPLE

(Extracted from Design for Manufacturing and Assembly (DfMA) Prefabricated Mechanical, Electrical and Plumbing (MEP) Systems)



STAGE 4: Construction on site

Developer	Consultant (including architect, structural, MEP etc.)	Builder	Subcontractor	MEP Prefabricator
N.A.		• Work closely to ensure just-in-time delivery of modules to project site • Install modules on site and integrate systems • Provide accurate site measurements for prefabrication of interfacing between modules and elements of the building structure, if applicable		

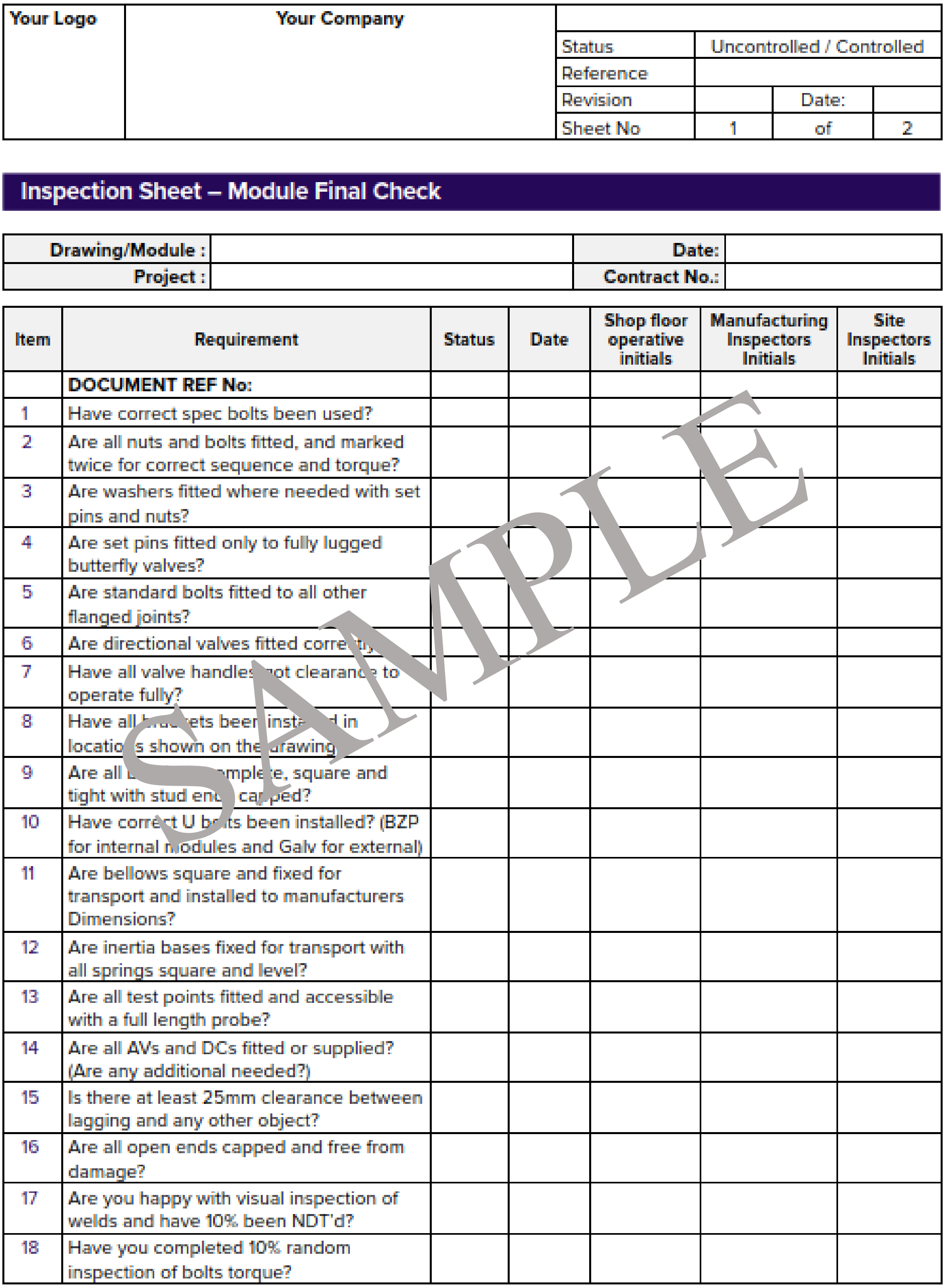
STAGE 5: Overall testing and commissioning of services

Developer	Consultant (including architect, structural, MEP etc.)	Builder	Subcontractor	MEP Prefabricator
N.A.	Consultant and their site team to oversee the testing and commissioning (T&C) of services.	• Conduct testing and commissioning of services according to the performance requirements and regulations • Rectify defects		• Provide maintenance manual to developer containing guidance for facilities maintenance team on the following: i. How to access and maintain the services within the modules ii. Dos' and don'ts compared to conventional installation

SAMPLE

(Extracted from Design for Manufacturing and Assembly (DfMA) Prefabricated Mechanical, Electrical and Plumbing (MEP) Systems)

4.3 Samples of Delivery Checklist



Your Logo	**Your Company**				
		Status	Uncontrolled / Controlled		
		Reference			
		Revision		Date:	
		Sheet No	1	of	2

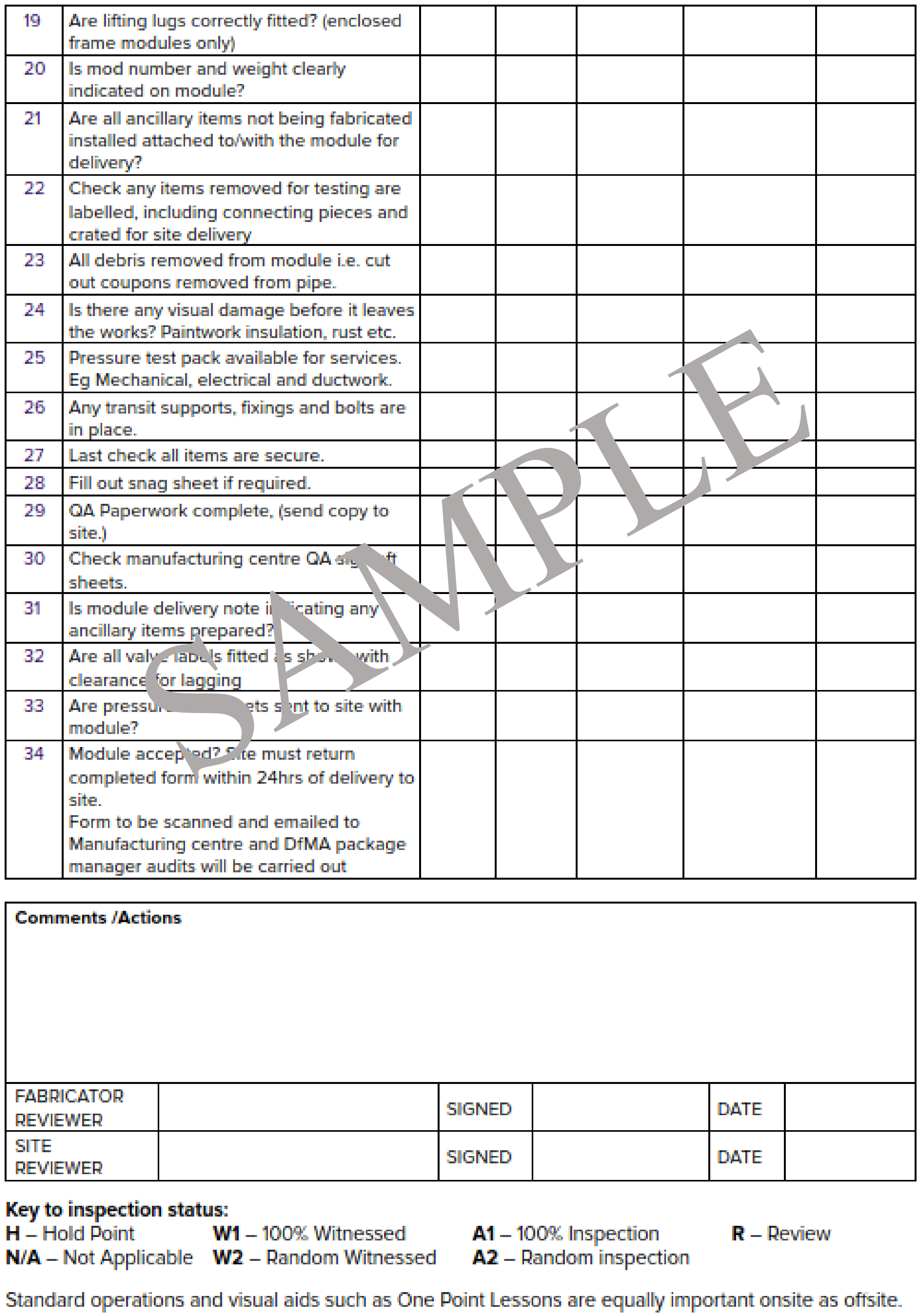
Inspection Sheet – Module Final Check

Drawing/Module :		**Date:**	
Project :		**Contract No.:**	

Item	Requirement	Status	Date	Shop floor operative initials	Manufacturing Inspectors Initials	Site Inspectors Initials
	DOCUMENT REF No:					
1	Have correct spec bolts been used?					
2	Are all nuts and bolts fitted, and marked twice for correct sequence and torque?					
3	Are washers fitted where needed with set pins and nuts?					
4	Are set pins fitted only to fully lugged butterfly valves?					
5	Are standard bolts fitted to all other flanged joints?					
6	Are directional valves fitted correctly?					
7	Have all valve handles got clearance to operate fully?					
8	Have all brackets been installed in locations shown on the drawing?					
9	Are all [illegible] complete, square and tight with stud ends capped?					
10	Have correct U bolts been installed? (BZP for internal modules and Galv for external)					
11	Are bellows square and fixed for transport and installed to manufacturers Dimensions?					
12	Are inertia bases fixed for transport with all springs square and level?					
13	Are all test points fitted and accessible with a full length probe?					
14	Are all AVs and DCs fitted or supplied? (Are any additional needed?)					
15	Is there at least 25mm clearance between lagging and any other object?					
16	Are all open ends capped and free from damage?					
17	Are you happy with visual inspection of welds and have 10% been NDT'd?					
18	Have you completed 10% random inspection of bolts torque?					

SAMPLE

(Extracted from An Offsite Guide for the Building and Engineering Services Sector by BESA)



19	Are lifting lugs correctly fitted? (enclosed frame modules only)					
20	Is mod number and weight clearly indicated on module?					
21	Are all ancillary items not being fabricated installed attached to/with the module for delivery?					
22	Check any items removed for testing are labelled, including connecting pieces and crated for site delivery					
23	All debris removed from module i.e. cut out coupons removed from pipe.					
24	Is there any visual damage before it leaves the works? Paintwork insulation, rust etc.					
25	Pressure test pack available for services. Eg Mechanical, electrical and ductwork.					
26	Any transit supports, fixings and bolts are in place.					
27	Last check all items are secure.					
28	Fill out snag sheet if required.					
29	QA Paperwork complete, (send copy to site.)					
30	Check manufacturing centre QA sign off sheets.					
31	Is module delivery note indicating any ancillary items prepared?					
32	Are all valve labels fitted as shown with clearance for lagging					
33	Are pressure test sheets sent to site with module?					
34	Module accepted? Site must return completed form within 24hrs of delivery to site. Form to be scanned and emailed to Manufacturing centre and DfMA package manager audits will be carried out					

SAMPLE

Comments /Actions					
FABRICATOR REVIEWER		SIGNED		DATE	
SITE REVIEWER		SIGNED		DATE	

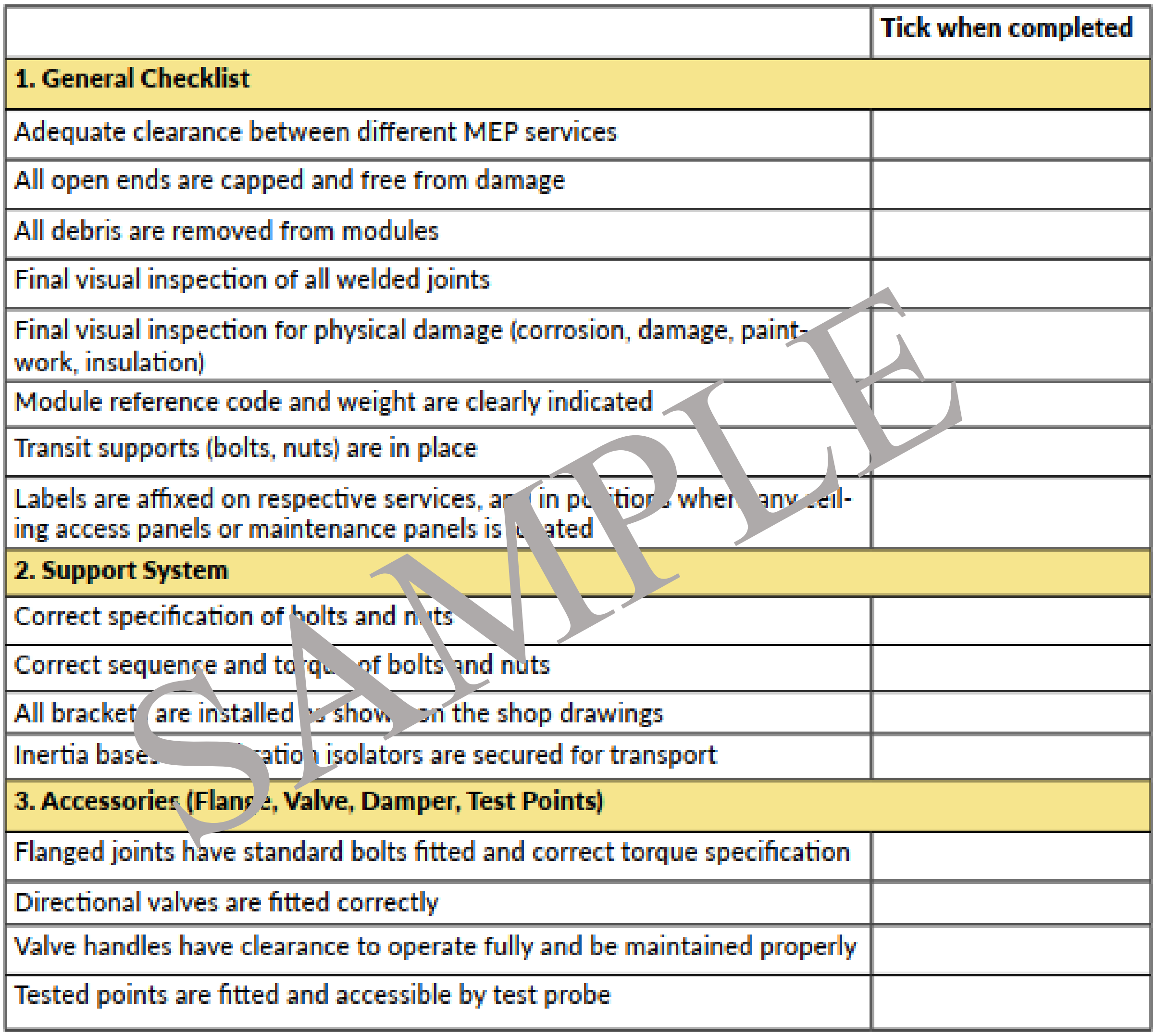
Key to inspection status:

H – Hold Point	**W1** – 100% Witnessed	**A1** – 100% Inspection	**R** – Review
N/A – Not Applicable	**W2** – Random Witnessed	**A2** – Random inspection	

Standard operations and visual aids such as One Point Lessons are equally important onsite as offsite.

