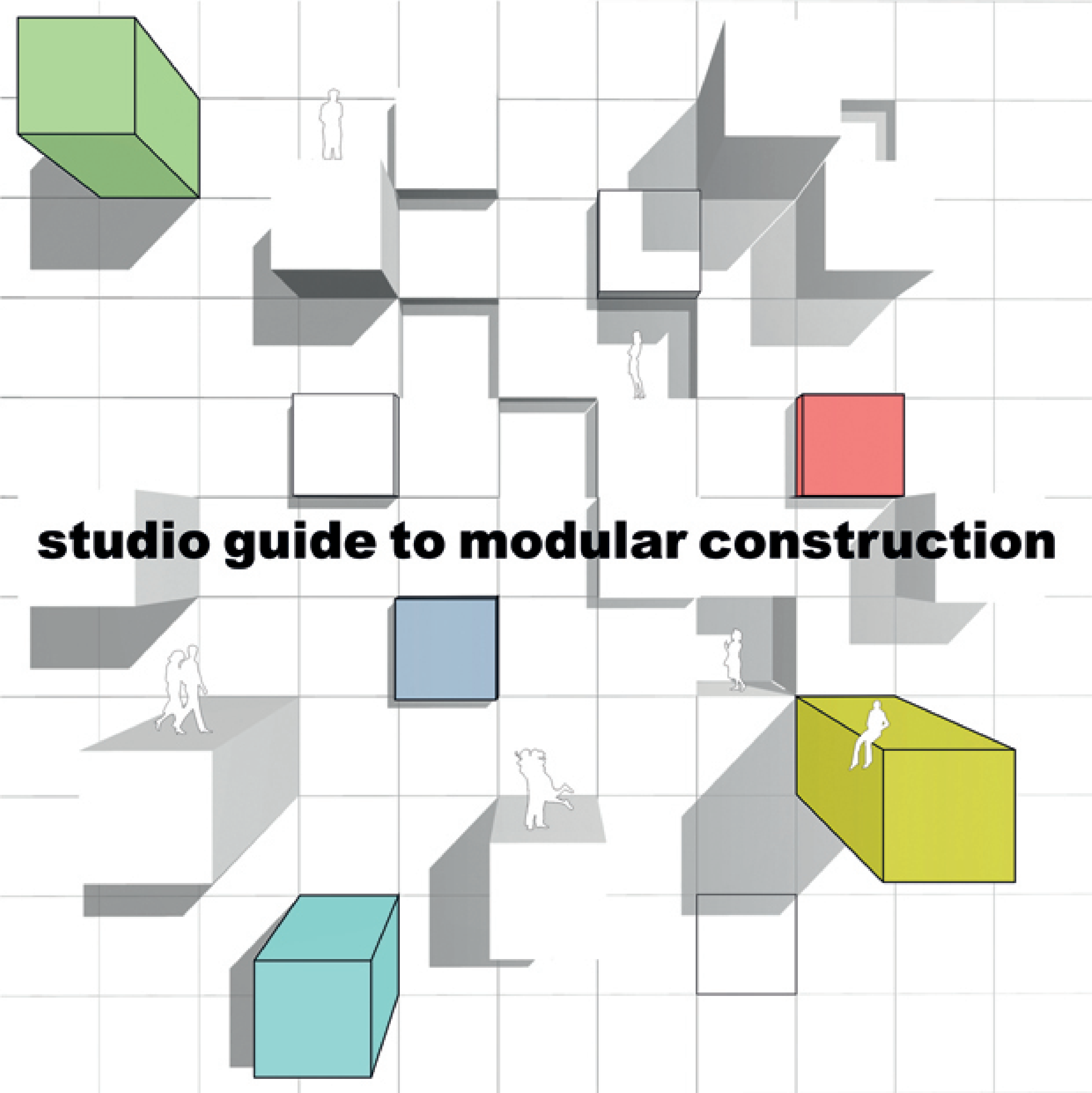
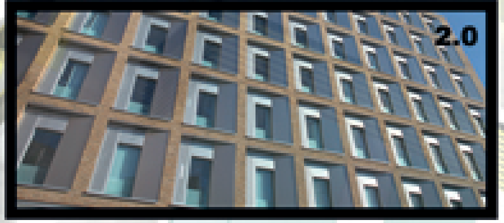
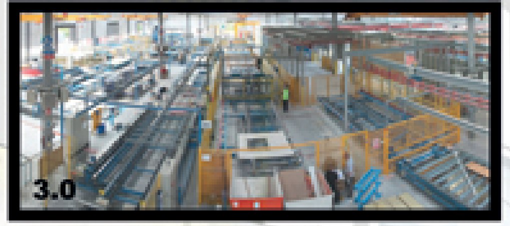
studio guide to modular construction







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0.0

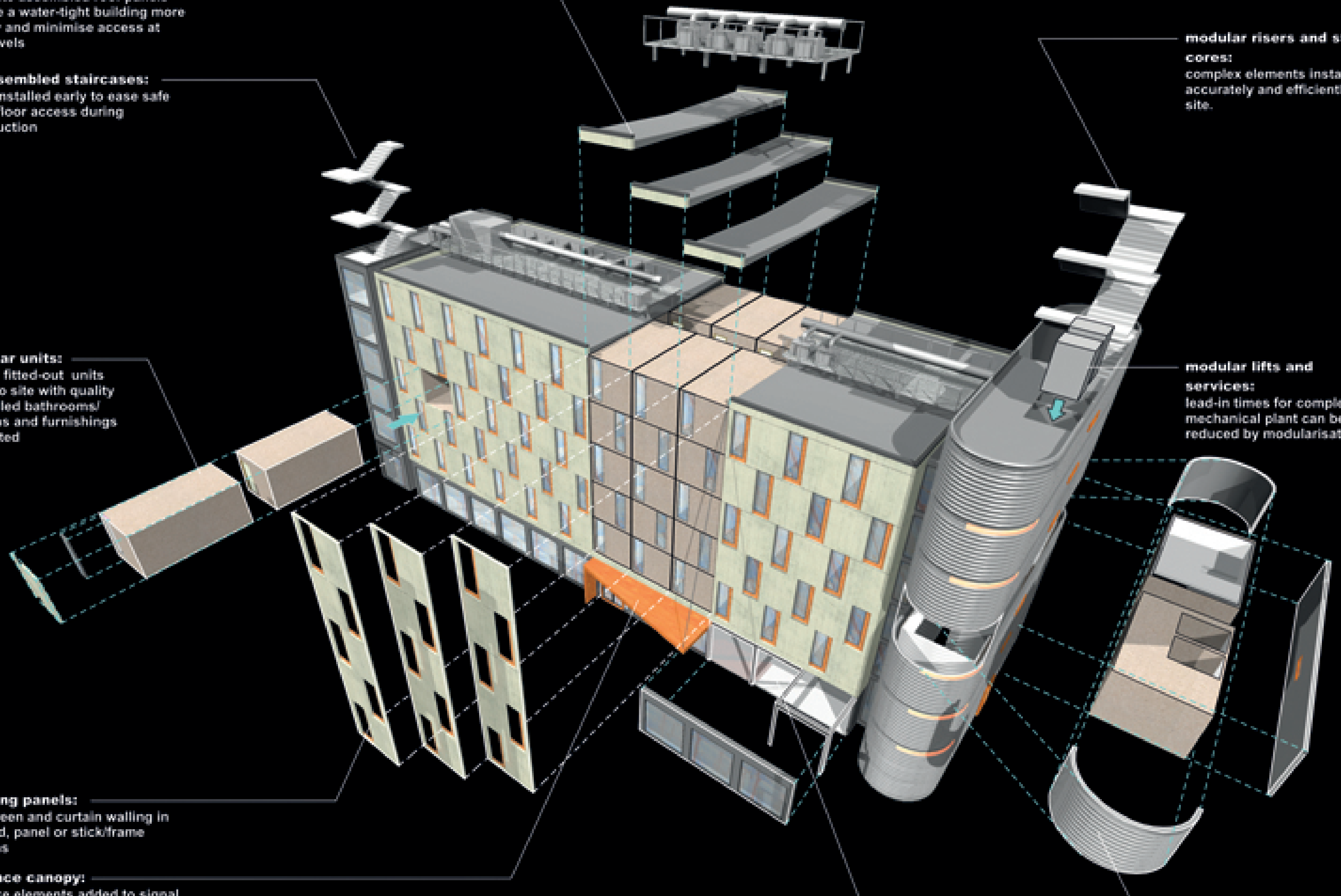
Module: a three dimensional room-size, or part room-size unit, constructed off-site for incorporation into a building.

