PLATFORM-BASED DfMA HOUSE

1) DfMA House Platform

The multidisciplinary consortium created a new platform for design and manufacture. A 'kit-of-parts' approach is used to develop DfMA house. To standardise and commodify the design and construction process, the DfMA house is broken down into pod units and panels units to enable feasible and efficient project delivery. Whilst meeting the Government's set targets and tackling the housing shortage at hand, DFMA also addresses the frustrating logistical challenges associated with restricted area and small space. The platform-based approach considered 3 aspects: (i) Design for Manufacture, (ii) Design for Assembly and (iii) Design for Life Cycle Performance

Platform descriptions

DfMA house shall accommodate a number of house types such as detached, semi-detached and terrace units, and is flexible enough to adopt different offsite systems and production methods. The following categorise the upper limits for platform-based design:

- Spanning capability up to 5m
- Loading capacity for transportation up to 10 tonnes
- Storey height up to 3m
- Building height up to 2 storeys
- Ability to accommodate various levels (3 standards – Gold, Silver and Bronze – are defined with various services provisions)
- Ability to accommodate various offsite systems: i.e. panelised, volumetric and a combination of both systems (Pod and panel system)
- Ability to accommodate open or close kitchen design
- Ability to accommodate semi-automated line production or automated production methods
  Flexible for changes in the facade appearance e.g. timber boarding, brick and rendering as well as sizes and positioning of openings for windows and doors

Kit-of-parts

The DfMA house platform consists of the following kit-of-parts:

Type	Kit-of parts
Carcass	Frame (panelised system), frame for Pods (volumetric system),
Components	Windows and external doors, façade system, stairs, fittings and fixture
Services systems	Hot and cold water, heating, solar and battery system, electricity system, telephone and TV distribution, lighting system, incoming data
Interfaces	Lift cleats, plug-and-play system for lighting, electricity and to fix the two pods

	together, pod system for windows and doors, cladding system
Sub-assemblies	Floor and wall panels, pods, roof

2) Design for Manufacture

Design for Manufacture is considered at 4 levels: (i) House; (ii) House Frame; (iii) Central Pod Units and (iv) Wall Panel Units.

DfMA House

Design Criteria	Design Solution
Economy of scope and scale - The house should aim to maximise all efficiencies from offsite prefabrication. To do this, the manufacture of the DfMA house should mainly compose of repeated units, with only a limited number of unique elements. The philosophy of standardisation should be strived at every level of manufacture from the frame to the whole house, to boost the overall efficiency and enable a high economy of scale. Flexibility – The DfMA house should be able to accommodate for different house typologies (2 bed, 3 bed) and house groupings (terrace, semi-detached, detached). This should be developed without making significant changes to the internal layout design or breaking any rules of the national space standards.	The DfMA house is designed to meet the requirements for two separate systems: panelised and volumetric systems. The panelised system for DfMA house is a 2-dimensional system that comprises of floor and wall panels for production in the factory. The factory-manufactured panels are then transported for onsite assembly to form part of the carcass of the DfMA house. The volumetric system for DfMA house is a 3-dimensional system that comprises of 6 pods with each comprising wall and floor panels, a pod frame, fittings, services installation, and potentially finishes (See Figure 1). The 6 pods design are not identical but similar with regards to having a central pod which incorporate kitchen and bathrooms, along with M&E equipment and distribution routes. The essence of the volumetric system is to maximise the production in a factory setting, so that only minor works are left to be carried out onsite. The design prototypes developed include 3 bedroom detached, semi-detached and terrace houses each comprising 6 pods. In the development of the design, a third option, i.e. the pod and panel system combining central pods and panels (floor and wall panels for the other parts of the building), has been developed to meet the need for more stringent site and/or transportation requirements yet maximise the offsite production potential. Figure 2 shows how the central pods and panels are

	combined to form the DfMA house (See detailed also Design for Assembly section). To accommodate the change in the number of bedrooms, the 3-bedroom house can be converted easily to a 2-bedroom house by simply removing a single partition wall and internal door, which is not an integrated structure of the relevant pod where 2 bedrooms are located (Figure 3).