(Extracted from An Offsite Guide for the Building and Engineering Services Sector by BESA)

Final Inspection Checklist for Prefabricated MEP Modules



SAMPLE

	Tick when completed
1. General Checklist	
Adequate clearance between different MEP services	
All open ends are capped and free from damage	
All debris are removed from modules	
Final visual inspection of all welded joints	
Final visual inspection for physical damage (corrosion, damage, paintwork, insulation)	
Module reference code and weight are clearly indicated	
Transit supports (bolts, nuts) are in place	
Labels are affixed on respective services, and in positions where any ceiling access panels or maintenance panels is located	
2. Support System	
Correct specification of bolts and nuts	
Correct sequence and torque of bolts and nuts	
All brackets are installed as shown on the shop drawings	
Inertia bases [illegible] vibration isolators are secured for transport	
3. Accessories (Flange, Valve, Damper, Test Points)	
Flanged joints have standard bolts fitted and correct torque specification	
Directional valves are fitted correctly	
Valve handles have clearance to operate fully and be maintained properly	
Tested points are fitted and accessible by test probe	

(Extracted from Design for Manufacturing and Assembly (DfMA) Prefabricated Mechanical, Electrical and Plumbing (MEP) Systems)

4.4 Sample of Commercial Checklist

The following list of questions intends to help project teams include contract clauses to support the inclusion of offsite options and to minimise unintended negative consequences. The list may be used at the project stage which the contracts are being drafted, either for design services or for construction.

1. Does the form of contract encourage collaborative methods of working?
2. Does the contract require the use of 3D BIM and application of BS EN ISO 19650 Part 1, Part 2 (with Hong Kong Local Annex in CIC's BIM Standards – General (Version 2 – December 2020), Part 3 and BS 1192 Part 4?
3. Do the payment terms link to delivery of the right thing at the specified quality and at the right time (not early or late)?
4. Does the contract ensure that suppliers are paid in a timely manner that reflects the profile of their own expenditure (as it would do if they were a supplier of labour and materials on site)?
5. Would the project benefit from single project insurance cover?
6. Does the contract encourage the early involvement of specialist sub-contractors in an advisory capacity?
7. Does the contract allow for a prototype or first run study?
8. Does the contract allow for the early procurement of project specific jigs and fixtures (including ATIFs)?
9. Does the contract allow for payment of early procurement of materials?
10. Does the contract allow for the holding of finished goods in a supplier's yard or 3rd party storage facility?
11. Does the contract recognise the need for a design freeze at the point which offsite elements are procured?
12. Does the contract require the application of formal configuration management to design changes and if so, from what point? (Ideally from the start of the project but the latest point being from the design freeze in 8 above).

(Modified from An Offsite Guide for the Building and Engineering Services Sector by BESA)

4.5 Building Information Modelling – LOD Responsibility Matrix for MEP

The Construction Industry Council has included sample templates of LOD Responsibility Matrix in Appendix A of its publication *CIC BIM Standards for Mechanical, Electrical and Plumbing (August 2019)*. The publication is available at the link provided in Appendix 3A of this Guidebook.

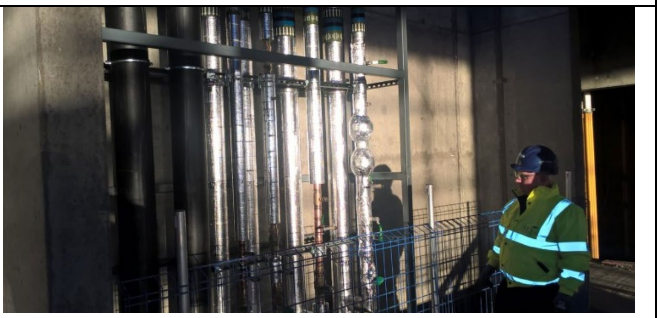
Appendix 5 Case Studies

5.1 United Kingdom

5.1.1 Quadram Institute

A. Basic information	
Project type	Institutional, with 14000 m^2 floor area
Procurement method	N/A
B. Main driver(s) / constraint(s) (e.g. regulations and tight schedule etc.)	
Statutory / Contract	- Offsite manufacturing being part of SES' strategy for over a decade
Programme	- Tight, i.e. research and clinical departments set to open in the middle of 2018
Safety	N/A
Others	N/A
C. Extent of DfMA for E&M Works, or prefabrication(s)	
Total quantity	217 Nos.
- Components, such as air ducts, cables and water pipes	- 36 Nos. AHU valve arrangements
- Horizontal modules, housing single / multiple MEP trades, with or without ceiling and lighting	- 164 Nos. pipework and electrical containment modules
- Vertical riser modules, housing single / multiple MEP trades	N/A
- Horizontal or vertical riser modules, completed with catwalks and platforms	- 6 Nos. ductwork risers (with platforms, 4 floors in height) - 4 Nos. pipework risers (ditto) - 3 Nos. electrical risers (ditto)
- MEP equipment skid and header modules	N/A
- MEP plantroom modules	- 4 Nos. plantroom pump skids
- Others	N/A
D. Outcome	
1	- The building was handed over to client on schedule in April 2018, with building services systems tested and commissioned (Offsite Hub, 2018)
E. Benefit(s) reported	
Cost	- The rise in cost due to prefabrication could be offset by shorter installation time, improvement in health and safety, quality and programme (Smith, 2020)

Time	- 1000 days of work saved (SES Engineering Services, 2020)
Quality	- The coordinated design ensured clashes were detected at an early stage, resulting in less redrawing, fewer snags and defects on site (Smith, 2018) - Better quality control on site as problems were identified during testing offsite (Smith, 2018)
Health and safety	- Tangible saving is the improvement in health and safety (Smith, 2018)
Productivity	- Over 8000 man hours taken from site into the factory (Offsite Hub, 2020; SES Engineering Services, 2020)
Sustainability	- Fewer tradespeople driving to site (Smith, 2018)
Site benefits	- Fewer deliveries of materials
Actual no. and percentage (%) of man-days saved for MEP works	- N/A
Actual no. and percentage (%) of man-days saved for non-MEP works	- N/A
Actual no. and percentage (%) of vehicle trips to and from the site	- N/A
Tonnes and percentage (%) of reduction in construction site waste	- N/A
Reduction in contract completion time	- N/A
Others	N/A
F. Key Lesson(s) Learnt	
1	- BIM and prefabrication enabled SES and the main contractor to work with the design team to maximum the offsite strategy (Smith, 2018)
2	- Early involvement of building services contractor allows working in partnership with consulting engineers and designing the services efficiently from day one (Smith, 2018)
G. Other information	
Logistics arrangement	N/A
Installation tools	N/A
H. Site Photos	

Photo 1 Vertical module (Offsite Hub, 2020)	
Photo 2 Vertical module (Offsite Hub, 2020)	
Photo 3 Horizontal modules (Offsite Hub, 2020)	

Reference

Offsite Hub. (2020). *SES Engineering Services Ltd – Quadram Institute.* Retrieved 12 July 2020, from https://www.offsitehub.co.uk/projects/ses-engineering-services-ltd-quadram-institute/

SES Engineering Services. (2020). *Quadram Institute.* Retrieved 12 July 2020, from https://www.ses-ltd.co.uk/case-study/quadram-institute/

Smith, A. (2018). *Make way for the revolution – inside SES Engineering Services' M&E factory*. Retrieved 12 July 2020, from https://www.cibsejournal.com/case-studies/make-way-for-the-revolution/

5.1.2 Two Fifty One

A. Basic information	
Project type	41-Storey residential tower + 7-Storey commercial
Procurement method	N/A
B. Main driver(s) / constraint(s) (e.g. regulations and tight schedule etc.)	
Statutory / Contract	N/A
Programme	- Logistically constrained
Safety	N/A
Others	N/A
C. Extent of DfMA for E&M Works, or prefabrication(s)	
Total quantity	534
- Components, such as air ducts, cables and water pipes	N/A
- Horizontal modules, housing single / multiple MEP trades, with or without ceiling and lighting	- 13 nos. Prefabricated horizontal modules
- Vertical riser modules, housing single / multiple MEP trades	- 11 nos. Prefabricated vertical riser modules
- Horizontal or vertical riser modules, completed with catwalks and platforms	N/A
- MEP equipment skid and header modules	N/A
- MEP Plantroom modules	- 11 nos. Prefabricated plantroom skids
- Others	- 499 nos. Bathroom pods
D. Outcome	
1	- Project delivered with improved cost certainty, quality, safety and logistics
E. Benefit(s) reported	
Cost	- Site running cost reduced due to site work minimization and earlier completion time - Cost saving due to standardized products of highly-efficient design - Reduced due to deployment of cheaper factory-based labour
Time	- Plant room modules manufactured and part commissioned off-site, giving better programme certainty

	- Critical MEP systems required for early commissioning installed as the structure progresses (vertical and horizontal modules) - Major plants, e.g. boilers and generators can operate earlier
Quality	- Finished bathroom pods manufactured and commissioned off-site to a better quality standard
Health and safety	- Unsafe scaffold decks not required when installing risers - Working in confined space not required
Productivity	- Enhanced due to more offsite work in factory, which the environment is safe and controlled
Sustainability	- Improved through reduced vehicle movements - Less waste due to adoption of standardized products of highly-efficient design
Site benefits	- Site work minimized
Actual no. and percentage (%) of man-days saved for MEP works	- N/A
Actual no. and percentage (%) of man-days saved for non-MEP works	- N/A
Actual no. and percentage (%) of vehicle trips to and from the site	- N/A
Tonnes and percentage (%) of reduction in construction site waste	- N/A
Reduction in contract completion time	- N/A
Others	N/A
F. Key Lesson(s) Learnt	
1	- Avoid up to 8 concurrent trades in the smallest rooms
2	- Patented, precast hollow core structural slabs able to span from core to edge beam without intermediate falsework, providing scope to load out MEP and bathroom pods
3	- Project fully designed, coordinated and constructed in the digital environment prior to delivery on-site, together with supply chain
4	- Advanced data exchange and component tracking
5	- Project success due to early engagement, an established client relationship, integrated direct

	delivery approach and optimised in-house manufacturing capabilities
G. Other information	
Logistics arrangement	N/A
Installation tools	N/A
H. Site Photos	
Photo 1 13m (H) Prefabricated mechanical riser services for residential floors. Installed concurrently with the structure. (Banks et al., 2018)	
Photo 2 Conceptual Image of Two Fifty One (Southwest Elevation) (Banks et al., 2018)	

Reference

Banks, C., Kotecha, R., Curtis, J, Dee, C. Pitt, N. and Papworth, R. (2018). Enhancing high-rise residential construction through design for manufacture and assembly – a UK case study. *Proceedings of the Institution of Civil Engineers – Management, Procurement and Law* 171(4): 164-175, https://doi.org/10.1680/jmapl.17.00027

5.1.3 Tottenham Court Road Station

A. Basic information	
Project type	Infrastructure
Procurement method	N/A
B. Main driver(s) / constraint(s) (e.g. regulations and tight schedule etc.)	
Statutory / Contract	N/A
Programme	N/A
Safety	- High-risk work environment, e.g. tunnels 25 – 35 m below ground
Others	N/A
C. Extent of DfMA for MEP, or prefabrication(s)	
Total quantity	N/A
- Components, such as air ducts, cables and water pipes	N/A
- Horizontal modules, housing single / multiple MEP trades, with or without ceiling and lighting	- Horizontal ceiling modules comprising cable trunking, cable tray and fire mains pipework. (The cables are pulled after installation of the modules on site)
- Vertical riser modules, housing single / multiple MEP trades	- Vertical riser modules comprising air conditioning ductwork, drainage, fire mains riser pipework and cable management systems (ladder racks)
- Horizontal or vertical riser modules, completed with catwalks and platforms	N/A
- MEP equipment skid and header modules	N/A
- MEP Plantroom modules	N/A
D. Outcome	
1	N/A
E. Benefit(s) reported	
Cost	N/A
Time	N/A
Quality	- Better quality control and workmanship
Health and safety	- Enhanced safety
Productivity	N/A
Sustainability	N/A
Site benefits	N/A

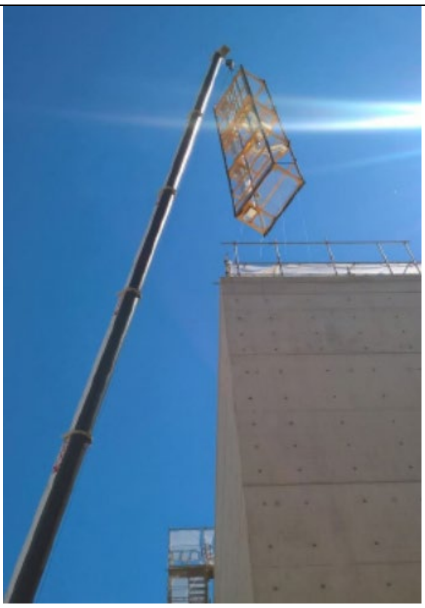
Actual no. and percentage (%) of man-days saved for MEP works	- N/A
Actual no. and percentage (%) of man-days saved for non-MEP works	- N/A
Actual no. and percentage (%) of vehicle trips to and from the site	- N/A
Tonnes and percentage (%) of reduction in construction site waste	- N/A
Reduction in contract completion time	- N/A
Others	N/A
F. Key Lesson(s) Learnt	
1	- Engage DfMA at the earliest project stage
2	- Fully integrated design
3	- Just-in-time delivery
4	- Use of Digital Technology, e.g. 3D model for checking
G. Other information	
Logistics arrangement	N/A
Installation tools	N/A
I. Site Photos	
Photo 1 Vertical riser module (Building and Construction Authority, 2018)	

Photo 2 Horizontal module (Building and Construction Authority, 2018)	

Reference

Building and Construction Authority. (2018). *Design for Manufacturing and Assembly (DfMA). Prefabricated Mechanical, Electrical and Plumbing (MEP) Systems.* Retrieved 10 July 2020, from https://www1.bca.gov.sg/docs/default-source/docs-corp-buildsg/mep_guidebook.pdf?sfvrsn=e8a20354_0