introduction

0-1 what is modular?

Modular approaches to building are amongst the fastest growing and most promising areas of the construction sector. There is a rich and long history of designers pursuing a vision of efficient industrialised construction. Their aim was to revolutionise the way that buildings were procured, and advance the construction industry by adopting principles used successfully in almost all other areas of manufacturing. Recent developments in modular construction are perhaps the first true realisations of this long-held vision.

This **Guide** is a succinct and focussed resumé of the current state of the art and the technologies that have underpinned the enormous advances that have been witnessed. It focuses particularly on lightweight, steel construction as used and developed in the UK.



1.0 modules

1.1 modular construction
benefits & use of modularisation

1.2 factory production
factory processes & production requirements

1.3 module types
closed and open-sided modules

1.4 transportation limits
module dimensions & lifting

Modular construction involves the fabrication and assembly in a factory environment of highly finished room-size, or part room-size building elements. These are transported to site and assembled together to form permanent buildings. Sometimes theses may also be used as non-permanent buildings or parts of buildings.

Modularisation offers many benefits. It minimises the uncertainties of site construction and maximises the benefits of factory production. A factory can optimise control of process, materials and mechanisation, and can deliver very high quality products.

Modular construction can be used for almost any building type. It offers particular advantages where there is a degree of repetition and a single highly considered, pre-engineered and optimised design can be reproduced many times. Current high volume applications include: student accommodation and hotels (where quality standard rooms are required), military accommodation, housing, and restaurants. Other applications include specialist building elements such as toilet pods, operating theatres, staircases, lift shafts, service risers and plant rooms, as well as any building where site conditions, access, location, economic factors, available skills, design complexity or architectural needs make on-site techniques less attractive. In combination these factors mean that the market for off-site construction is growing rapidly, underpinned by an ability to produce reliable, architecturally successful quality products economically.

The economic case for modularisation involves much more than just capital cost. It includes risk reduction, predictable performance, the value of early completion, low site impact, improved health and safety, and reliable standards of construction (including latent defects reduction). Modular buildings have also been shown to produce long term savings in operation and maintenance due to good environmental performance and quality.

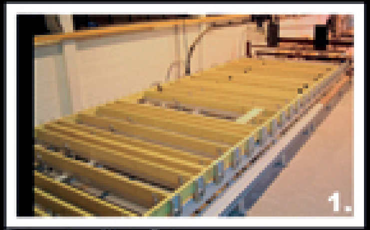
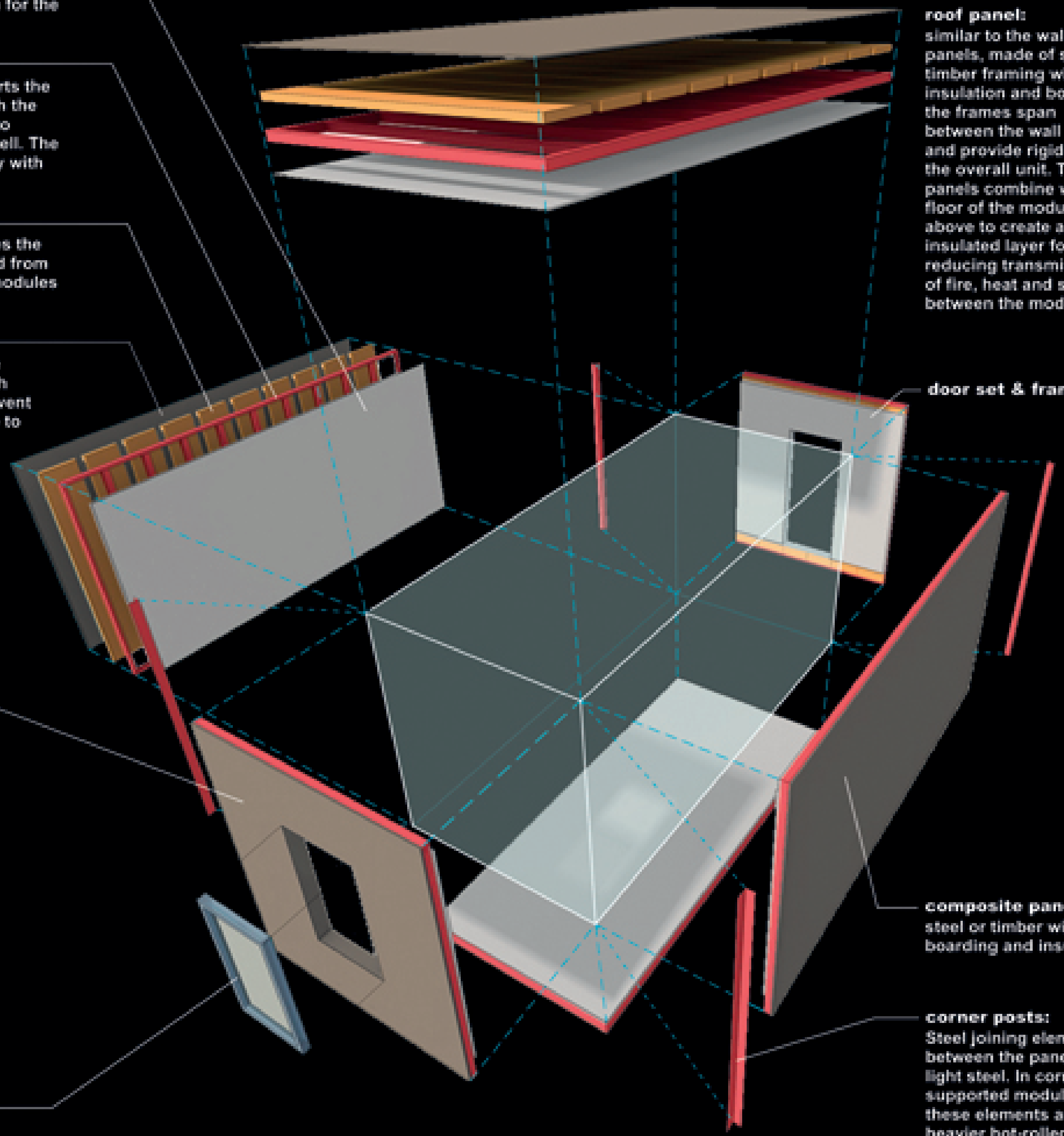