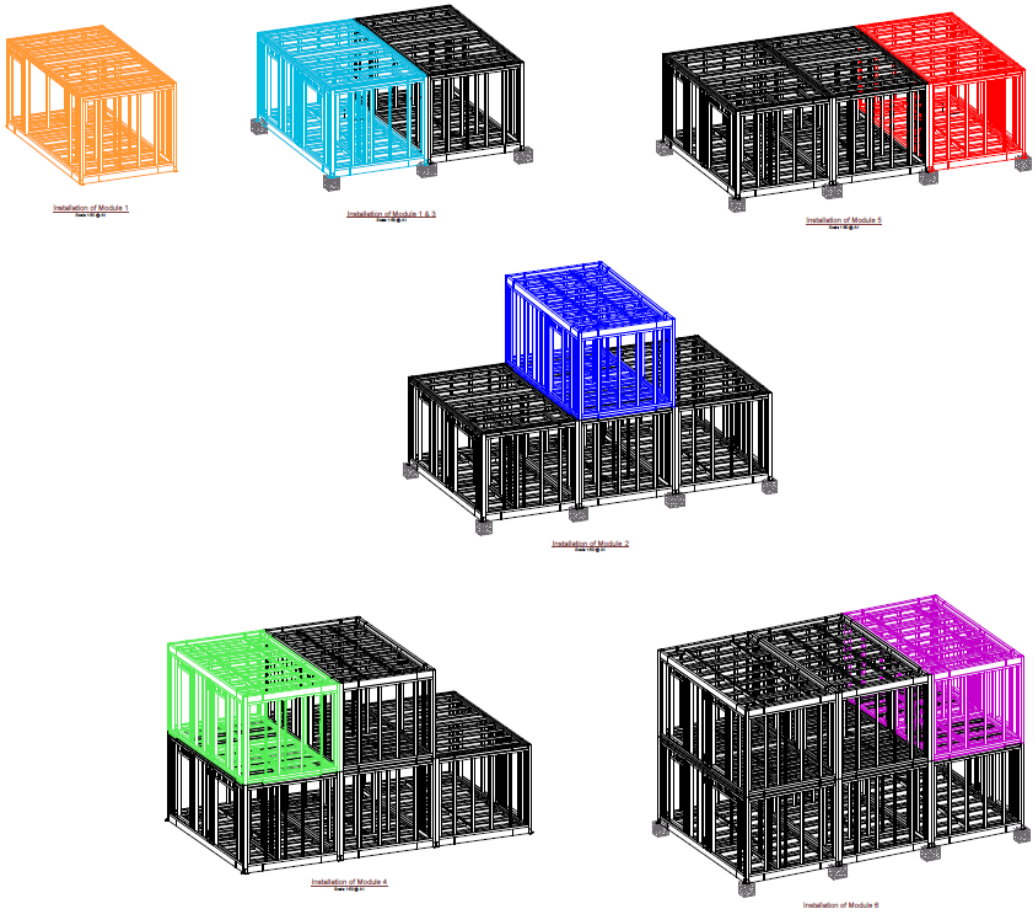

Figure 1: DfMA house built by volumetric method comprising 6 pods

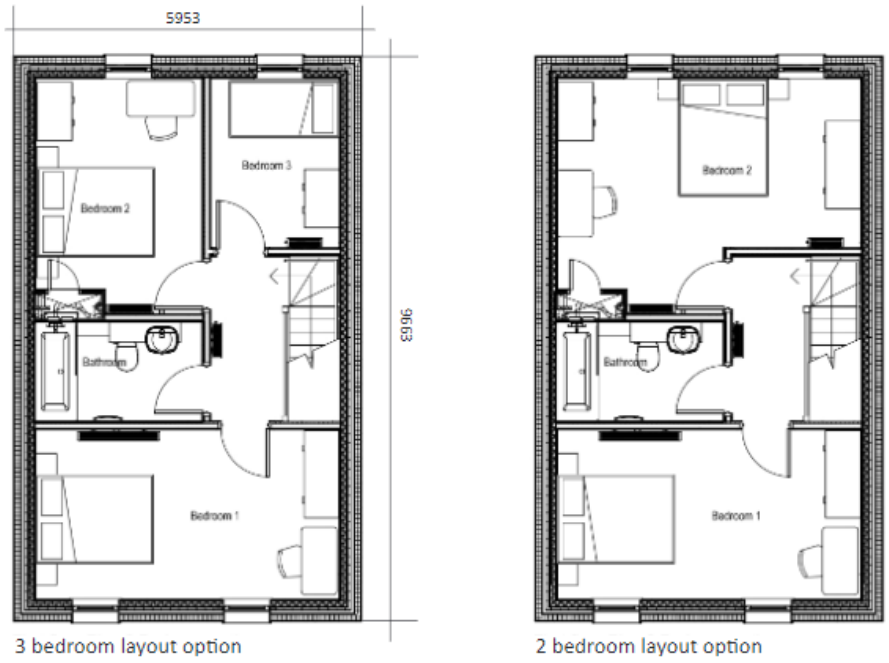

Figure 2: First Floor Layout Options

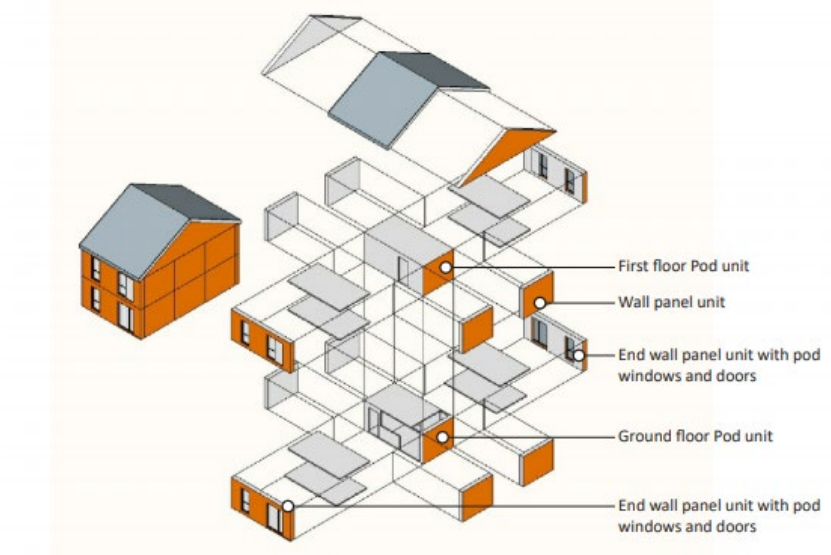

Figure 3: Exploded Axonometric of the pod and panel system

DfMA House Frame

Design Criteria	Design Solution
Standardisation - To allow standardisation, the type of frame design for the pod unit and panel units, should be kept to a minimum, and be	As a proposed solution, the panel frame is compatible to be installed as part of the pod unit for the volumetric system as well as the product for a panelised system. In

flexible to adopt both a volumetric and a panelised system. This will allow significant cost savings to be generated as component's are prefabricated in bulk, thus improving the lead time and boosting efficiencies. Number of profiles - The number of different steel profiles within the frame should be limited to simplify the supply flow and storage of raw materials. This will lead to better management of inventory and reduction in material waste generated. Loadbearing capacity – All frames should be designed to have the same load bearing capacity, so that they can be used across various projects (i.e. bungalow to a 10-storey low rise apartment, etc). Additionally, ensuring the weight is uniform will allow feasible distribution and storage of stock.	addition to meeting the structural requirements, the frame for the panel also incorporates studwork at appropriate centres to allow internal linings and external wall finishes to be fitted accordingly (See Figure 4). The material for the frame is constituted of lightweight cold rolled steel sections, as it has higher internal strength and durability. The cold rolled sections are delivered to the factory by truck in standard lengths and then stored in the factory grouped by profile size and weight for easy identification and picking. The steel members are cut precisely through a standard process to reduce excessive waste production and allow better storage management.