5.1.4 The Madison

A. Basic information	
Project type	Commercial
Procurement method	N/A
B. Main driver(s) / constraint(s) (e.g. regulations and tight schedule etc.)	
Statutory / Contract	- The contractor's offsite manufacture and modular strategy, i.e. 25% by 2025
Programme	N/A
Safety	N/A
Others	N/A
C. Extent of DfMA for E&M Works, or prefabrication(s)	
Total quantity	N/A
- Components, such as air ducts, cables and water pipes	N/A
- Horizontal modules, housing single / multiple MEP trades, with or without ceiling and lighting	N/A
- Vertical riser modules, housing single / multiple MEP trades	N/A
- Horizontal or vertical riser modules, completed with catwalks and platforms	N/A
- MEP equipment skid and header modules	N/A
- MEP Plantroom modules	N/A
- Others	- 482 bathroom pods on 51 floors - MEP Panels, comprising Heat Interface Units (HIU), insulated water supply pipework, drainage pipework, Miniature Circuit Breaker (MCB) board and socket outlets
D. Outcome	
1	N/A
E. Benefit(s) reported	
Cost	- Risk of damage by weather reduced
Time	N/A
Quality	- Snags / flaws reduced - Consistent quality and finish
Health and safety	N/A
Productivity	- Stolen parts reduced

Sustainability	N/A
Site benefits	N/A
Actual no. and percentage (%) of man-days saved for MEP works	- N/A
Actual no. and percentage (%) of man-days saved for non-MEP works	- N/A
Actual no. and percentage (%) of vehicle trips to and from the site	- N/A
Tonnes and percentage (%) of reduction in construction site waste	- N/A
Reduction in contract completion time	- N/A
Others	N/A
F. Key Lesson(s) Learnt	
1	- 150mm raised floor provided to achieve uniform floor level between in-situ floor slab and floor within the bathroom pod (±10mm tolerance on concrete slab thickness)
2	- Defined demarcation between drainage provision between bathroom pod supplier and plumbing and drainage sub-contractor
3	- Defined routes across floors for bathroom pods' access during installation
4	- Application of QR code on bathroom pods and provision of bathroom pod check sheet on BIM 360 Field, together with Off Site and On Site Tracker
5	- Testing of each pipe set individually before fitting insulation; every E&M component is Quality Assurance (QA) checked before leaving the production bay; After final assembly, final testing, QA and labelling will be carried out.
6	- Design process of prefabricated MEP panel is as follows:- 1. **Concept:** creation of a design concept and organisation of workshop with the consultants 2. **Concept design:** Review on detailed concept drawings, visualisations and renders for discussion, along with feasibility study and type selection 3. **Design approval submittal**: Design update per comments, addition of further details and drawing issuance for final approval by project team

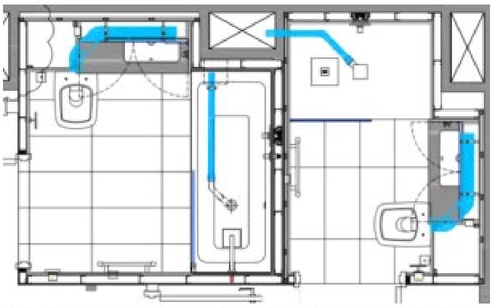
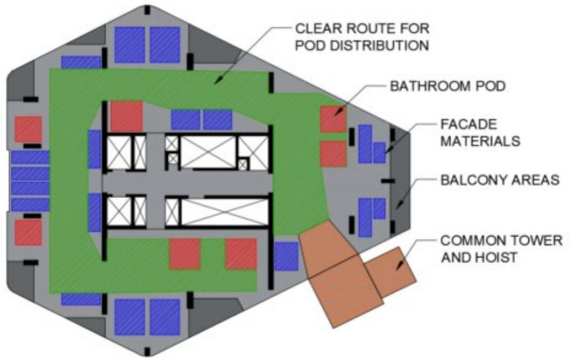
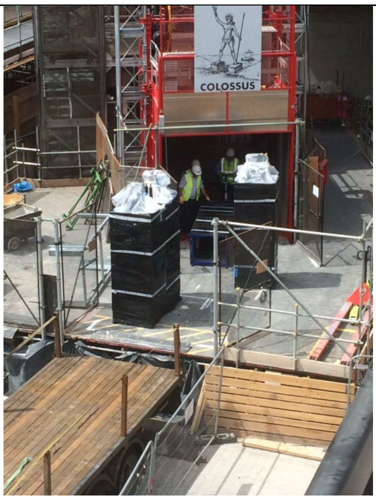
	4. **Final sign off**: Sign-off of drawing's models and specification schedules for manufacture 5. **Production starts:** Finalization of production drawings and manufacture of MEP panels; procurement of plant items and equipment 6. **Offline batching starts:** Manufacture of pipework, electrical looms, insulation and transport frame 7. **Powder coating:** Application of protective coating for MEP panels 8. **Final assembly:** Assembly of E&M components (individually tested and QA checked) 9. **Conclusion:** Final QA, labelling and packaging
G. Other information	
Logistics arrangement	- Logistics trackers for MEP Panels, showing:- o Dates, o Batch no.; o Brand / Type of product and quantity; o Progress of the batch (Not started / in production, under QA/ Ready for dispatch / Vested / Out for delivery / On site / Positioned / 1st Fix / Tested / Commissioned; o Status, i.e. complete / on schedule / overdue
Installation tools	N/A
H. Site Photos	
Photo 1 Demarcation between on site and offsite works	 Defined break points between contractors

Photo 2 Access route planning for modules	 Defined routes across floors for pods logistics
Photo 3 MEP panel	
Photo 4 Delivery of MEP panel	

Reference
Information provided by Balfour Beatty

5.2 Singapore

5.2.1 CapitaSpring

A. Basic information	
Project type	Grade A office, service apartment and retail
Procurement method	Design and Build (Dragages Singapore, 2017)
C. Main driver(s) / constraint(s) (e.g. regulations and tight schedule etc.)	
Statutory / Contract	- Client's commitment to adopt the latest building technologies for productivity gains (CapitaLand, 2018)
Programme	N/A
Safety	N/A
Others	N/A
D. Extent of DfMA for E&M Works, or prefabrication(s)	
Total quantity	N/A
- Components, such as air ducts, cables and water pipes	N/A
- Horizontal modules, housing single / multiple MEP trades, with or without ceiling and lighting	- Horizontal MEP modules for corridor (Ministry of National Development, 2019)
- Vertical riser modules, housing single / multiple MEP trades	- Vertical riser modules (Ministry of National Development, 2019)
- Horizontal or vertical riser modules, completed with catwalks and platforms	N/A
- MEP equipment skid and header modules	N/A
- MEP Plantroom modules	- Plant room modules (Ministry of National Development, 2019)
- Others	N/A
E. Outcome	
1	N/A
F. Benefit(s) reported	
Cost	N/A
Time	N/A
Quality	- Better workmanship (Ministry of National Development, 2019)
Health and safety	- Improved safety (Ministry of National Development, 2019)

Productivity	- Estimated productivity increase by around 50% (Ministry of National Development, 2019)
Sustainability	N/A
Site benefits	N/A
Actual no. and percentage (%) of man-days saved for MEP works	- N/A
Actual no. and percentage (%) of man-days saved for non-MEP works	- N/A
Actual no. and percentage (%) of vehicle trips to and from the site	- N/A
Tonnes and percentage (%) of reduction in construction site waste	- N/A
Reduction in contract completion time	- N/A
Others	- Better coordination (Ministry of National Development, 2019)
G. Key Lesson(s) Learnt	
1	N/A
2	N/A
3	N/A
H. Other information	
Logistics arrangement	N/A
Installation tools	N/A
I. Site Photos	

Photo 1 Conceptual Image of CapitaSpring (Dragages Singapore, 2017)	

Reference

CapitaLand. (2018). *New 51-storey integrated development on 88 Market Street breaks ground, set to rejuvenate Singapore's CBD with thriving vertical community*. Retrieved 14 July 2020, from https://www.capitaland.com/international/en/about-capitaland/newsroom/news-releases/international/2018/feb/Nr-20180209-new-51-storey-development-in-Raffles-Place-breaks-ground.html#menu-lang-main

Dragages Singapore. (2017). *CapitaSpring*. Retrieved 14 July 2020, from http://dragages.com.sg/projects-post/capitaspring/

Ministry of National Development. (2019). *Speech by MOS Zaqy Mohamad at the BCA Awards Night*. Retrieved 14 July 2020, from https://www.mnd.gov.sg/newsroom/speeches/view/speech-by-mos-zaqy-mohamad-at-the-bca-awards-night

5.2.2 Global Switch Singapore Woodlands Data Centre

A. Basic information	
Project type	Building (Data Centre)
Procurement method	Design and Build
B. Main driver(s) / constraint(s) (e.g. regulations and tight schedule etc.)	
Statutory / Contract	N/A
Programme	- Fast track project with a tight schedule, the Prefabricated MEP modules gave the client assurance the programme could be delivered
Safety	N/A
Others	N/A
C. Extent of DfMA for E&M Works, or prefabrication(s)	
Total quantity	~ 450 nos. (including catwalk)
- Components, such as air ducts, cables and water pipes	- Roof Condenser Water (CDW) pipe modules including platform
- Horizontal modules, housing single / multiple MEP trades, with or without ceiling and lighting	- Horizontal multi-purpose modules - Raised floor modules
- Vertical riser modules, housing single / multiple MEP trades	- Vertical riser modules for Chilled Water (CHW) pipes and CDW pipes
- Horizontal or vertical riser modules, completed with catwalks and platforms	- MEP services integrated with catwalk modules at facade
- MEP equipment skid and header modules	- Pump skid and header
- MEP Plantroom modules	- CHW & CDW pipe modules
D. Outcome	
1	- High quality building completed within a short period
E. Benefit(s) reported	
Cost	N/A
Time	- 60% programme saving
Quality	- 70% less defects compared with areas where traditional installation was adopted
Health and safety	- Improves safety (reduce working at height and removes hot works)
Productivity	- 40% less labour
Sustainability	- Reduced material waste and reuse in factory
Site benefits	N/A

Actual no. and percentage (%) of man-days saved for MEP works	- N/A
Actual no. and percentage (%) of man-days saved for non-MEP works	- N/A
Actual no. and percentage (%) of vehicle trips to and from the site	- N/A
Tonnes and percentage (%) of reduction in construction site waste	- N/A
Reduction in contract completion time	- N/A
Others	- Improves coordination
F. Key Lesson(s) Learnt	
1	- Limit the extent of works required from sub-contractors and keep the factory works in-house
2	- Closely monitor the site progress with the factory production to achieve, 'just in time' deliveries
3	- Coordinate the module size with the available access and building structure
G. Other information	
Logistics arrangement	- Multi-Purpose – Forklift and Mobile Elevating Work Platforms (MEWP) - Riser – Mobile Crane and lifting beam - Plant Room – Mobile Crane, Forklift and industrial rollers
Installation tools	N/A
H. Site Photos	
Photo 1 Vertical riser module (Building and Construction Authority, 2020)	

Photo 2 Horizontal E&M module (Building and Construction Authority, 2020)	

Reference

Building and Construction Authority. (2020) *Prefabricated mechanical electrical & plumbing systems.* Retrieved 3 July 2020, from https://www1.bca.gov.sg/buildsg/productivity/design-for-manufacturing-and-assembly-dfma/prefabricated-mechanical-electrical-plumbing-systems/global-switch-singapore-woodlands-data-centre

Supplementary information provided by Gammon Pte Ltd.

5.3 Hong Kong

5.3.1 Plumbing and Drainage Installation at Eastern Medical Centre, Hong Kong Sanatorium and Hospital

A. Basic information	
Project type	Healthcare
Procurement method	Lump sum
B. Main driver(s) / constraint(s) (e.g. regulations and tight schedule etc.)	
Statutory / Contract	N/A
Programme	N/A
Safety	N/A
Others	N/A
C. Extent of DfMA for E&M Works, or prefabrication(s)	
Total quantity	7 nos. of pipe riser modules
- Components, such as air ducts, cables and water pipes	N/A
- Horizontal modules, housing single / multiple MEP trades, with or without ceiling and lighting	N/A
- Vertical riser modules, housing single / multiple MEP trades	- Pipe riser modules completed with pipework, valve and pipe accessories
- Horizontal or vertical riser modules, completed with catwalks and platforms	N/A
- MEP equipment skid and header modules	N/A
- MEP Plantroom modules	N/A
D. Outcome	
1	- The 7 nos. of vertical pipe riser modules were completed within 1 day
E. Benefit(s) reported	
Cost	N/A
Time	N/A
Quality	- Reduced defect rectification works
Health and safety	- Reduced material storage and debris on site - Reduced labour on site - Improved working environment
Productivity	N/A
Sustainability	N/A

Site benefits	N/A
Actual no. and percentage (%) of man-days saved for MEP works	- N/A
Actual no. and percentage (%) of man-days saved for non-MEP works	- N/A
Actual no. and percentage (%) of vehicle trips to and from the site	- N/A
Tonnes and percentage (%) of reduction in construction site waste	- N/A
Reduction in contract completion time	- N/A
Others	N/A
F. Key Lesson(s) Learnt	
1	Alignment of the pipe module connection can be verified by: - Pre-assembling the modules at the workshop; and - Checking the positions of the installed pipework against service connection template
2	N/A
3	N/A
G. Other information	
Logistics arrangement	N/A
Installation tools	N/A
H. Site Photos	
Photo 1 Offsite fabrication of pipe riser modules at workshop	

Photo 2 Installation of pipe riser modules on site	

Reference

Courtesy of Majestic Engineering Company Limited

5.3.2 Vehicle Examination Centre at Sai Tso Wan Road, Tsing Yi

A. Basic information	
Project type	Government Building
Procurement method	Design and Build
B. Main driver(s) / constraint(s) (e.g. regulations and tight schedule etc.)	
Statutory / Contract	N/A
Programme	N/A
Safety	N/A
Others	- To improve installation sequence
C. Extent of DfMA for E&M Works, or prefabrication(s)	
Total quantity	- 20 nos. of Multi-trade Prefabricated Racks (MTPRs)/ horizontal MEP modules
- Components, such as air ducts, cables and water pipes	N/A
- Horizontal modules, housing single / multiple MEP trades, with or without ceiling and lighting	- 20 nos. of MTPRs completed with ductwork, Variable Air Volume (VAV) box and trunkings
- Vertical riser modules, housing single / multiple MEP trades	N/A
- Horizontal or vertical riser modules, completed with catwalks and platforms	N/A
- MEP equipment skid and header modules	N/A
- MEP Plantroom modules	N/A
D. Outcome	
1	N/A
E. Benefit(s) reported	
Cost	N/A
Time	N/A
Quality	- Reduced defect rectification works
Health and safety	- Reduced material storage and debris on site - Reduced labour on site - Improved working environment
Productivity	N/A
Sustainability	N/A
Site benefits	N/A