Photo courtesy of Hunter Timber

Photo courtesy of Old Castle Precast/ CRH, plc

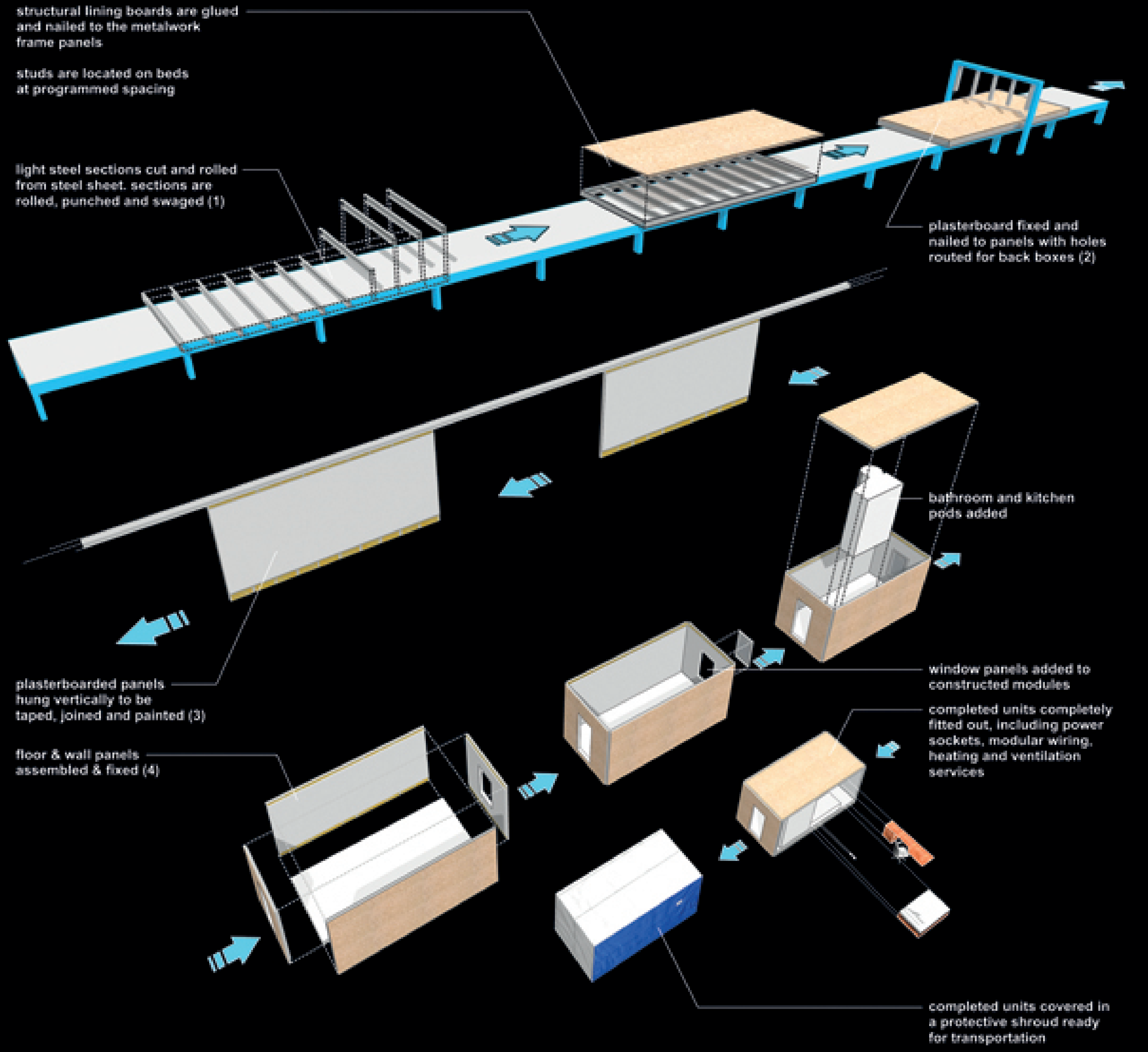


1·1 modular construction

1·2 factory production

Factory production benefits from a highly controlled working environment. All materials that enter the factory environment are logged, securely stored and drawn down when needed. Assembly areas and production lines are arranged to maximise efficiency and to achieve balanced outputs such that entire sets of module components are produced exactly in line with demand. Components arrive to the work area on a just in time basis and are assembled in a smooth-running continuous process.

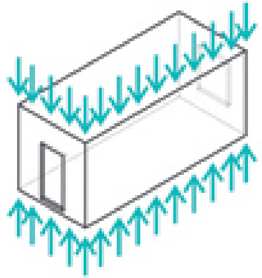
It is common for **factory production** to be supported by a contracted supply chain that benefits from continuity of market. Deliveries are optimised against production requirements and minimum stock levels are kept. Components arrive pre-cut to size and matched to mechanical handling and jig requirements. As a result there is minimum waste in the assembly operation.



Modules typically have a steel, concrete or hybrid primary structure. In the case of framed modules (joisted floors and ceilings and studwork walls), the structure may act compositely with other elements such as lining materials. They may be closed-sided or open-sided.