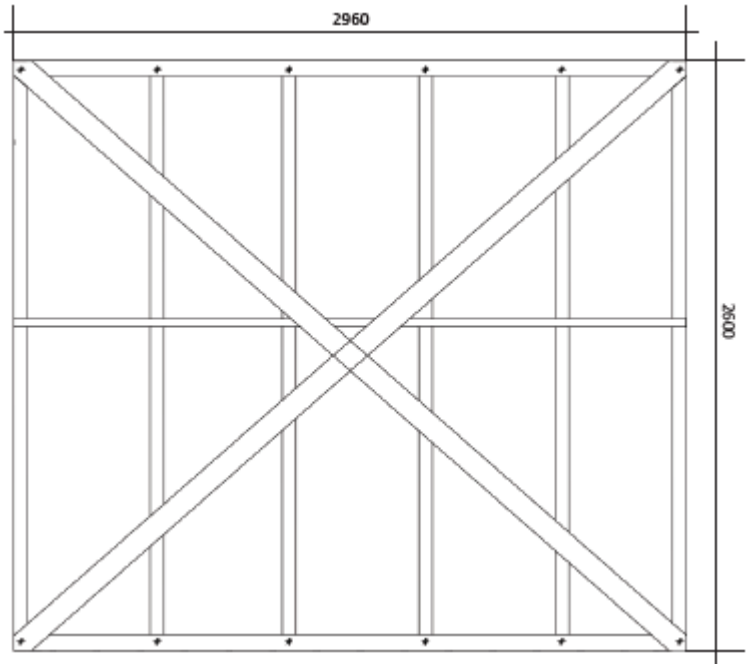

Figure 4: Wall Panel Unit Frame

DfMA House Central Pod Units

Design Criteria	Design Solution
Variation of choice - The central pod units should be designed to allow various selection of different fixed furniture options to be installed, without overengineering the installation process. Integration - The central pod units must integrate M&E systems and fixed furniture items (i.e. kitchens, bathroom furniture and final finishes) within factory conditions.	The central pod units are the heart of the volumetric system or the pod and panel system of the DfMA house, which are the core modules. They are built from the frames and then the M&E systems are installed, followed by fittings and white goods as listed in Table 1. The services systems, fittings and white goods will be fitted into the pod units before delivering to the site (Figure 5). While the pod layouts need to be the same, there are different fitting options in bathroom and kitchen suites for customisation including a choice of open or close kitchen. On arrival to the site, the installation and assembly process is relatively straight forward as the plug and play system for lighting and electricity integrated to the central pod units, which will only need to be connected to the mains supply. This will reduce the amount of work required on site and enhance quality assurance and control.

Table 1: Furniture fixtures into the pod units prior to site delivery

Level of Floor in the Pod Unit	Type of Room	Type of Fixed Fittings and White Goods
Ground Floor	Kitchen	Sink, Fridge, Freezer, Dishwasher
	Toilet	WC, Wash Hand Basin, Heated Towel Rack, Washing Machine
	Utility Cupboard	Boiler Cylinder, Fuse Box, Smart Meter
Second Floor	Bathroom	Bath, WC, Wash Hand Basin
All Pod Layout	All Rooms	Lighting, Mechanical Extract, Power Sockets, Radiators