Actual no. and percentage (%) of man-days saved for MEP works	- N/A
Actual no. and percentage (%) of man-days saved for non-MEP works	- N/A
Actual no. and percentage (%) of vehicle trips to and from the site	- N/A
Tonnes and percentage (%) of reduction in construction site waste	- N/A
Reduction in contract completion time	- N/A
Others	N/A
F. Key Lesson(s) Learnt	
1	Alignment of the pipe module connection can be verified by: - Pre-assembling the modules at the workshop; and - Checking the positions of the installed pipework against service connection template
2	- Planning is critical for installation MTPRs, due to their physical size and the installation time required
3	N/A
G. Other information	
Logistics arrangement	N/A
Installation tools	N/A
H. Site Photos	
Photo 1 Delivery of a MTPR	

Photo 2 Installation of a MTPR	

Reference
Information provided by Young’s Engineering Company Limited

5.3.3 West Kowloon Government Offices in Yau Ma Tei, Kowloon

A. Basic information	
Project type	Government Building
Procurement method	Design and Build
B. Main driver(s) / constraint(s) (e.g. regulations and tight schedule etc.)	
Statutory / Contract	N/A
Programme	- Tight schedule
Safety	N/A
Others	N/A
C. Extent of DfMA for E&M Works, or prefabrication(s)	
Total quantity	- 21 nos. of pipe modules and 20 cooling tower modules
- Components, such as air ducts, cables and water pipes	N/A
- Horizontal modules, housing single / multiple MEP trades, with or without ceiling and lighting	- 21 nos. of pipe modules
- Vertical riser modules, housing single / multiple MEP trades	N/A
- Horizontal or vertical riser modules, completed with catwalks and platforms	N/A
- MEP equipment skid and header modules	- 20 nos. of cooling tower modules
- MEP Plantroom modules	N/A
D. Outcome	
1	- More than 90% of the cooling tower installation were completed within 11 days
E. Benefit(s) reported	
Cost	N/A
Time	- Reduced site installation time as modules were fabricated before the handover of the plant room by builder for E&M installation
Quality	- Reduced defect rectification works
Health and safety	- Reduced material storage and debris on site - Reduced labour on site - Improved working environment
Productivity	N/A
Sustainability	N/A
Site benefits	N/A

Actual no. and percentage (%) of man-days saved for MEP works	- N/A
Actual no. and percentage (%) of man-days saved for non-MEP works	- N/A
Actual no. and percentage (%) of vehicle trips to and from the site	- N/A
Tonnes and percentage (%) of reduction in construction site waste	- N/A
Reduction in contract completion time	- N/A
Others	- Minimised disruption to neighbouring campus - Reduced amount of noise - Less traffic congestion
F. Key Lesson(s) Learnt	
1	Alignment of the pipe module connection can be verified by: - Pre-assembling the modules at the workshop; and - Checking the positions of the installed pipework against service connection template
2	- Limited clearance space in pipe modules, leading to difficulty in services connections between modules
3	- Additional transportation cost from workshop to site incurred.
G. Other information	
Logistics arrangement	- Mid-night delivery of modules due to the restriction in lorry width for daytime traffic
Installation tools	N/A
H. Site Photos	
Photo 1 Offsite inspection of pipe modules	

Photo 2 Accurate Positioning – Robotic Total Station (RTS) for pipe modules during on site installation	
Photo 3 Midnight delivery of pipe modules	
Photo 4 Module being hoisted by tower crane	

Reference

Fong, G. L P. (2019). *DfMA for MEP in West Kowloon Government Office.* Retrieved 20 November 2020, from http://www.cic.hk/files/page/10325/190724-04-FSE.pdf

Information provided by Young's Engineering Company Limited

5.3.4 Tuen Mun Chek Lap Kok (TMCLK) Link J3728

A. Basic information	
Project type	Infrastructure
Procurement method	Re-measurement and Design and Build (E&M)
B. Main driver(s) / constraint(s) (e.g. regulations and tight schedule etc.)	
Statutory / Contract	N/A
Programme	-
Safety	N/A
Others	N/A
C. Extent of DfMA for E&M Works, or prefabrication(s)	
Total quantity	2 x 4.5km in length
- Components, such as air ducts, cables and water pipes	N/A
- Horizontal modules, housing single / multiple MEP trades, with or without ceiling and lighting	- Pipe modules at service maintenance tunnel, comprising of fire service and drainage
- Vertical riser modules, housing single / multiple MEP trades	- Ditto
- Horizontal or vertical riser modules, completed with catwalks and platforms	N/A
- MEP equipment skid and header modules	N/A
- MEP Plantroom modules	N/A
D. Outcome	
1	- Installation task completed within the defined programme
E. Benefit(s) reported	
Cost	- Reduced cost of delivery – frequency of delivery decreased - Reduced cost of installation on site – fewer workers involved in installing the utilities on site - Reduced material cost – wastage reduced due to the use of BIM for estimating the materials needed for modules
Time	- Shorter installation time - Concurrent fabrication and installation made possible - Reduced delivery frequency

Quality	- The modules were checked at the fabrication yard so defects could be rectified on the scene - Easier quality control at the fabrication yard
Health and safety	- Chance of injury for site workers reduced due to fewer installation works on site - Easier management of workers from various trades in a congested site, due to fewer workers on site
Productivity	- Precise estimation of material required made possible through use of BIM for DfMA approach - Site constraint could be foreseen
Sustainability	- Records were computerised - Less wastage due to precise estimation
Site benefits	- Fewer skills involved on site due to plug-and-play installation - Fewer monitoring works
Actual no. and percentage (%) of man-days saved for MEP works	- N/A
Actual no. and percentage (%) of man-days saved for non-MEP works	- N/A
Actual no. and percentage (%) of vehicle trips to and from the site	- N/A
Tonnes and percentage (%) of reduction in construction site waste	- N/A
Reduction in contract completion time	- N/A
Others	N/A
F. Key Lesson(s) Learnt	
1	- Precise survey scan is critical, but the processing time could be long
2	- Training is needed to maximise the benefits from adopting DfMA approach. Input at each process checkpoint shall be precise for a smooth execution
3	- Coordination and communication between fabrication yard, logistics and site operational team are critical for success
G. Other information	
Logistics arrangement	N/A
Installation tools	N/A

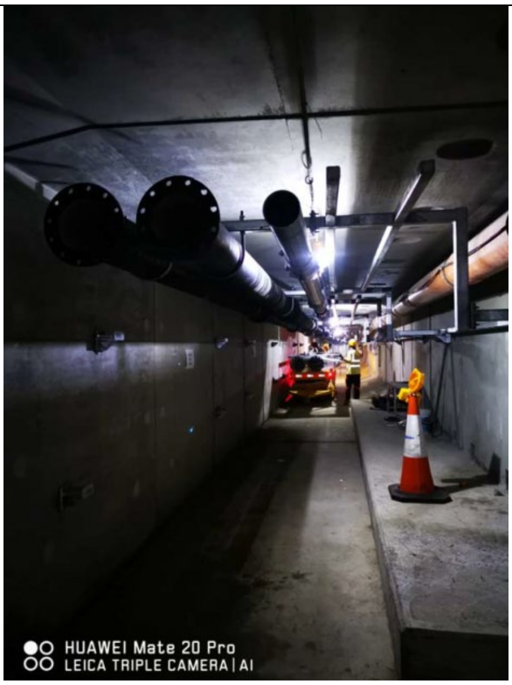
H. Site Photos	
Photo 1 Pipe module under installation	
Photo 2 Use of mobile crane in delivering pipe modules	
Photo 3 Pipe module after installation	

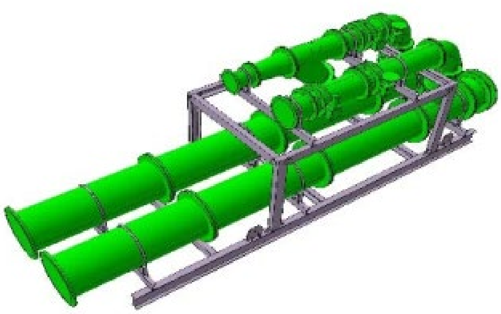
Photo 4 Pipe modules at storage	

Reference
Information provided by Gammon E&M Limited

5.3.5 I-Square

A. Basic information	
Project type	High rise office and commercial complex
Procurement method	Lump Sum Contract
B. Main driver(s) / constraint(s) (e.g. regulations and tight schedule etc.)	
Statutory / Contract	N/A
Programme	- Tight construction programme
Safety	- Heavy lifting, high level works and risk of falling objects
Others	- Highly congested site, while works of multiple trades in Roof Floor and Upper Roof Floor considered challenging
C. Extent of DfMA for E&M Works, or prefabrication(s)	
Total quantity	N/A
- Components, such as air ducts, cables and water pipes	N/A
- Horizontal modules, housing single / multiple MEP trades, with or without ceiling and lighting	- Ductile iron pipe header modules completed with branch and tee-off, valves and accessories
- Vertical riser modules, housing single / multiple MEP trades	N/A
- Horizontal or vertical riser modules, completed with catwalks and platforms	N/A
- MEP equipment skid and header modules	- Counter flow type cooling tower modules completed with upper and lower deck assemblies
- MEP Plantroom modules	N/A
D. Outcome	
1	- Works completed in shorter time than traditional approach and with good quality
E. Benefit(s) reported	
Cost	- Reduced site labour cost due to adoption of prefabrication of modules offsite in advance, i.e. fewer site activities and number of site workers - Reduced cost of delivery due to reduced delivery frequency - Reduced wastage handling due to use of BIM, which improved precision of fabrication works for pipe modules

Time	- Reduced site installation time - Improved site program certainty due to prefabrication and assembly in advance
Quality	- Improved quality control as hydrostatic test and welding test for pipe modules were completed before delivery to site
Health and safety	- Chance of injury for site workers reduced due to fewer installation works on site - Easier management of workers from various trades in a congested site, due to fewer workers on site
Productivity	- Higher productivity, i.e. 80% of installation works including the pipe modules and cooling tower modules were completed within 2 to 3 weeks - Reduced frequency in material hoisting as the materials were placed in the prefabricated modules instead
Sustainability	- The steel supporting frame facilitated the subsequent mounting for conduit and drain pipe, and steel cage ladder
Site benefits	- Reduced site activities, e.g. hot works on site - Reduced site wastage - Improved environmental control
Actual no. and percentage (%) of man-days saved for MEP works	- N/A
Actual no. and percentage (%) of man-days saved for non-MEP works	- N/A
Actual no. and percentage (%) of vehicle trips to and from the site	- N/A
Tonnes and percentage (%) of reduction in construction site waste	- N/A
Reduction in contract completion time	- N/A
Others	N/A
F. Key Lesson(s) Learnt	
1	- Other than DfMA design, the logistic planning and installation and sequence of works planning with other trades are also crucial to the site delivery and installation
2	- Earlier design freeze is important to allow offsite fabrication and assemble works to be carried out in advance
3	N/A

G. Other information	
Logistics arrangement	- Delivery to site by lorry truck - Tower crane for hoisting from G/F to Roof Floor
Installation tools	- Tower crane, chain blocks and jack
H. Site Photos	
Photo 1 BIM model for the pipe header module (Courtesy of Gammon E&M Limited)	
Photo 2 Pipe header module (Courtesy of Gammon E&M Limited)	
Photo 3 Pipe header module during installation (Courtesy of Gammon E&M Limited)	

Reference

Information provided by Gammon E&M Limited

5.3.6 The First Innovative Modular Integrated Construction (MiC) Negative Pressure Isolation Ward in Hong Kong

A. Basic information	
Type	Healthcare (Mock-up)
Procurement method	Design and build
B. Main driver(s) / constraint(s) (e.g. regulations and tight schedule etc.)	
Statutory / Contract	N/A
Programme	N/A
Safety	N/A
Others	- The mock-up was built to: o prove the feasibility of applying MiC techniques to cater for any need for high-quality isolation rooms during a health crisis; and o showcase the capability of the Hong Kong engineering profession
C. Extent of DfMA for E&M Works, or prefabrication(s)	
Total quantity	- 2 nos. of containers were combined to form an isolation ward, providing 4 compartments (see Photo 1 in Section, namely: o Ante Room o Toilet o Bedroom o E&M service room Note: Area for information display is excluded.
- Components, such as air ducts, cables and water pipes	N/A
- Horizontal modules, housing single / multiple MEP trades, with or without ceiling and lighting	N/A
- Vertical riser modules, housing single / multiple MEP trades	N/A
- Horizontal or vertical riser modules, completed with catwalks and platforms	N/A
- MEP equipment skid and header modules	N/A
- MEP Plantroom modules	- 1 No. MiC module, completed with o Air-conditioning system, including ductwork (fresh air, supply air and exhaust air), exhaust and fresh air fans, HEPA filter (exhaust side) and fan control panels etc. o Lighting and small power

	o Pipe module, including medical gas and plumbing and drainage pipework
- Others	- 1 No. MiC module for bedroom, toilet and ante room, completed with: o Bedhead services trunking o Emergency call bell system o Other E&M services such as lighting and small power, plumbing and drainage etc.
D. Outcome	
1	- The design, construction and testing and commissioning of the mock-up were completed within **24 days** (Gammon Construction Limited, 2020a), with the support from project partners on long-lead procurement items (Gammon Construction Limited, 2020b).
E. Benefit(s) achieved	
Cost	N/A
Time	- See outcome
Quality	N/A
Health and safety	N/A
Productivity	N/A
Sustainability	N/A
Site benefits	N/A
Actual no. and percentage (%) of man-days saved for MEP works	- N/A
Actual no. and percentage (%) of man-days saved for non-MEP works	- N/A
Actual no. and percentage (%) of vehicle trips to and from the site	- N/A
Tonnes and percentage (%) of reduction in construction site waste	- N/A
Reduction in contract completion time	- N/A
Others	N/A
F. Key Lesson(s) Learnt	
1	- Some of the E&M components were arranged to be installed in the aluminium container housing for a combined assembly approach
2	- Collaborative process involved the Main Contractor's in-house structural, building, E&M, BIM façade and fit-out teams