Closed-Sided Modules

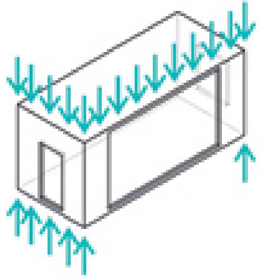
A closed-sided module will normally have perimeter walls on all four sides. Walls normally provide support to the ceiling and can contribute to the spanning ability of floors by providing additional stiffening. Modules may comprise one or more rooms and assemble as a series of closed boxes. These boxes are relatively stiff (normally requiring no additional bracing for transportation and erection) and are easily weather-proofed (often using wrapping or simple jackets dropped over the roof and walls).



Load path through walls, can accommodate small openings

Open-Sided Modules

An open-sided module will normally have one or more external walls omitted such that it can be used in conjunction with other similar modules to form large open rooms, for example classrooms. Unlike closed sided modules, one open sided module may rely on another for bracing and stability or on another building element such as a core (for example, a centre open module in a classroom may rely on the end modules which incorporate the long external wall). Additional bracing may be required for transportation and erection together with temporary weather-proofing.

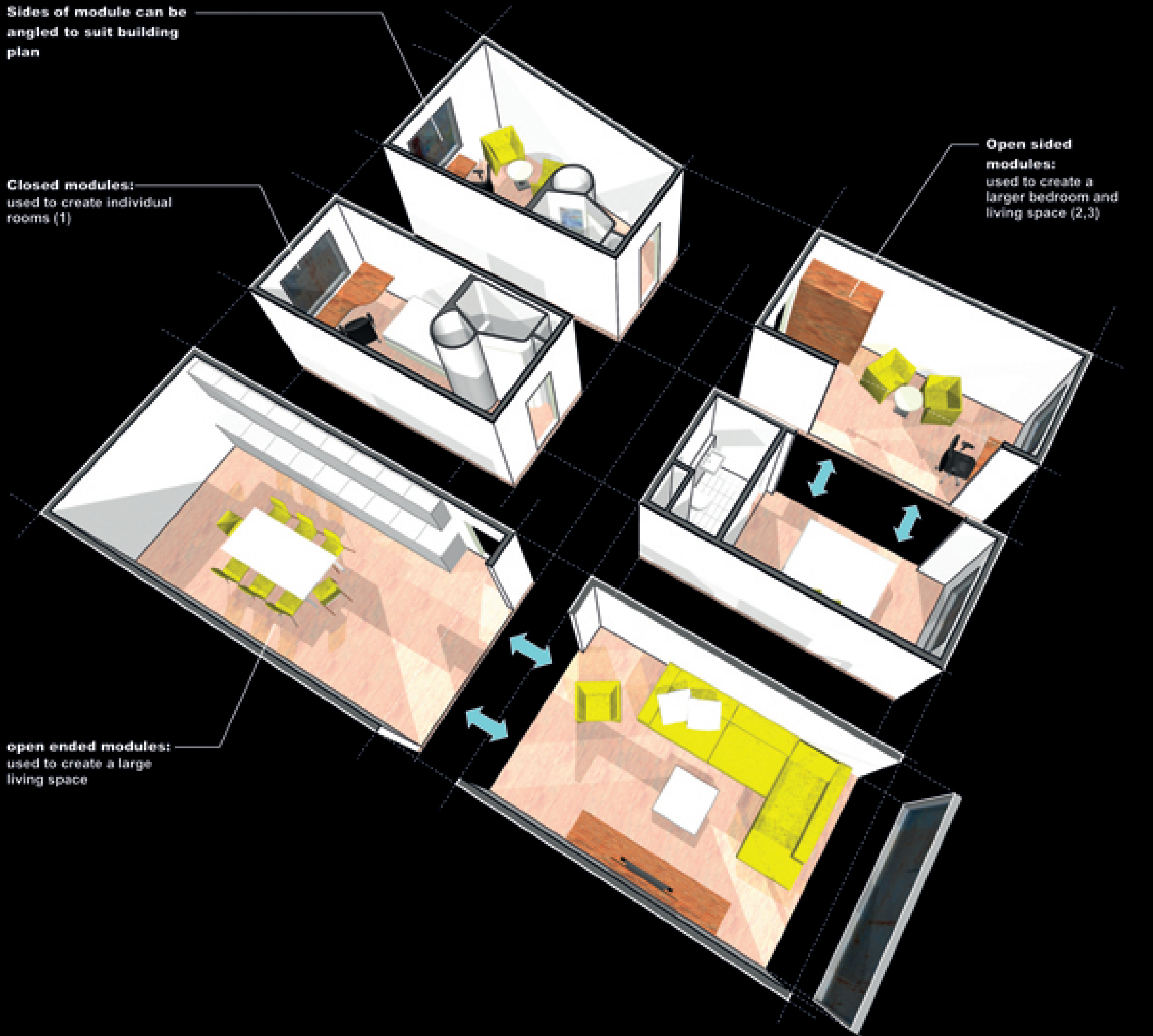


Load paths through corner columns to allow maximum sized openings.

Photo courtesy of Old Castle Precast/ CRH, plc.

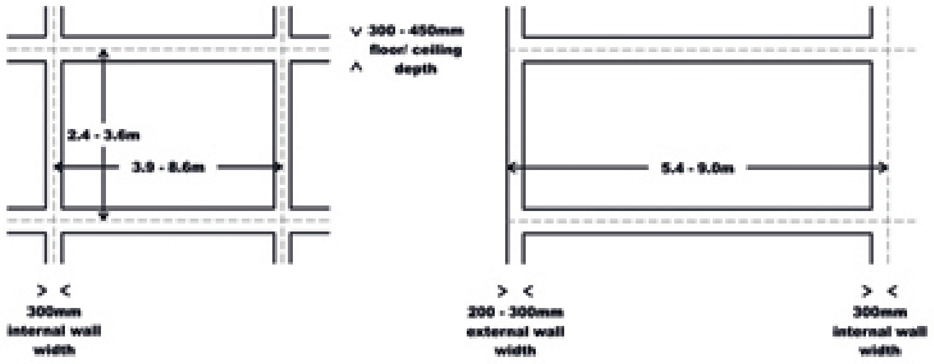
Photo courtesy of Yorkon Ltd.

Photo courtesy of Old Castle Precast/ CRH, plc.