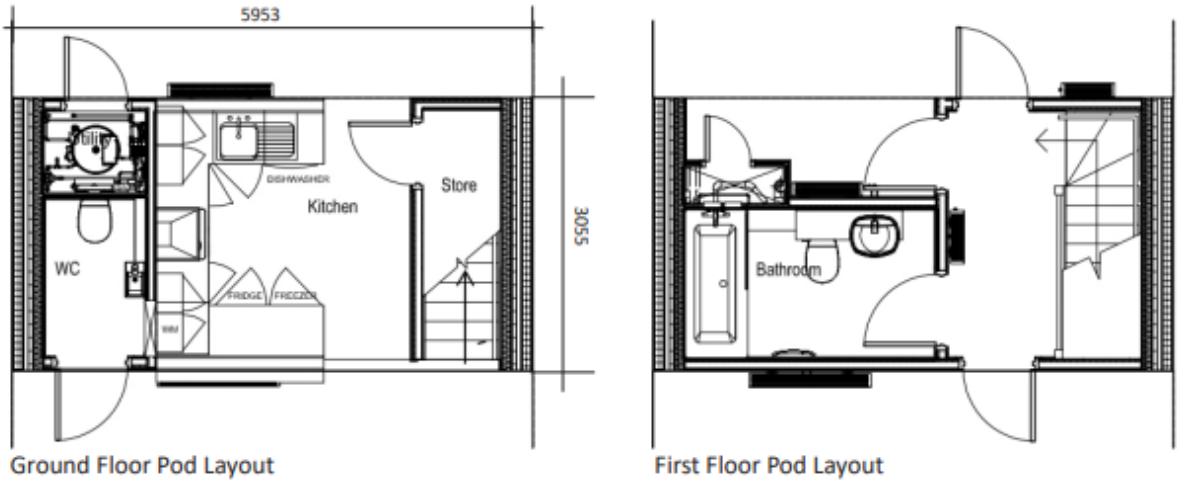

Figure 5: Central Pod Layout

DfMA House Wall Panel Units

Design Criteria	Design Solution
Meeting requirements - While the house is designed to be adopted for the house types of detached, semi-detached and terrace, and restricted by specific site layout, the DfMA house must be able to perform well, whilst complying to all legal requirements regardless of its location, orientation and arrangement. Furthermore, all panelled units (i.e. windows and doors) must be designed to meet all worst-case scenario requirements for climatic conditions. To ensure all requirements are met accurately, it is necessary to standardise components for a feasible manufacture process within factory settings. Utilising established methods – Besides prefabricating the panels, other standard methods of construction should be utilised to aid the assembling process. Storage - The panels should be manufactured to have high internal strength and robustness, so they can be stored safely off-site without	The living spaces of the DfMA house will be formed using panels prefabricated in the factory. There are 3 main categories of wall panels. A standard side panel is a blank wall with an interior lining to one side and an external wall built on the opposite side. 1. The front and back panels are similar to the standard panels but also include window pod units and door pod units with the panel. 2. The part-wall panel is specifically used in DfMA houses, which have a semi-detached or terraced house configuration. These wall panels only have an internal lining and insulation and no external wall on the opposite side. The wall panels have been designed to optimise the use of a single production line. All wall panel units are manufactured following the same production line comprising stations for frame assembly, cladding system installation and installation for windows and doors. On successful manufacture of the wall panel units, they should be stored safely within

compromising the quality, prior to delivery onsite.	the factory and be packaged securely to prevent the formation of any defects. These components must be stored in such a way that makes it easily identifiable and practical to load onto transportation for delivery onsite.

3) Design for Assembly

There are 3 key design considerations in association with the transportation of the manufactured units in the factory (i.e. wall panels and pods), storage and assembly onsite.