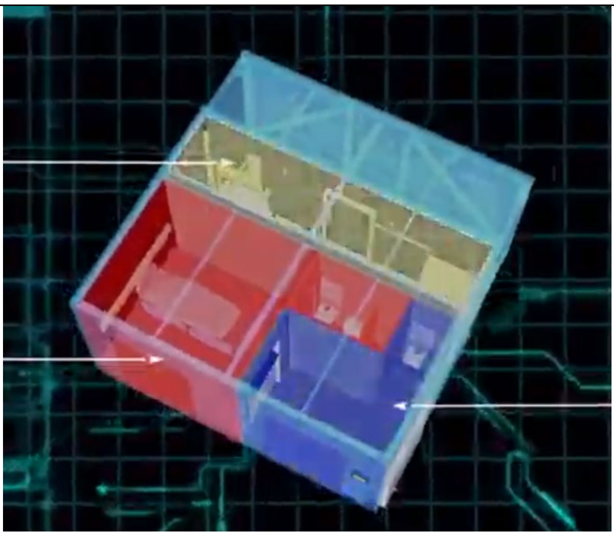
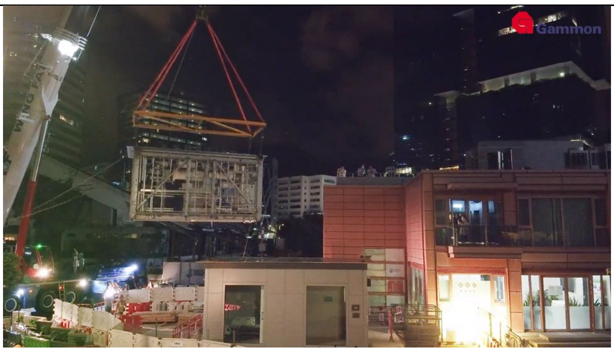
3	- Detailed BIM model for the mock up was developed within a week
G. Other information	
Logistics arrangement	- Delivery of the 2 nos. of containers were scheduled at night, such that impact to the traffic and the neighbourhood could be minimized - Delivery of the containers by 2 articulated vehicles
Installation tools	- The MiC modules were hoisted by mobile crane
H. Site Photos	
Photo 1 Layout of the MiC isolation ward module (Gammon Construction Limited, 2020a):- - Part in red: Bedroom and toilet - Part in deep blue: Ante room - Part in yellow: E&M service room - Part in light blue: Area for information display	
Photo 2 Hoisting of the E&M module onto the articulated vehicle by mobile crane (Gammon Construction Limited, 2020a)	
Photo 3 Delivery of the 2 nos. MiC containers by articulated vehicles at night (Gammon Construction Limited, 2020a)	

Photo 4 Installation of the MiC module for E&M services room (Gammon Construction Limited, 2020a)	

Reference

Gammon Construction Limited (2020a). *MiC negative pressure isolation ward.* Retrieved 23 July 2020, from https://www.youtube.com/watch?v=dV7QdGYip1s

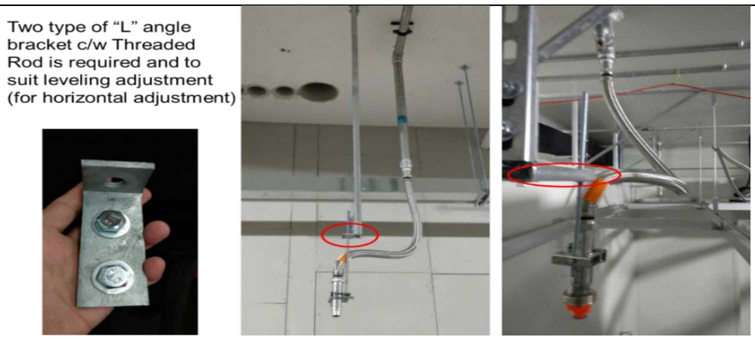
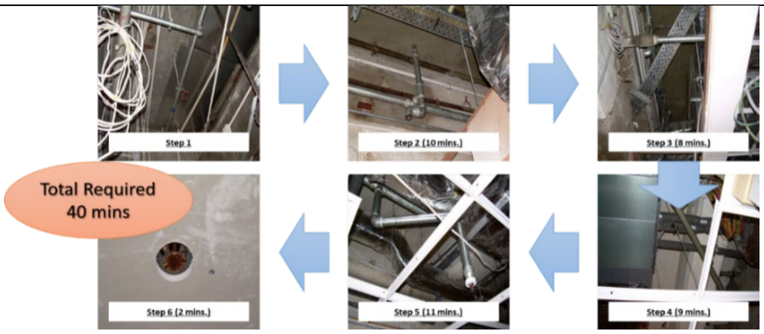
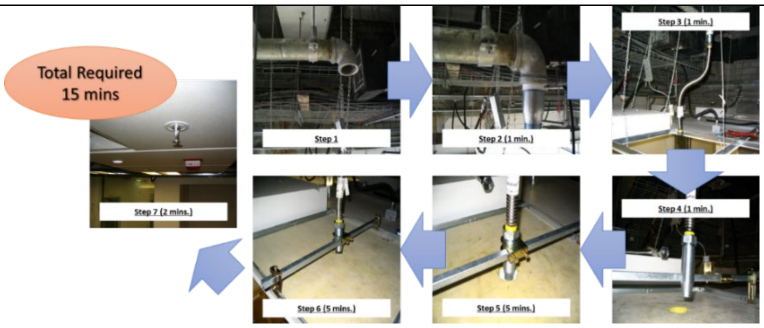
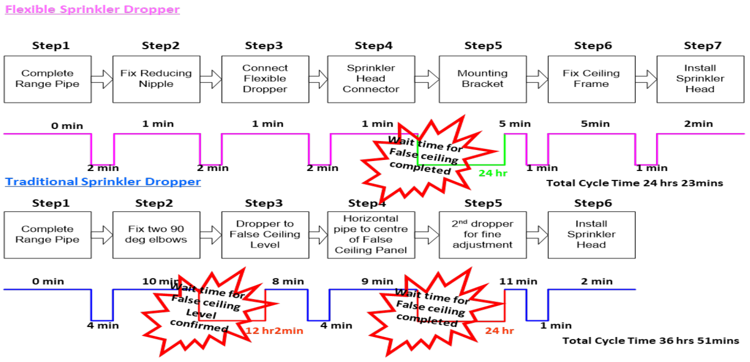
Gammon Construction Limited (2020b). *Under negative pressure.* Retrieved 22 July 2020, from https://mailchi.mp/b86ae6fa0ef1/under-negative-pressure#

5.3.7 DfMA for MEP Works at Possehl Electronic

A. Basic information	
Project type	Industrial Building
Procurement method	Design and Build
B. Main driver(s)/ constraint(s) (e.g. regulations and tight schedule etc.)	
Statutory / Contract	- The client was a global leading & innovative semicon company which develops and manufactures a broad range of etched parts for the semiconductor and automotive industry, relocated its manufacturing facility to a new location. Due to business needs, the relocation project had to be completed within four (4) months to resume production. Contract - All statutory licensing requirements including Fire Certificate, WWO 46 for water supply and Dangerous Goods license were required to be obtained. Statutory - It would take long time e.g. 6-9 months to obtain approval from the statutory body for new application of innovative installation.
Programme	- The corridor was vertically congested with four (4) MEP trades. Traditional installation method and sequence would not achieve the tight program. The lower layer sprinkler dropper installation was on critical path as the last MEP item to be installed. Innovative DfMA approach was needed to adopt in order to reduce the total MEP installation period to meet the target.
Safety	Constraints - The sprinkler system of Tsuen Wan Industrial Center was built about 30 years ago. All sprinkler sub-mains of each floor are directly connected to the raising main of the sprinkler system without any subsidiary valve in between. Whenever upgrading work/maintenance work is to be carried out, it will be required to drain off leaving the sprinkler system of the entire building without any sprinkler protection. Driver

	- The application of flexible sprinkler drops will reduce down time of the entire sprinkler system to improve fire safety.
Others	- A systemic approach was adopted. At design stage, Value Stream Mapping (VSM) was adopted to critically analyse the **value stream** (see Section 6.2.1 of this Guidebook) for identification and elimination of wastes in the MEP installation of the project.
C. Extent of DfMA for E&M Works, or prefabrication(s)	
Total quantity	- 700 flexible sprinkler drop modules - 3,000m prefabricated air-duct - 2,000 modular lighting-fittings - 500 m^2 modular ceiling panel
- Components, such as air ducts, cables and water pipes	- Majority MEP installation was prefabricated off site, being the last component of the critical path for completion of the project, flexible sprinkler drops could be offset by shorter installation time, reduced the time of working at height.
- Horizontal modules, housing single / multiple MEP Trades, with or without ceiling and lighting	N/A
- Vertical riser modules, housing single / multiple MEP trades	- Planning was critical for four layers MEP installation located within same vertical zone at the congested corridor.
- Horizontal or vertical riser modules, completed with catwalks and platforms	N/A
- MEP equipment skid and header modules	N/A
- MEP Plantroom modules	N/A
D. Outcome	
1	Contract - It was concluded that the application of flexible sprinkler drops had reduced the installation time by 60%, eliminated the waiting time of other MEP installation, and finally reduced the total project time by 33%
2	Statutory - The quantification and qualification of installation constraints and fire safety risk elimination convinced the statutory body to approve the application. Six (6) weeks after the

	application was submitted, the statutory body approved the application. - Key points to secure the approval are: 1) tags to be provided to identify each flexible sprinkler drop; 2) inspection and endorsement by RPE to be provided to ensure the compliance; 3) minimize the impacts/ risks of system shutdown during A&A works in future; and 4) independent to false ceiling system by using self-mount bracket (see Diagram 1).
E. Benefit(s) achieved	
Cost	- Material cost is 25% higher than traditional - Labour cost has 60% saving, i.e. from 40 minutes to 15 minutes
Time	- Traditional method – 40 minutes to install one (1) sprinkler dropper, while using flexible pipe – required 15 minutes (see Diagrams 2 and 3) - Time saving is 25 minutes. For 700 nos., total time saving is 17,500 minutes
Quality	- Better workmanship and the pipework can be pressure tested before interior decoration
Health and safety	- Improved as the working at height man-day was 60% lower than traditional approach
Productivity	- 60% time saving
Sustainability	- Reduced material waste
Site benefits	- Reduced on site installation time
Actual no. and percentage (%) of man-days saved for MEP works	- See Outcome 1
Actual no. and percentage (%) of man-days saved for non-MEP works	- N/A
Actual no. and percentage (%) of vehicle trips to and from the site	- N/A
Tonnes and percentage (%) of reduction in construction site waste	- N/A
Reduction in contract completion time	- See Outcome 1
Others	N/A
F. Key Lesson(s) Learnt	
1	- Quantification and qualification of the value stream from different stakeholders’ views.
2	- Process control during execution stage.
3	- Time management

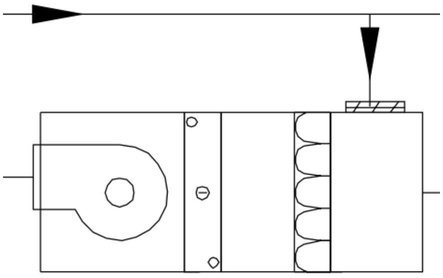
4	- Construction planning and work sequence to be conducted through Value Stream Mapping (VSM) during design stage (see Diagram 4).
G. Other information	
Logistics arrangement	- Smaller storage area
Installation tools	N/A
H. Site Photos	
Diagram 1 Mounting Details of Flexible Sprinkler Dropper	 Two type of "L" angle bracket c/w Threaded Rod is required and to suit leveling adjustment (for horizontal adjustment)
Diagram 2 Time Mapping of G.I. Sprinkler Droppers Installation (Traditional Method)	
Diagram 3 Time Mapping of Flexible Sprinkler Droppers Installation	
Diagram 4 VSM to compare traditional method with Flexible Sprinkler Drops for DfMA	

Reference

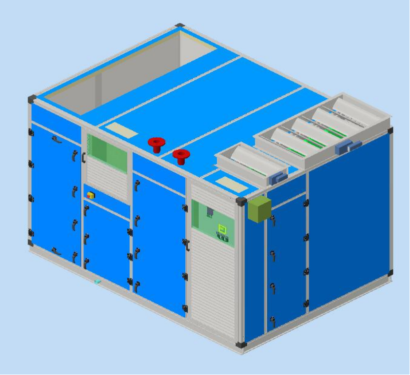
Information provided by InnoTec Engineering Limited