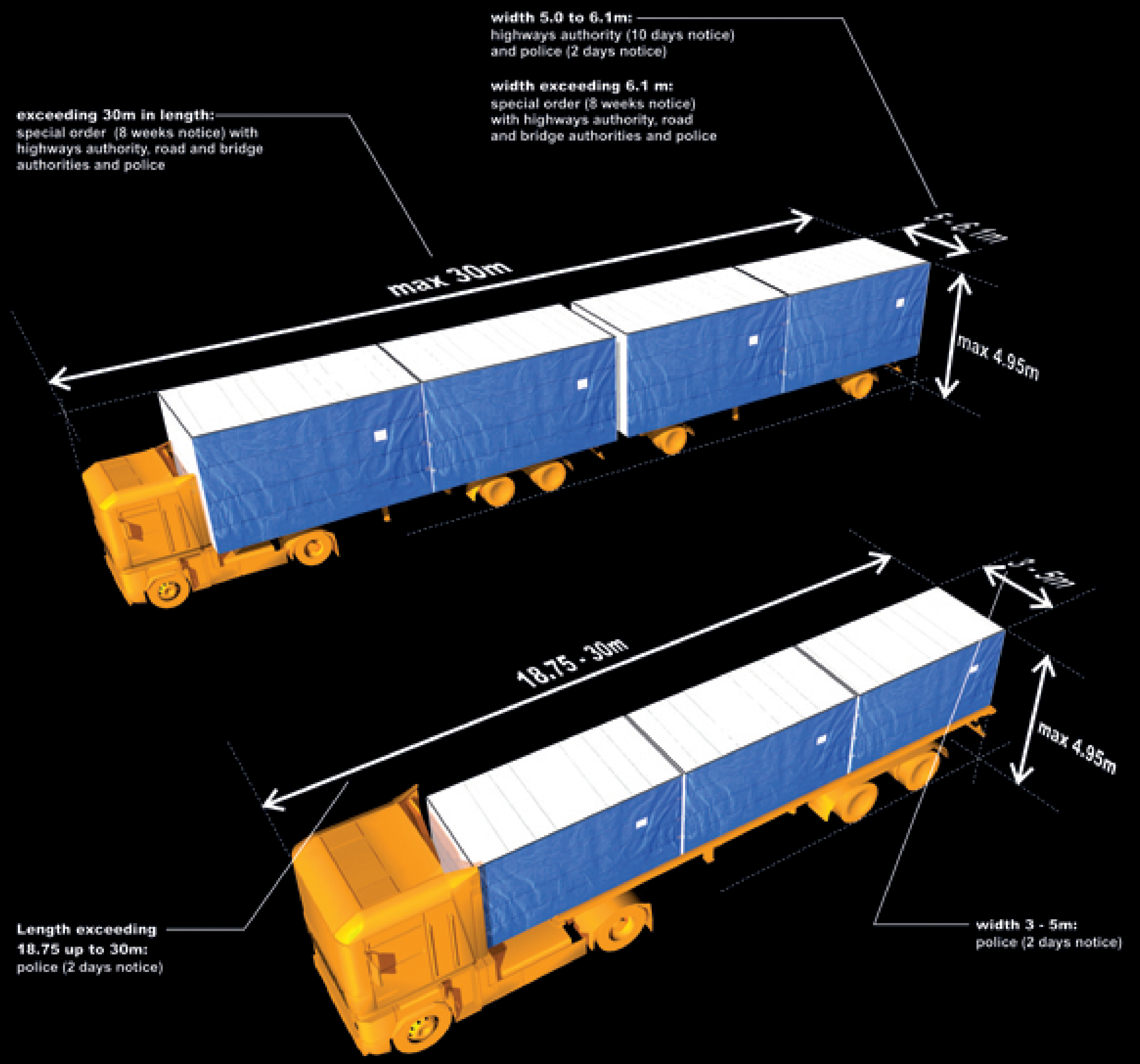
1-3 module types

Typical economic **module dimensions** tend to come from fabrication and transportation considerations. Common width and height variants include 2.4m-3.6m (to suit standard flatbed and low loader transport and motorway bridges) with lengths up to 14.4m (based on a 12.0m trailer with an overhang).



It is technically possible to manufacture very large modules but there are practical limits for transportation and handling. There are currently no transport restrictions for a trailers and units under 18.75m long by 3 m wide. Units wider than 3m, but under 4.1 m do not require an escort but may have timing or delivery restrictions imposed by the police.

Lifting cranes are sized for module weight and the required reach. Load spreaders may be used to reduce horizontal forces arising in the module as a result of lifting. Various crane types are available to lift modules. Mobile cranes are frequently used for low rise buildings on accessible sites. On large or difficult sites tower cranes can be the most economic solution.



1.4 transportation limits

2.0 buildings not boxes

2.1 building forms

2.2 cladding & roofing

2.3 circulation, lifts and balconies

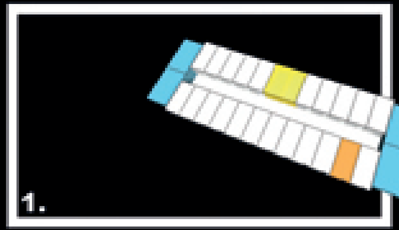
2.4 services, connections

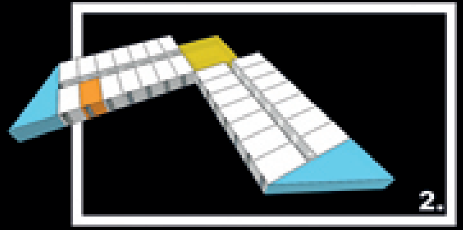
2.5 technical performance

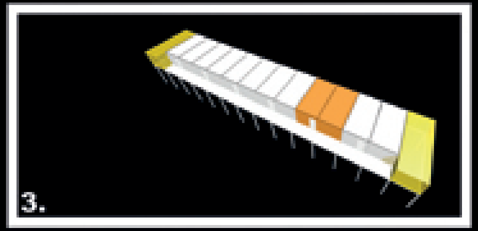
2.6 structural design

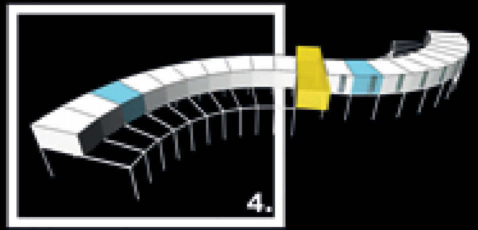
Cellular **buildings** such as hotels, student accommodation, housing and small apartments tend to be well suited to closed-sided modular construction. Large space buildings such as schools, offices and commercial buildings tend to be better suited to open-sided modular construction.