Design Criteria	Design Solution
Transportation – The design of the wall panel and central pod units should minimise delivery and logistical constraints during transportation.	The DfMA house adopts a kits-of-parts approach to construction. The choice of the offsite system would have an implication on transportation. The pod and panel system has been designed to reduce the transportation requirement. Not only is CO2 minimised, but this approach offers a hybrid solution of allowing ease of access to small and restricted construction sites. Prior transportation of the DfMA house, planning is carried out to enable safe and efficient delivery. All the components are protected to ensure that internal finishes and insulation are not damaged by weather prior to assembly. This is achieved by wrapping each wall panel and pod units with a thick gauge polythene sheet which is then taped and sealed. To deliver a detached DfMA house, five articulated lorries that uses a standard 13.2m by 2.55m size are required; where one lorry transports the ground floor and first floor pod together, the second lorry transports roof modules, and finally the remaining three lorries transports the floor and wall panel units. Transportation with lorries is kept to a minimum to ultimately reduce the carbon footprint and impact of global warming. The volumetric system will require 1 more trip of lorry travel, non-central unit pods require a trip per pod.
Site storage – Storage of wall panels and pod units onsite should be avoided to prevent damage to the components from poor weather conditions. If storage is required, components should be kept inside transport vehicles for a limited time.	The design of the DfMA house is practical for the assembling process onsite. A Just-in-time approach is adopted, whereby the DfMA house components is only dispatched when the site is prepared to assemble the units. This enables timely assembly immediately on arrival onsite, without

	compromising any land space or reduce the risk of damaging components prior to assembly.
Ease of Assembly - The wall panels and central pod units should be installed onsite with minimal effort and negative implications.	To assist with assembly, the wall panel units are supplied with lifting cleats, so they can be craned into position and fixed together using standard fixing details (Figure 6). Sacrificial panels are designed to have openings within the pods to maintain structural integrity during the lifting process both onto the truck for transportation and off the truck for assembly. The central pod unit comprises of all utility rooms (i.e. kitchen, WC and bathroom), including the staircase on the ground floor pod. The pod unit itself is split into two sections; the ground floor and the first floor, to allow ease of transport and onsite storage. Both sections are supplied with lifting cleats, so the ground floor section can be lifted onto a pre-prepared foundation, followed by the first floor section and then bolted together to create the DfMA house. The pod unit contains rooms heavily M&E dependent with fixed fittings, which are manufactured in factory settings for the volumetric or the pod and panel system. Any rooms without fixed fittings are constructed onsite using wall panel units and transported in greater quantities. To ensure a feasible onsite installation process, all building services are accessible through the floor of the utility cupboard. This allows all preinstalled pipework and electrical services between the two sections to be connected. Furthermore, pipe coils are unrolled onsite to allow secure connection of further services such as power wiring, controls, ductwork and drainage. Overall, ere is careful coordination and consideration to the design of the unit pods to aid the onsite installation process.