Appendix 6 Concept for DfMA MEP Standard Design Templates

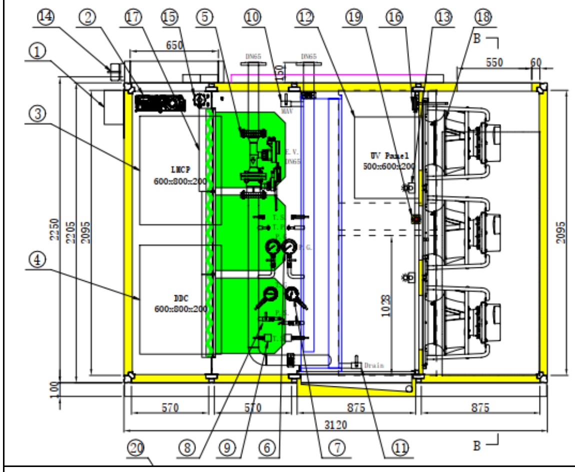
6.1 Template for Air Handling Unit



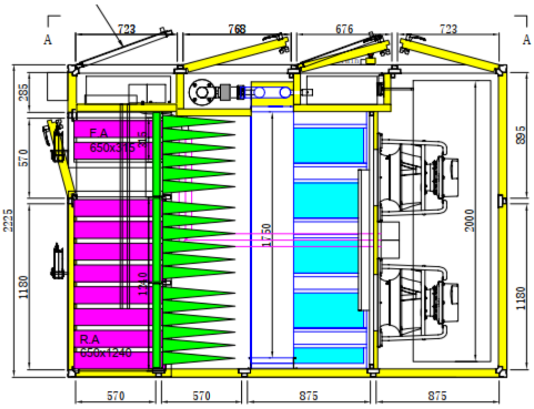
Schematic Diagram



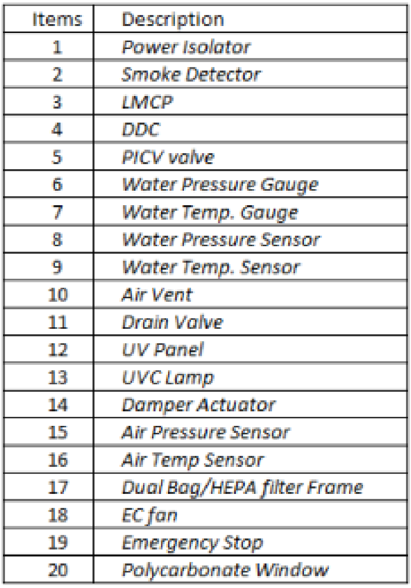
3D View



Plan View 1

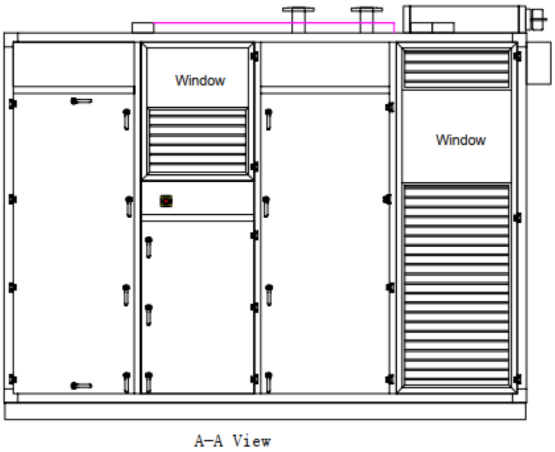


Plan View 2



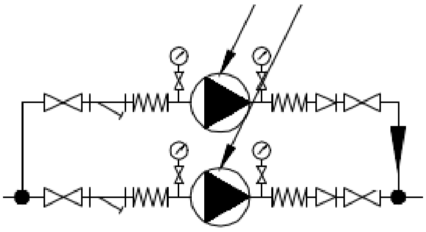
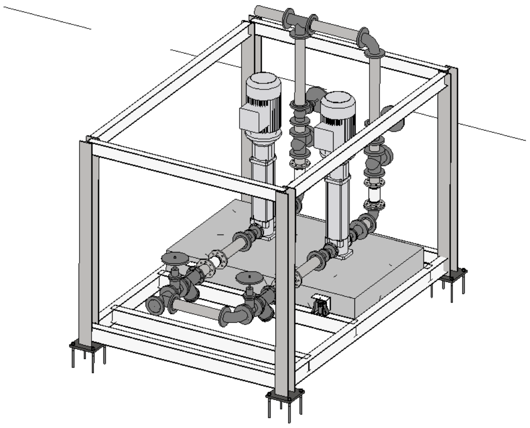
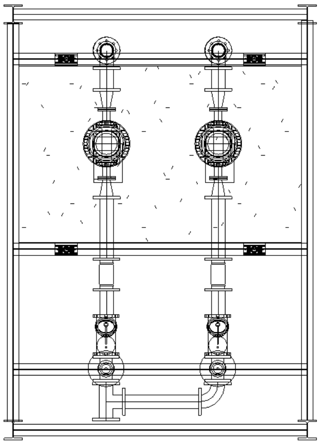
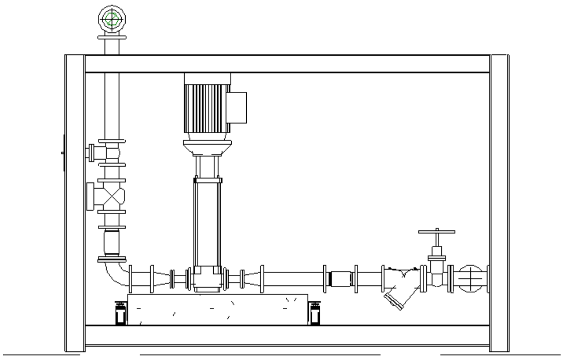
Items	Description
1	Power Isolator
2	Smoke Detector
3	LMCP
4	DDC
5	PICV valve
6	Water Pressure Gauge
7	Water Temp. Gauge
8	Water Pressure Sensor
9	Water Temp. Sensor
10	Air Vent
11	Drain Valve
12	UV Panel
13	UVC Lamp
14	Damper Actuator
15	Air Pressure Sensor
16	Air Temp Sensor
17	Dual Bag/HEPA filter Frame
18	EC fan
19	Emergency Stop
20	Polycarbonate Window

Descriptions

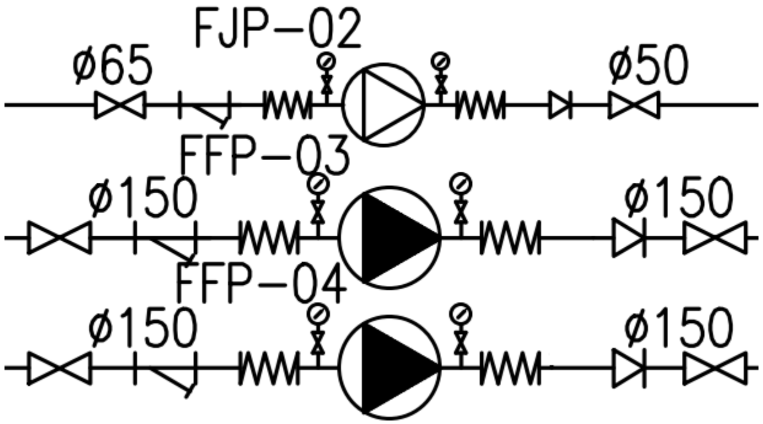


Sectional View

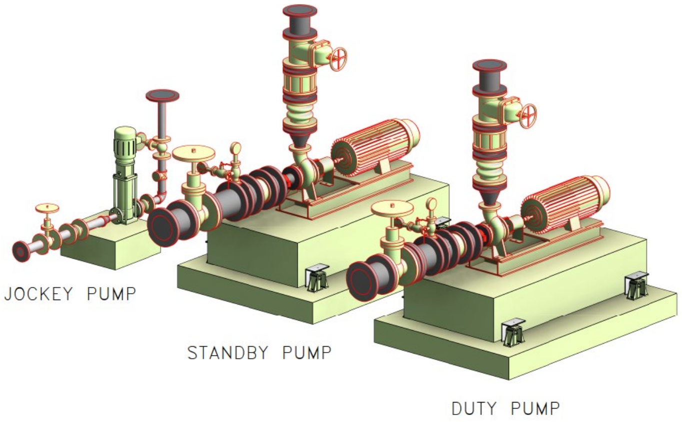
6.2 Template for Pump Skid

	
Schematic Diagram	**3D View**
	
Plan View	**Sectional View**

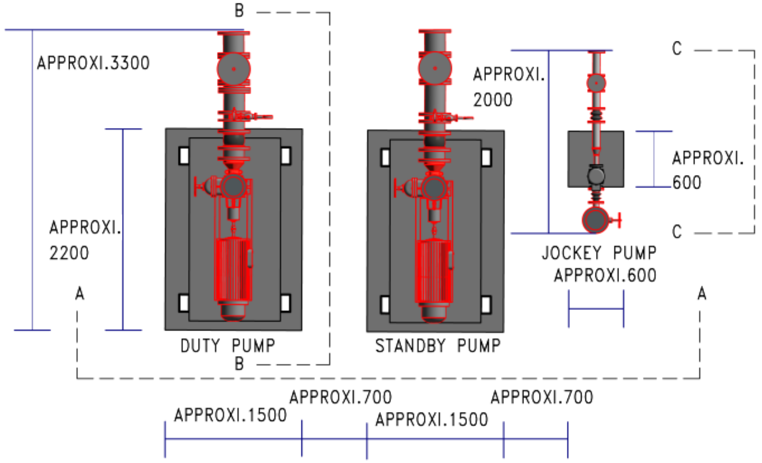
6.3 Template for Fire Service Pump



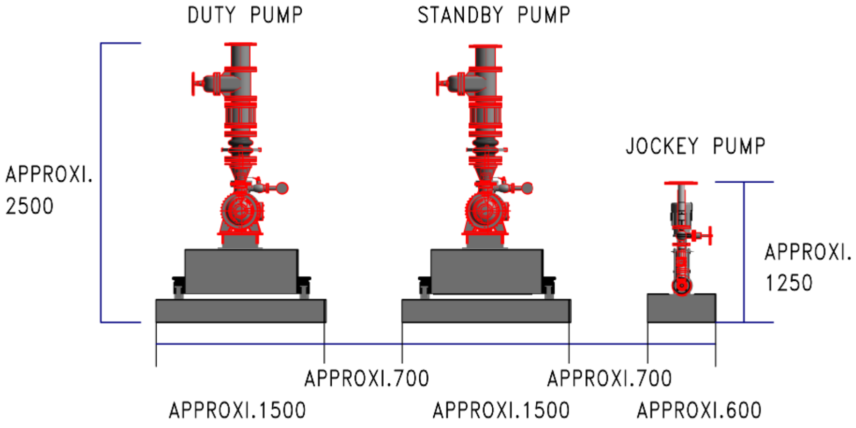
Schematic Diagram



3D View

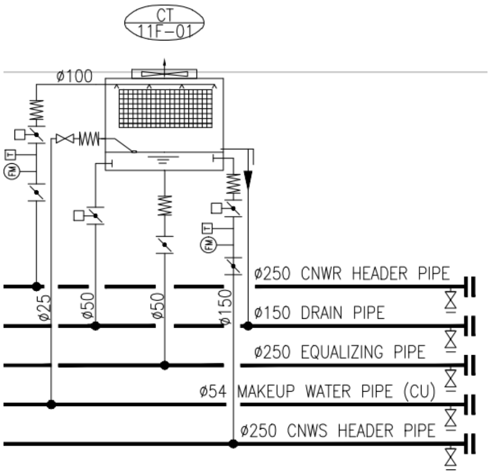
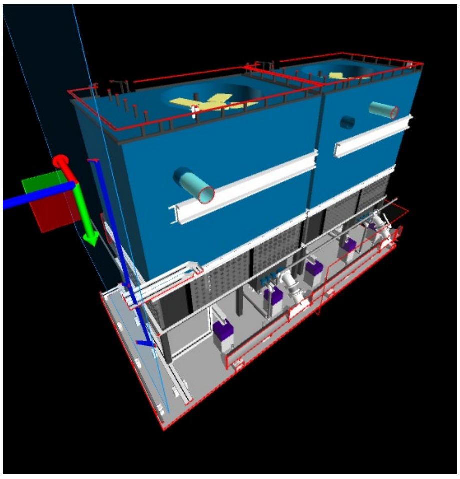
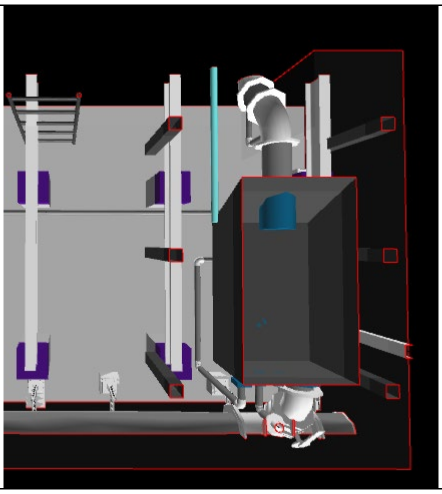
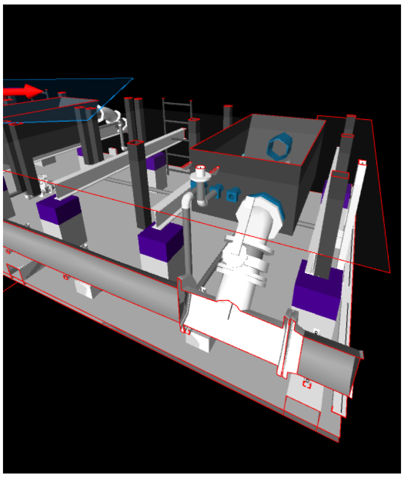
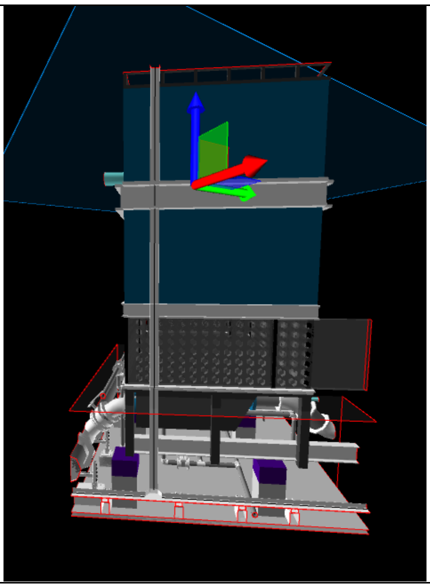
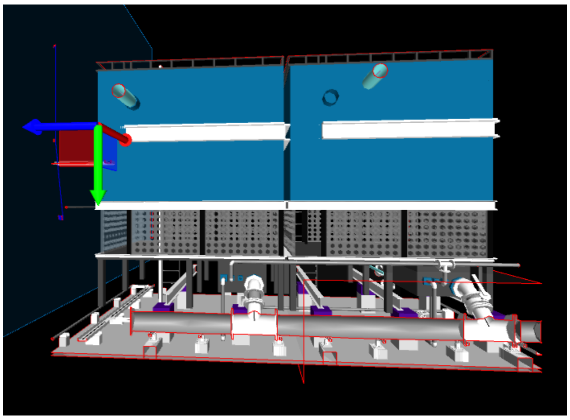


Plan View



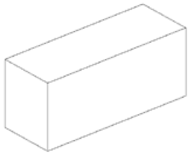
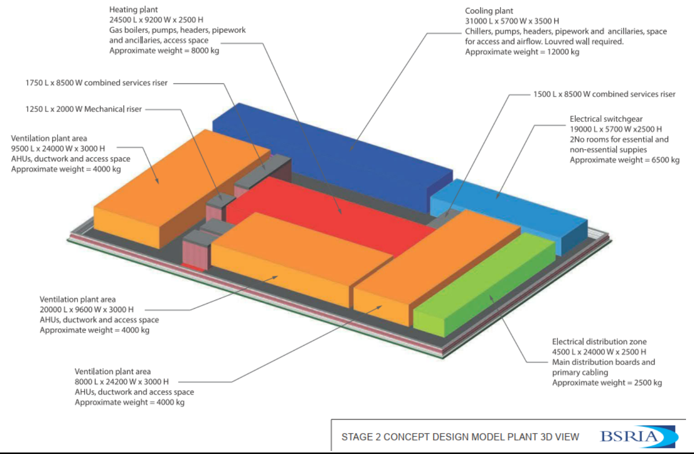
Sectional View

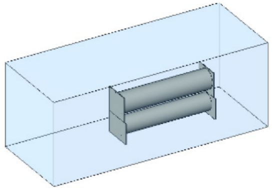
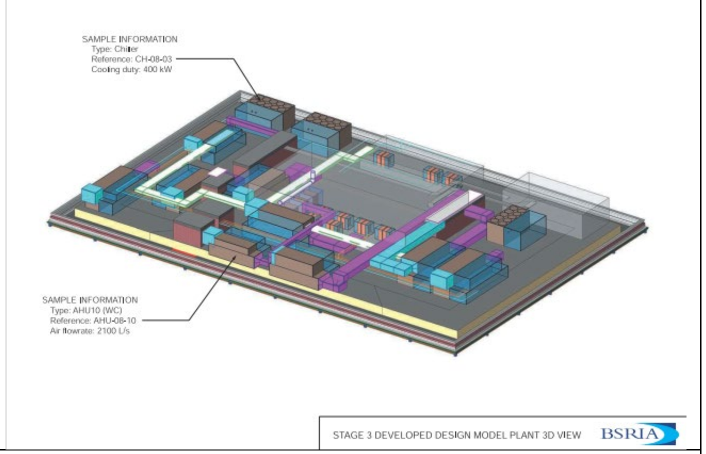
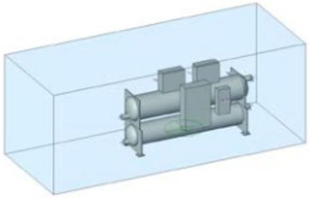
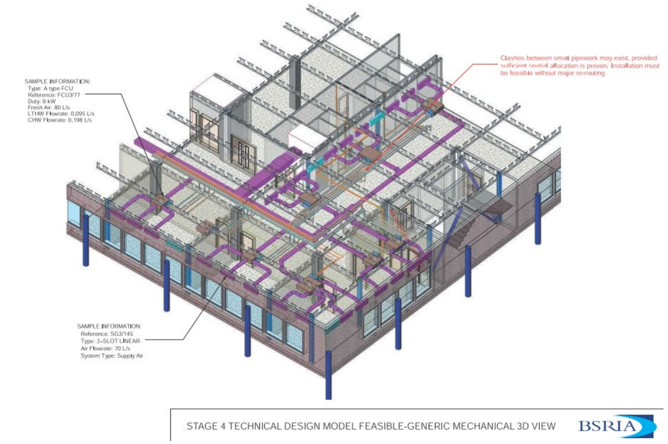
6.4 Template for Cooling Tower