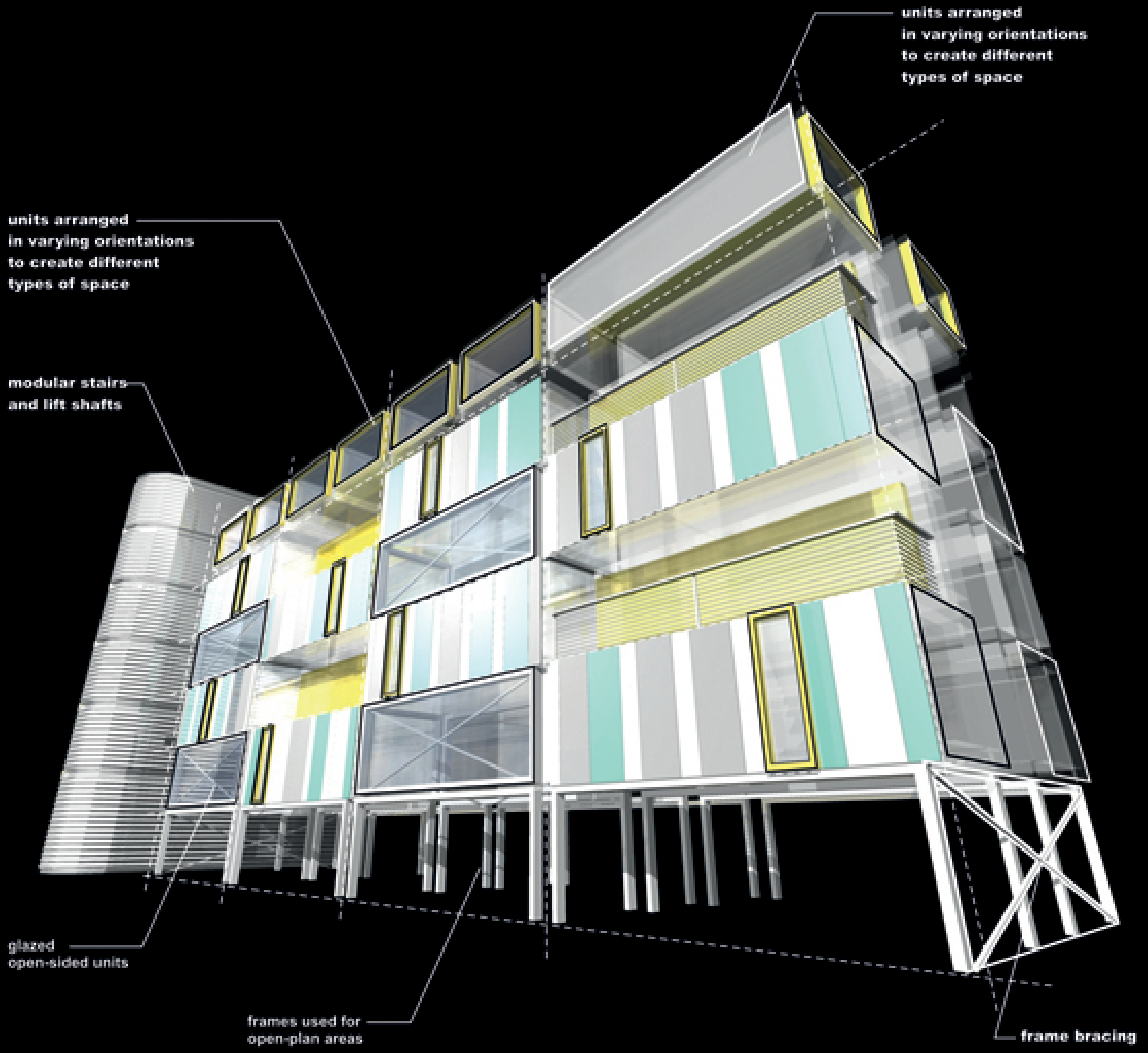
Advanced manufacturing techniques allow **modules** to be built in varying geometries and there are numerous techniques for accommodating irregular arrangements. For example, buildings that are curved in plan can be accommodated by varying the angles of sidewalls. Modules can be stepped or staggered in plan or section and building axes can be adjusted at cores or corners. The range of possibilities is enormous.











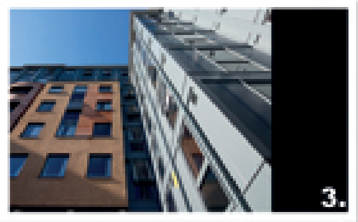
2·1 building forms

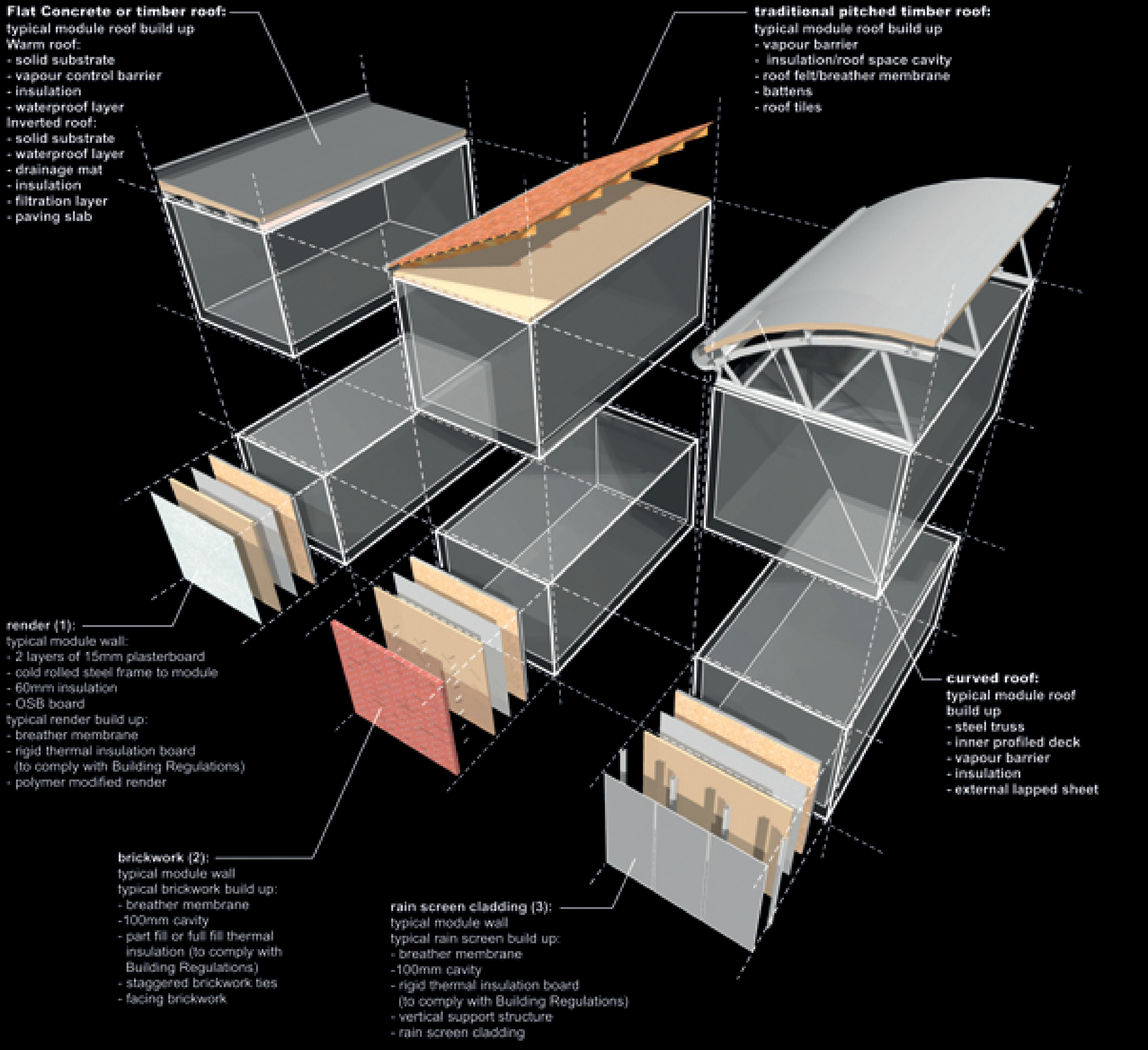
Modular units leave the factory in a weatherproof state ready for transportation. Generally this weatherproofing will remain in place to provide protection from any adverse weather which could cause damage during storage, transportation or site assembly.