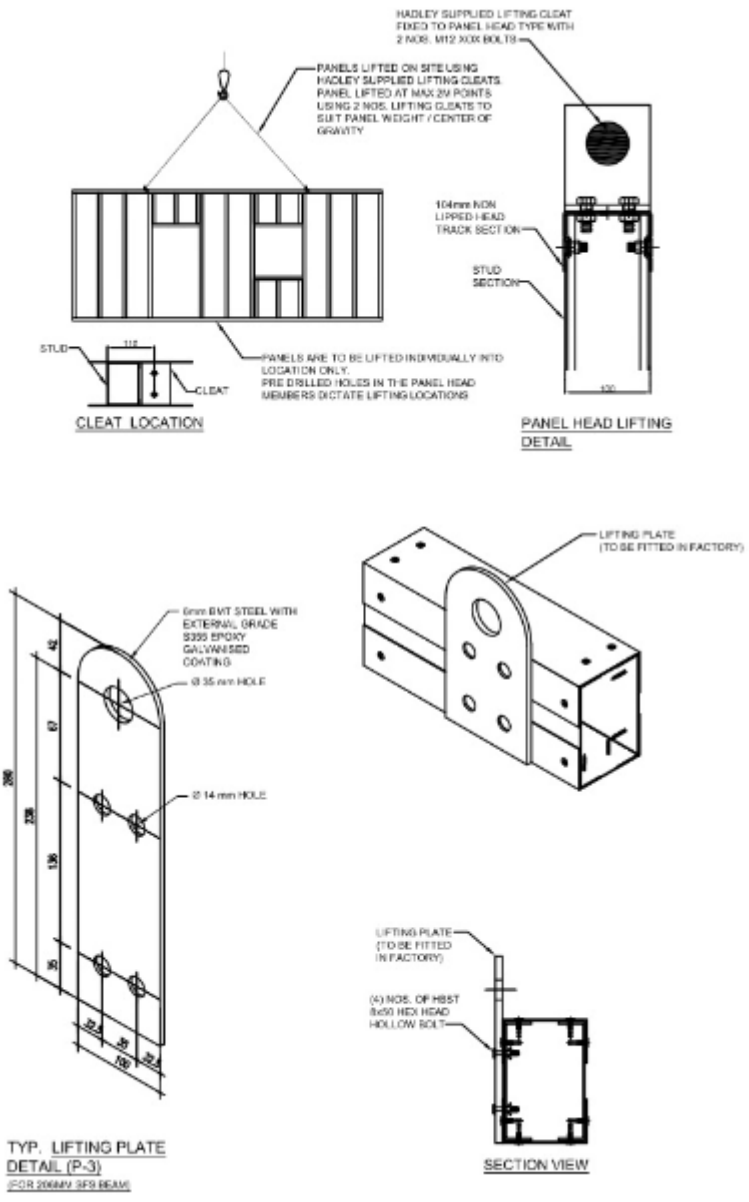

Figure 6: Lifting Cleats Detail

4) Design for high performance and low impact

Design Criteria	Design Solution
• Renewable adoption - The DfMA house should be designed in a holistic manner to ensure that it is low impact and high performing in terms of reducing fuel poverty and energy consumption. This should be achieved through the utilisation of active technologies, renewable resources, and compliance to the Building Regulations and NHBC standards in the design phase, whilst also considering ease of maintenance.	The BIM models developed were shared to enable design issues to be highlighted on the proposed house design. This has allowed for an iterative design to take place as test data can be fed back into the design and solutions formed accordingly to mitigate any issues. To ensure high energy efficiency across the iterative design process, the target U-values (rate of heat loss through an element of a building such as walls, doors and windows etc.) are lower than Notional Dwelling Specification provided in Approved Document L1A. Energy System Catapult have designed a Home Energy Dynamics model to review U-values and insulation thickness required to achieve targeted U-values. This modelling has enabled a continuous iterative design process to take place as different systems can be tested theoretically and design decisions revised as the project progresses. Renewable sources and active technologies have been utilised to optimise sustainability and minimise operational costs during the in-use phase. Photovoltaic panels and air source heat pumps are predominantly chosen to achieve cost-effective reductions in building running costs. DfMA house is expected to have high air tightness and meet targeted insulation levels, to form ideal conditions for an air source heat pump to run efficiently. Moreover, active technologies have been deployed to prevent overheating. This includes incorporating automatic blinds, pre-programmed to open and close at certain times of the day to reduce internal heat gains. DfMA also contains a remote monitoring system and lighting systems, all connected to a central router within the home and then transferred to a cloud

	space for access. Once the prototype is fully complete and validated, the heating and energy usage is monitored to provide insight of the home's energy performance overtime.
• Target U-values for building elements - The DfMA house should comprise of building elements stated in Notional Dwelling Specification as set out in Approved Document L1A Conservation of fuel and power.	To ensure high energy efficiency across the iterative design process, the target U-values (rate of heat loss through an element of a building such as walls, doors and windows etc.) are lower than Notional Dwelling Specification provided in Approved Document L1A. Energy System Catapult have designed a Home Energy Dynamics model to review U-values and insulation thickness required to achieve targeted U-values. This modelling has enabled a continuous iterative design process to take place as different systems can be tested theoretically and design decisions revised as the project progresses