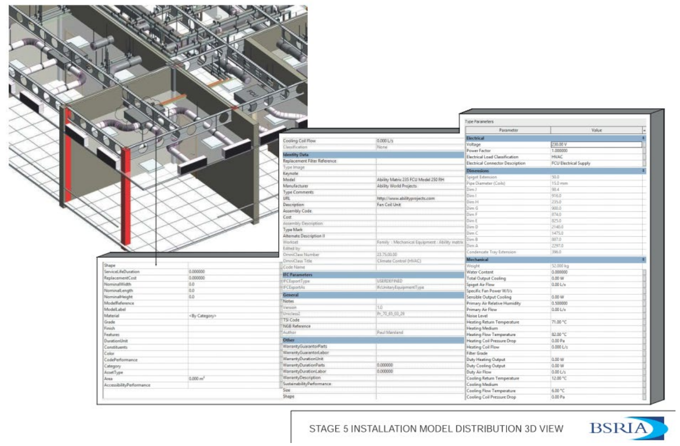
	
Schematic diagram	**3D View**
	
Plan View	**3D View 2**
	
Elevation	**Elevation 2**

6.5 Note on the Level of Development (LOD) Specified in the Publications by the Construction Industry Council (CIC) and BSRIA

While local practitioners may refer to BSRIA's BG 6/ 2018 for a framework for allocation of duties including BIM practices, they should consider local practices such as CIC BIM standards. Using current work stages in public projects as a starting point, the table below intends to give the practitioners a general view on what has been done outside Hong Kong with very similar practices, such that progressive refinement can be achieved.

CIC Building Information Modelling Standards Mechanical, Electrical and Plumbing (August 2019) (Chiller (HVAC equipment) referred as an example)				**BSRIA BG 6/ 2018 A Design Framework for Building Services (5th edition)**	
LOD-Graphics	Requirements		Sample Images	RIBA Work Stages (Note 1)	Sample Images showing Comparable Level of Detail
100	- Conceptual, schematic element or symbol	Overall shape		Stage 2 Concept Design (Work Stage 2 Outline Proposals & Sketch Plans)	

CIC Building Information Modelling Standards Mechanical, Electrical and Plumbing (August 2019) (Chiller (HVAC equipment) referred as an example)				**BSRIA BG 6/ 2018 A Design Framework for Building Services (5th edition)**	
LOD-Graphics	Requirements		Sample Images	RIBA Work Stages (Note 1)	Sample Images showing Comparable Level of Detail
200	- Generic element - Nominal size, dimensions	Overall shape, space for access & maintenance		Stage 3 Developed Design/ Spatial Coordination (Work Stage 3 Detail Design)	
300	- Specific elements - Actual size, dimensions & orientation - Proposed location	Chilled water inlet / outlet, condense water inlet / outlet, anti-vibration footing, power provision, compressor, evaporator, space for access & maintenance		Stage 4 Technical Design (Work Stage 4 Documentation/ Tendering)	

CIC Building Information Modelling Standards Mechanical, Electrical and Plumbing (August 2019) (Chiller (HVAC equipment) referred as an example)				**BSRIA BG 6/ 2018 A Design Framework for Building Services (5th edition)**	
LOD-Graphics	Requirements		Sample Images	RIBA Work Stages (Note 1)	Sample Images showing Comparable Level of Detail
400	- Specific elements - Actual dimensions & orientation - Sufficient detail & accuracy for fabrication - Follow product catalogue for graphical detail	Chilled water inlet / outlet, condense water inlet / outlet, anti-vibration footing, power provision, compressor, evaporator, space for access & maintenance, sufficient graphical details for fabrication		Stage 5 Construction/ Manufacturing and Construction (Work Stage 5 Construction Supervision)	

Note 1 Comparable Work Stages in Public Projects in Hong Kong are shown in brackets.

Appendix 7 Typical Specifications for MiMEP (Courtesy of the ArchSD)

A sample of typical specifications for MiMEP are given below for the practitioners who wish to adopt MiMEP in their own projects.

TYPICAL SPECIFICATIONS

FOR

MULTI-TRADE INTEGRATED MECHANICAL, ELECTRICAL & PLUMBING (MiMEP)

FOR

[CONTRACT NAME]

(CONTRACT NO. XXX)

Typical Specifications for
Multi-trade Integrated Mechanical, Electrical and Plumbing (MiMEP)

1. Scope of Works

1.1 The Contractor shall design, assemble, install and test the building services components / installations preinstalled at off-site factory as an integral part of * Multi-trade Integrated Mechanical, Electrical and Plumbing (MiMEP) modules as specified in the Contract.

1.2 Multi-trade Integrated Mechanical, Electrical and Plumbing (MiMEP)

The following building services systems shall be modularised off-site for on-site assembly and installation:

- * Chilled water plant pipework system;
- * Cooling tower and condensing water pipework system;
- * Air-handling unit /Pre-treated air-handling unit plant;
- * Water pump set module;
- * Electrical services in Electrical and/or Extra Low Voltage Switch Rooms;
- * Panelised electrical module;
- * Hose reel cabinet module;
- * Sprinkler control valve set module; and
- * Sprinkler subsidiary stop valve set module.
- * Ceiling building services module;
- * Building services riser module;

[* please delete if not applicable]

1.3 The Contractor shall submit plan to define the detailed scope of building services components and related domestic products for installation by MiMEP process for the approval by the Supervising Officer before fabrication. The information and details to be submitted under the plan should include, but not limited to, the following:

(a) The scope of the installation /system(s) being constructed under MiMEP process respectively;

(b) The detailed demarcation of the building services components of the MiMEP modules shall be illustrated in coloured drawing plans or/and Building Information Modelling (BIM) models to demarcate whether the works to be fabricated/assembled/installed in:

a) the off-site factory;
b) the off-site prefabrication yard; or
c) in-situ.

(c) Construction details of the building services installation to be integrated as a part of the MiMEP modules, in particular the interfacing details with in-situ installation;

(d) Maintenance facilities and access after the MiMEP modules are put in place on site;

(e) Method statement of the assembly work covering from the fabrication work process inside MiMEP factory to on-site installation, including precautionary site survey check of in-situ installation for interfacing with MiMEP modules, services duct / pipework alignment tweak, etc.;

(f) testing and commissioning procedure to be conducted at factory;

(g) Factory production time schedule for MiMEP modules and the associated inspection schedule;

(h) Temporary protective measures for building services installation of MiMEP modules in the course of transportation for delivery to the Site;

(i) Delivery and logistic proposal, such as marine, air or land access;

(j) The estimated quantities of various building services components assembled under the MiMEP process respectively against the overall building services installation, including proportion of areas for individual installation/system, estimated cost and area incurred;

(k) The supply sources of the building services components for assembly and installation in the MiMEP modules outside Hong Kong;

(l) Where prescribed product is involved to be pre-installed off-site outside Hong Kong, the supply sources of the prescribed products under the Energy Efficiency (Labelling of Products) Ordinance, Cap.598. for installation in the MiMEP modules; and

(m) The quality assurance certification scheme covering the building services installation and the associated certificate(s) for the MiMEP factory.

(n) The Contractor shall stocktake and summarize the as-built quantities of various building services components assembled under the MiMEP process against the overall building services installation, including proportion of areas for individual installation/system, the estimated cost per unit area incurred. The updated figures shall be provided upon request and the final figures shall be provided within 6 months after the certified completion of the Contract.

2. Statutory Requirements and Guidelines

MiMEP shall comply with but not limited to the following statutory requirements and guidelines:

(a) Statutory requirements as specified in the General Specifications for building services installations;

(b) FSD Circular Letter No. 3/2019 Guidance Notes on Submission, Approval and Acceptance Inspection of Fire Service Installations and Equipment in Modular Integrated Construction Building Projects issued by the Fire Services Department (FSD);

(c) Circular Letter No. 2/2019 Procedures for Applications for Water Supply in New Building Projects adopting "Modular Integrated Construction" Method issued by the Water Supplies Department (WSD);

(d) Practice Note for Authorized Persons, Registered Structure Engineers and Registered Geotechnical Engineers (PNAP) ADV-36 on Modular Integrated Construction issued by the Buildings Department (BD);

(e) Guidance Note on Fixed Electrical Installations with Modular Integrated Construction Method issued by the Electrical and Mechanical Services Department;

(f) Guidance Note on Household Electrical Products with Modular Integrated Construction Method issued by the Electrical and Mechanical Services Department (EMSD);

(g) Guidance Note on Gas Supply Installations issued by the Electrical and Mechanical Services Department (EMSD);

(h) Guidance Note on Supply of Energy Label Prescribed Products at MiC Projects issued by the Electrical and Mechanical Services Department (EMSD);

(i) Guidelines on the Statutory Requirements for Modular Integrated Construction Projects issued by the Construction Industry Council (CIC);

(j) Road Traffic (Traffic Control) Regulations;

(k) Guidelines on Application of Construction Noise Permit for using Modular Integrated Construction (MiC) Method" by the Environmental Protection Department (EPD);

(l) Code of Practice for the Structural Use of Steel issued by Buildings Department (BD); and

(m) Any other statutory requirements and guidelines in relating to the MiC construction method.

3. Design Requirements

3.1 The Contractor shall design the individual MiMEP module including the corresponding construction details for submission to the Supervising Officer for approval. The design details should include, but not limited to, the following information:

(a) The use of materials, equipment, configurations, routings and positions of covered up and exposed multi-trades building services installations and the associated integrated supporting frame /hanger system;

(b) The methodology, preparation work and process for the fixing, jointing and assembly of the installations and associated integrated supporting frame /hanger system on site;

(c) Due consideration on the provision of site facilities including sufficient loading & unloading area, lifting, access route, module dimensions and weight, and plant room space to facilitate the adoption of MiMEP;

(d) The plinth, footing and fixing details to the designated pedestals of the building structure;

(e) Provisions of anti-vibration accessories and calculation;

(f) The provision of access points, inspection pits or accessible recesses to facilitate inspection and repair/replacement of building services connections, drainage pipes and joints; and

(g) The logistic and delivery methodology of the MiMEP modules to the final installation location on site.

3.2 The following considerations should be addressed for the design of MiMEP modules:

(a) Compliance to relevant statutory requirements;

(b) Building services installation layout and configuration should be well planned and coordinated in a fashion of an effective modular design to ease on-site installation with minimization of ductwork / pipework joints as far as practicable;

(c) Building services sectional modules should be standardized as far as practicable to maximize the benefits of MiMEP process;

(d) The configuration and geometry of building services components should be simplified to avoid complicated routing, excessive bends and joints;

(e) Tolerance of gradient and necessary extended short length of services for connections should be allowed between building services module sections at joints. Due consideration on different types of joint and flexible joints to facilitate the services connections between modules with allowance for services alignment;

(f) The volumetric size and geometry of individual modules should be optimized to suit the particular site environment for proper transportation, hoisting, delivery and assembly on site;

(g) Integrity and performance of building services installation should not be compromised due to connections and joints;

(h) Adequate access to the building services components for frequent inspection, operation and maintenance should be allowed after the assembly of units /modules;

(i) Integrated supporting frame / hanger system should be designed for composite fixing of multi-services trades within a MiMEP module. The steel frame / hanger shall be of robust and adjustable framing design featured with flexible fixing and bracketry facilities for mounting of different services duct / pipe in position. The flexible fixing facilities should be able to accommodate certain degree of services fixing adjustment in order to suit the alignment of module interfacing with on-site installation or among modules themselves;

(j) Metal framework and overall loading of modules imposed on building structure shall be submitted for approval by the Supervising Officer;

(k) Lifting lugs shall be incorporated in the design of the modules to facilitate transportation and delivery. The design of steel frame and hangers for the sole purpose of maintaining structural integrity during transportation and delivery should be able to taken down after the assembly module is put in place on site in order to allow more flexibility in access to maintenance;

(l) Reasonable loading capacity for the integrated supporting frame / rack should be allowed for the addition and alteration works for the building services components.

3.3 The Contractor shall use BIM technology to design, coordinate and demonstrate the proposed design of MiMEP modules meeting the specified requirements in the Contract. The quantities and details of the building services components should be able to read from the BIM model.

4. Delivery, Temporary Storage and Protection

4.1 The Contractor shall be responsible for the delivery, logistic, protection and temporary storage of the MiMEP modules from the off-site factory to the Site for assembly.

4.2 If physical size of the MiMEP modules exceeds that permitted under the Road Traffic (Traffic Control) Regulations, the Contractor shall liaise with the Transport Department and tunnel / bridge operators where required to submit the road transportation proposal for approval of the “Long Load” and “Wide Load” permit. The Contractor shall provide suitable escort vehicles as required by Regulations.

4.3 Adequate protection shall be provided to prevent damage to the pre-assembled modules during delivery and temporary storage. Building services components forming part of the modules shall be protected from the ingress of water and foreign matters as detailed in the General Specifications for various building services installations. Modules shall be covered with shrink wrap/protection sheet or equivalent means to the Supervising Officer’s satisfaction in order to protect them from exposure to weather and to prevent from damage prior to site assembly work.

4.4 Upon delivery of the modules to the Site, the Contractor shall arrange inspection with various parties. Any damaged parts or components shall be recorded and replaced before on-site assembly work, unless the damaged part is fully accessible for rectification or replacement after the module is put in place on site.

4.5 The Contractor shall demonstrate due consideration on provision of site facilities including sufficient loading and unloading area, hoisting facilities, access route, module dimensions and weight, and plant room space for delivery of the MiMEP.

5. Quality Control and Supervision

5.1 Production of assembly work shall be carried out under a quality assurance scheme with surveillance check and audit system under a 3rd party independent certification body.