Modular construction tends not to inhibit the range of cladding and roofing options that are possible for any particular scheme.

Generally **buildings** constructed from modular units rely on either site applied cladding such as masonry, render or panelised systems, or factory applied alternatives which usually require either site fixed panels at the interfaces of modules or some form of site applied jointing. Where cladding is on the critical path, quick, dry construction techniques tend to be popular (whether site or factory applied) to minimise build programmes.

Photo courtesy of Yorkon Ltd





2:2

cladding, roofing

2.3 circulation, lifts, balconies

Internal corridors between modules can be constructed on site or can be integral within modules i.e. a portion of the corridor can be constructed as an open sided part of a combined room corridor module. Where they are constructed on site corridor floors and ceilings can be built either conventionally or using pre-finished panels usually supported off the modules.

External accessways and **balconies** are also commonly used. These typically attach to elements of the module structure such as corner posts using appropriate bracketry. Techniques exist for the minimisation of thermal bridging, reliable cladding penetrations and controlling and accommodating the additional torsional loading that is generated in the module frame.

Staircases and lift shafts can be integrated into modules, freestanding or contained within cores. When unfinished stair modules are installed early in the construction sequence they can provide safe vertical access during construction. Alternatively stair modules can be delivered as finished units reducing fit-out time.

Lift modules can incorporate pit sections, shafts and upper mechanical housings. The benefits of modular lifts are improved dimensional accuracy and a short installation time.

Photo courtesy of Old Castle Precast CRH, plc

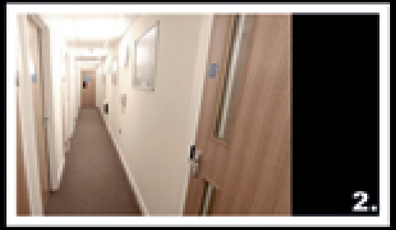
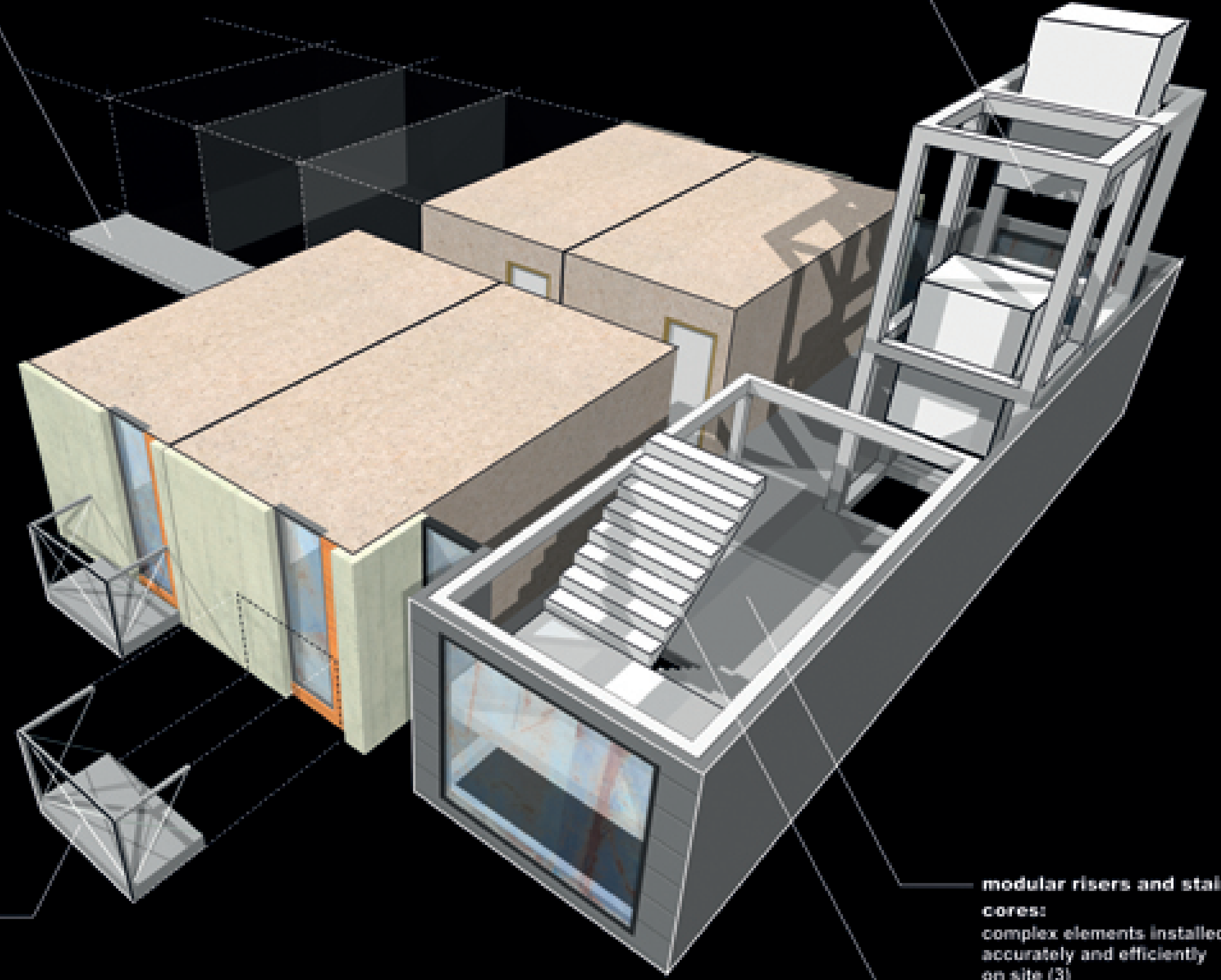