5.2 The Contractor shall submit plan addressing the fabrication, assembly, installation, inspection, testing and commissioning of building services elements and domestic products for the MiMEP modules for the approval by the Supervising Officer. The information and details to be submitted should include, but not limited to, the following:

(a) The organization chart indicating the roles and responsibilities of various parties for the quality control and supervision;

(b) Inspection schedule of building services components at off-site factory, on-site and off-site prefabrication yard;

(c) Inspection, examination and acceptance process in accordance with the requirements in the *Site Supervision Plan (SSP) / *Quality Site Supervision Plan (QSSP) / *Inspection, Test and Approval Plan (ITAP); and

(d) The inspection recording mechanism for ready examination by the Supervising Officer.

5.3 The Contractor shall allow the Independent Inspection Agent (IIA) engaged by the Employer for the regular access to the off-site factory/ off-site prefabrication yard, to carry out routine supervision and inspections of the MiMEP. The Contractor shall provide necessary temporary office accommodation in the factory to facilitate IIA to execute the inspection duties.

5.4 After the MiMEP modules delivered to the Site and before the on-site assembling process, the Contractor shall arrange necessary inspection and checking, especially if there is concern over possible deformation damage or the like during transit and difficulty in replacing /repairing the components after assembly on site. The Contractor shall also arrange joint inspection by relevant parties to monitor the on-site assembling process.

5.5 The Contractor shall verify on site regarding the provision of preparatory builder's works (e.g. wall/floor openings, surface for fixing of modules' frame, delivery route, provision for hoisting/lifting facilities, etc.) before the delivery of the MiMEP modules.

5.6 The Contractor should keep an inspection log book, including the identification of various parties responsible for conducting the quality assurance supervision, and details of the inspection, auditing and testing of the off-site installation works, and provide the log book for ready inspection when requested.

5.7 The Contractor shall keep both paper record and digital records (by adopting system such as Digital Works Supervision System (DWSS)), including photographs and videos during inspection and testing in off-site factory and on-site assembly process, for ready examination by the Supervising Officer, independent inspection authority (IIA) and the representatives of the statutory authorities.

5.8 Each MiMEP module shall be assigned with a unique code for identification in the design, fabrication and assembly process. Individual module shall be labelled for the identification. Details such as room name, floor level, circuitry numbers, etc. shall be included in the label to ensure all modules are properly positioned as designed. Radio-frequency identification (RFID) tags, QR codes or other equivalent identification methodology agreed with the Supervision Officer should be used to facilitate tracking of fabrication, delivery and installation of module to ensure traceability.

6. Particular Requirements of MiMEP

6.1 * Chilled Water Plant and Pipework System

6.1.1 The chilled water plant and pipework system shall be designed and constructed in sectional modules and assembled to form a complete system for the proper operation of the system. The sectional modules may cover composition of chiller units, pipe headers, straight pipes, bends, thermal insulation, cladding, valves, fittings, pump set module, associated electrical and control accessories, metering accessories, steel frame, hanger fixing, provision of vibration isolation accessories and maintenance platform where applicable.

6.1.2 The supporting framework of the modules shall be designed with adequate structural integrity to support the components of the modules, the loading of the circulating water, maintenance load and allowance for alteration and addition works. For modules accommodating chiller or other equipment, the supporting framework of the modules shall also further cater for the wind load imposed to the equipment for outdoor installations.

6.1.3 The design of chilled water pipework modules shall cater for situation that air-conditioning plant components could be isolated for servicing without complete drain-off of entire pipework of the chilled water plant. Isolating valves and drain valves shall be provided to modules as appropriate.

6.1.4 Mechanical coupling or flange, joint and fitting shall be used as far as practicable, and in compliance with the General Specification for Air-Conditioning, Refrigeration, Ventilation and Central Monitoring & Control System Clause B9.8.5. All mechanical grooved couplings, grooved fittings, grooved valves, lubricant for coupling installation and specialties shall be the products of a single manufacturer. Grooving tools shall be of the same manufacturer as the grooved components.

6.1.5 Welding of pipework shall be minimized as far as practicable on site unless prior approval by the Supervising Officer.

6.1.6 The module support framework shall be constructed of welded or bolted galvanized steel sections. The footing design of the module shall be suitable for on-site fixing with anchor bolts to the designated pedestals in the building structure. The framework shall be marked with alignment reference for easy checking of the alignment with adjacent modules.

6.1.7 The Contractor shall allow provisions for fine movement of the module in adjustment to the correct horizontal and vertical alignments with adjacent module(s). The anti-vibration mounting for air-cooled chiller unit(s) shall be designed for the rotating frequency of the chiller fan and also for the lateral movement due to wind acting on the chiller.

6.2 * Cooling tower and condensing water pipework system

6.2.1 The cooling tower and condensing water pipework system shall be designed and constructed in sectional modules and assembled to form a complete system for the proper operation of the condensing water system. The sectional modules may cover composition of cooling tower units, pipe headers, straight pipes, bends, cladding, valves, fittings, pump set modules, associated electrical and control accessories, metering accessories, steel frame, hanger fixing, provision of vibration isolation accessories and maintenance platform where applicable.

6.2.2 The supporting framework of the modules shall be designed with adequate structural integrity to support the components of the modules, the loading of the circulating water, maintenance load and allowance for alteration and addition works. For modules accommodating cooling tower or other equipment, the supporting framework of the modules shall also further cater for the wind load imposed to the equipment.

6.2.3 The design of cooling tower and condensing water pipework modules shall cater for situation that cooling tower system could be isolated for servicing without complete drain-off of entire pipework of the condensing water system. Isolating valves and drain valves shall be provided to modules as appropriate.

6.2.4 Mechanical coupling or flange, joint and fitting shall be used as far as practicable, and in compliance with ACGS B9.8.5. All mechanical grooved couplings, grooved fittings, grooved valves, lubricant for coupling installation and specialties shall be the products of a single manufacturer. Grooving tools shall be of the same manufacturer as the grooved components.

6.2.5 Welding of pipework shall be minimized as far as practicable on site unless prior approval by the Supervising Officer.

6.2.6 The module support framework shall be constructed of welded or bolted galvanized steel sections. The footing design of the module shall be suitable for on-site fixing with anchor bolts to the designated pedestals in the building structure. The framework shall be marked with alignment reference for easy checking of the alignment with adjacent modules.

6.2.7 The Contractor shall allow provisions for fine movement of the module in adjustment to the correct horizontal and vertical alignments with adjacent module(s). The anti-vibration mounting for cooling tower(s) shall be designed for the rotating frequency of the cooling tower fan and also for the lateral movement due to wind acting on the cooling tower.

6.3 * Air-handling Unit (AHU) /Pre-treated Air-handling Unit (PAU) plant

6.3.1 The AHU /PAU plant shall be designed and constructed in sectional modules and assembled to form a complete installation for connection to the chilled / hot water distribution pipework and air conditioning ductwork in the plant room(s). The sectional modules shall covers integrated AHU/PAU, chilled water /hot water pipework, cladding, valves, fittings, associated electrical and control accessories, metering accessories, steel frame, hanger fixing, provision of vibration isolation accessories and maintenance platform where applicable.

6.3.2 Integrated AHU /PAU shall be a packaged unit pre-fabricated with the electrical motor control panels, direct digital control (DDC) panels, control system, isolating valves, electrical and water pipe terminals for connections, associated control and metering accessories, and supporting base frame /hanging frame /lifting lugs to form a complete unit for transportation, delivery and services connection on site. The framework of the integrated AHU/PAU shall be constructed with corrosion resistant material of inherent strength for mounting the specified components as a whole package. Tampered glass viewing panel(s) shall be provided at the outer framework for inspection of the major internal components of the integrated AHU/PAU.

6.3.3 The control system of the integrated AHU/PAU shall be pre-assembled and tested in the off-site factory to ensure proper wiring connection and installation.

6.4 * Water Pump Set Module

6.4.1 The individual water pump set module shall be designed and constructed as a self-contained packaged unit comprises of pump, motor, header pipes, sectional pipework, valves, fittings, thermal insulation, cladding, power supply connection to the pump motor from the motor control panel, control and metering accessories, skid plate and the mounting framework as appropriate.

6.4.2 The concrete inertia block, or floating plinth for pump skid, and anti-vibration provisions should be integrated into the water pump set module as far as practicable subject to the consideration of volume, weight, transportation and delivery of the modules.

6.4.3 The skid base shall be constructed of epoxy coated carbon steel or galvanized steel. Locking of the skid base to the concrete inertia block shall be by locking bolts embedded in the inertia block and passing through holes accurately pre-drilled in the skid base.

6.4.4 The skid base shall be fixed with necessary framework of the same construction material for the suitable mounting/support of piping, electrical and piping accessories etc. Footings of framework supporting pipework sections downstream of the anti-vibration flexible connectors shall be designed for direct mounting onto the floor slab of the pump room to avoid vibration transmission from the running pump(s) to downstream pipework.

6.4.5 Suitable mechanical or flange joints shall be allowed for the interface connections between the pump set module and the in-situ water pipes at the plant room. Other pipe joint arrangement can be proposed for the approval by the Supervising Officer.

6.4.6 Centralized dashboard shall be designed and provided to accommodate the meter displays, pressure switches or monitoring devices of metering

/sensing devices /probe for easy housekeeping and maintenance. The metering or sensing elements mounted in the pipework shall be wired back to the corresponding devices in the dashboard. Identification tags shall be provided to clearly indicate each device mounted in the dashboard.

6.5 * Electrical Services in Electrical and/or Extra Low Voltage (ELV) Switch Rooms

6.5.1 The electrical services in Electrical and/or Extra Low Voltage (ELV) Switch Rooms comprising MCCB/MCB distribution boards, electrical /ELV panels, metering devices, cable containments, connection boxes and other accessories shall be installed on purposely-built bracketry framework(s) to form standalone module(s) for assembly on site.

6.5.2 Electrical cabling works of a completed circuit /sub-circuit within the individual module(s) shall be pre-installed off-site. Interconnection of cables between the MiMEP module(s) and other electrical installation shall be conducted on-site. Joint of cables, if unavoidable, shall ensure the complete continuity with acceptable connection methodology. Pre-installed electrical wirings shall be neatly grouped and terminated in cable terminals for easy identification.

6.6 * Modular Electrical Wiring System

6.6.1 The Contractor shall submit schematic and layout drawings showing circuitry numbers, cable size, connection coupler locations, mounting heights of components etc. to Supervising Officer for agreement prior to material ordering and installation.

6.6.2 The size and length of modular cables and connection components should be well selected based on the technical calculations and on-site coordination. If damage of cable and connection components was found during on-site installation, the materials should be replaced at Contractor’s own cost. On-site rectification works to the damaged modular cable services shall not be allowed.

6.6.3 The Contractor shall follow the installation instructions of the cable connector during on-site installation. The Contractor shall be responsible to check and inspect if the cable connectors are firmly and properly connected.

6.6.4 The cables should be accommodated in cable containment, i.e. cable trays or trunking. The Contractor may consider using proprietary fixings to anchor cables to building structure if there is site constraint. The locations and fixing method shall be approved by Supervising Officer prior to installation.

6.7 * Hose Reel Cabinet Module

6.7.1 The module(s) shall be designed and constructed with one or two chamber(s) as required by the design and approved by the Supervising Officer.

6.7.2 For module with two chambers, the top chamber shall house the hose reel, hose reel guide, pipework, manual call point, alarm bell, visual fire alarm, monitor and control modules, power supply /control cables of completed circuit within module, cable containments, emergency luminaire and operation instruction as required by design. The bottom chamber shall be designed to store two sand buckets and one portable fire extinguisher. Each chamber shall be provided with hinge door completed with magnetic door catches and pull handle.

6.7.3 For exposed type hose reel module, extended framework above the top chamber may be used for mounting of visual alarm unit and emergency luminaire subject to the approval of the Supervising Officer.

6.7.4 Where alarm bells are mounted inside the module, small holes shall be allowed at suitable location of the cabinet to ensure that a minimum sound level of 80 dB(A) at 3 m from the cabinet can be attained when the alarm bell is in operation.

6.7.5 The module shall be constructed of welded galvanized steel framework with cover plates fixed properly on the framework. Openings for connection of pipework and cables shall be provided.

6.7.6 The design layout and arrangement of all components inside the cabinet shall be approved by the Supervising Officer before commencement of off-site fabrication work.

6.8 * Sprinkler Control Valve Set Module

6.8.1 The module shall comprise the completed sprinkler control valve set, cable containment, monitoring and control devices, wirings of completed circuits within the module, identification plates, tagging, earth bonding, associated components and steel framework for direct mounting to the building structure.

6.8.2 All pipework, components and devices shall be assembled and properly fixed to the framework and completed with hangers, brackets, saddles, guide etc. Pipework supports shall be welded, screwed or bolted to the framework. The framework shall be designed with pre-drilled holes for onsite direct fixing to building structures. Provisions shall be allowed to facilitate the transportation, delivery, assembly and services connection on site.

6.8.3 Exposed framework and pipework shall be factory painted according to the painting finish specified by the Supervising Officer.

6.8.4 The framework shall be designed and constructed without any obstruction to operation and maintenance of all components and devices inside the module.

6.8.5 Riser-mounted air compressor and associated components shall be assembled and integrated in the module for dry pipe sprinkler system, pre-action and recycle sprinkler system.

6.9 * Sprinkler Subsidiary Stop Valve Set

6.9.1 The module shall be completed with pipework, subsidiary stop valve, flow alarm switch, gate valves, monitor modules, signal cables, earth bonding, associated accessories and steel framework as an integrated assembly.

6.9.2 Provisions shall be allowed to facilitate the transportation, delivery, assembly and services connection on site.

6.9.3 Exposed framework and pipework shall be factory painted according to the painting finish specified by the Supervising Officer.

6.9.4 The framework shall be designed and constructed without any obstruction to operation and maintenance of all components and devices inside the module.

6.10 * Ceiling Building Services Module

6.10.1 The ceiling building services module(s) shall be a pre-assembled unit comprising of steel framework, pipework, ductworks, cable containment and associated components as required by the design.

6.10.2 Jointing details, material /equipment and assembly methodology shall be submitted to the Supervising Officer for approval.

6.10.3 Individual module section should not pass through fire compartmentation wall unless appropriate fire rated connection unit is facilitated between services modules passing through the compartmentation wall.

6.10.4 Lifting lugs shall be provided to facilitate transportation and delivery. The Contractor shall remove the temporary support framework for the sole purpose of maintaining integrity during transportation and delivery on completion of the final assembly on-site so as to free up access space for future maintenance.

6.11 * Building Services Riser Module

6.11.1 Building services riser module(s) shall be a pre-assembled unit comprising of steel framework, pipework, ductworks, cable containment and associated components as required by the design

6.11.2 The building services riser module(s) shall be assembled and installed on-site prior to, and/or independent of, the erection of block walls of the riser shaft construction. Alternatively, the riser module may be delivered into the riser shaft through designated openings. As such, lifting lugs and bracketry shall be incorporated in the design of the modules.

6.11.3 Town gas / Liquefied Petroleum Gas pipe shall not be allowed in the riser module unless the statutory requirements under Regulation 17 of Cap. 51B and Regulation 17(5) of Cap.51C are fully complied with.