Photo courtesy of Bourne Construction Engineering Ltd



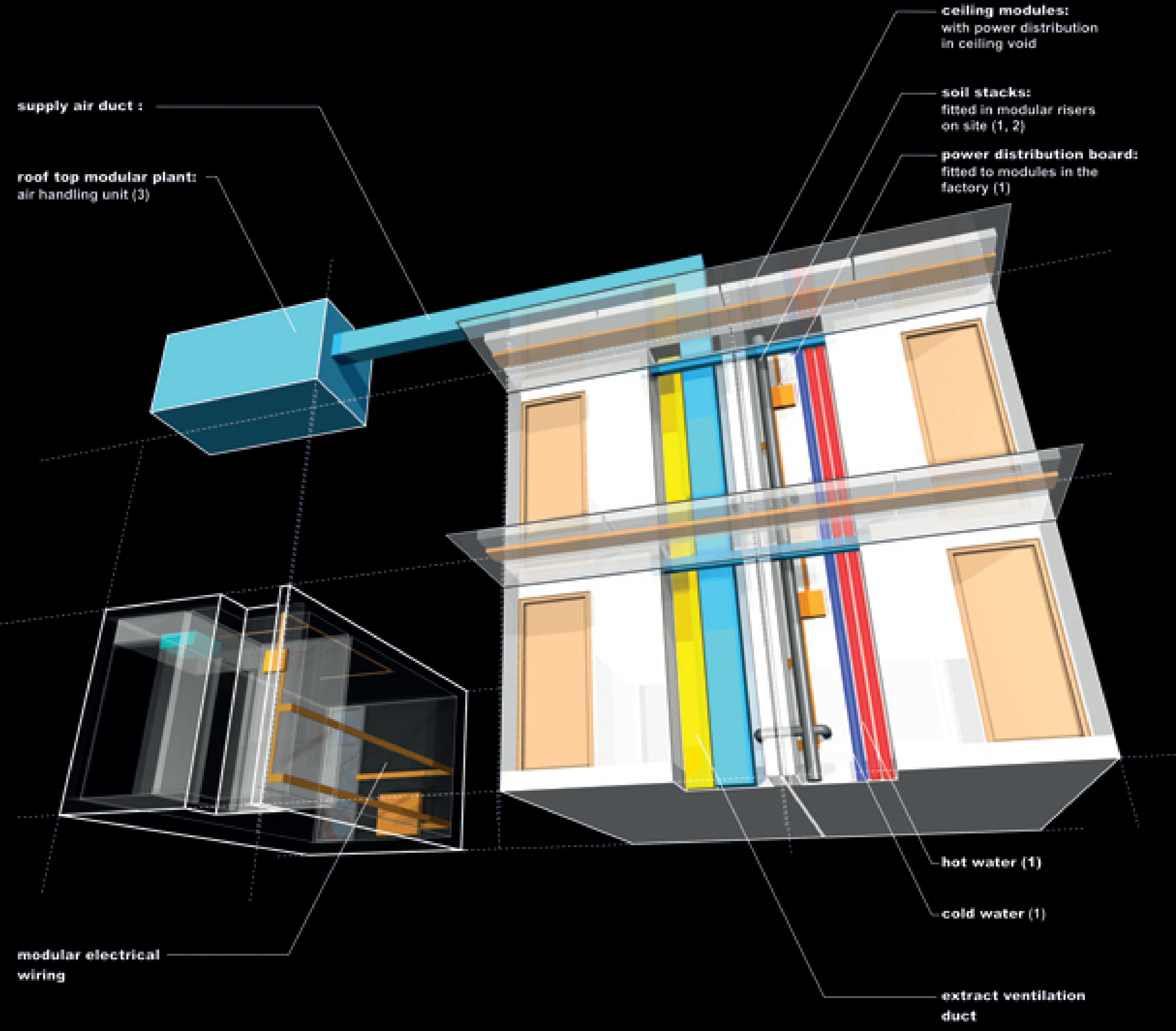
Most **modules** arrive on site with the internal services complete and tested prior to delivery. 'Plug and play' connections for modular wiring systems and push-fit drainage are popular as these can be completed rapidly by module fit-out teams (final checks undertaken by certified electricians and plumbers).

The local distribution of utilities such as electricity, water and gas together with drainage and ventilation services are usually built into modules during manufacture. These are connected directly to the main building **service runs** on site. Services cassettes can be added in corridors for rapid installation of distribution services, as well as for plant room areas.

Modular **plant rooms** contain factory-installed plant and services. Pre-commissioning takes place prior to delivery, with full commissioning and final certification taking place once the module has been installed.

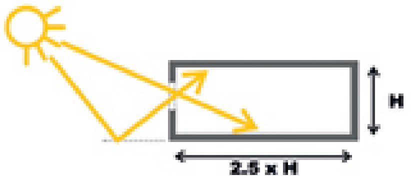
Photo courtesy of Precast Cellular Structures Limited

Photo courtesy of Bourne Construction Engineering Ltd



2.4 services, connections

Modular manufacturers engage in large test and development programmes to ensure performance and to develop optimised cost effective solutions. Very high standards of thermal and acoustic insulation, air-tightness and fire separation are possible.



In framed modules insulation is generally incorporated between studs, floor or roof joists, on the external face of modules or in the cladding systems, or in a combination of these locations. Almost any required level of thermal insulation can be achieved by these means.

The sound attenuation provided by external elements will generally be considerably influenced by the performance of the fenestration elements. In noisy or insecure areas, windows may be sealed and there will be reliance on mechanical supply and extract air either ducted from remote air treatment plant or conditioned locally in the room through a fan coil unit. The acoustic insulation provided by floors and ceilings also benefits from the structural separation between modules, in this case benefiting both impact and airborne sound attenuation.

The quality benefits of off-site construction allow for high levels of airtightness. It is important that air ingress to the spaces between modules, floor and roof zones is also controlled. With suitable measures in place good reliable performance can be ensured.

All modules have protection against fire and flame spread. Frequently the structure is protected internally by the use of board lining materials. The risk of fire spread between modules is minimised by using fire stops in cavities, particularly around windows, and in service risers. Similar closure is required between compartment walls and floors.

2.5 technical performance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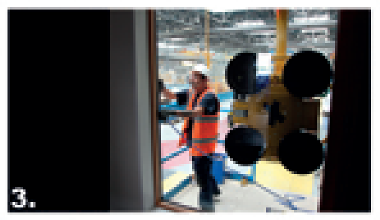
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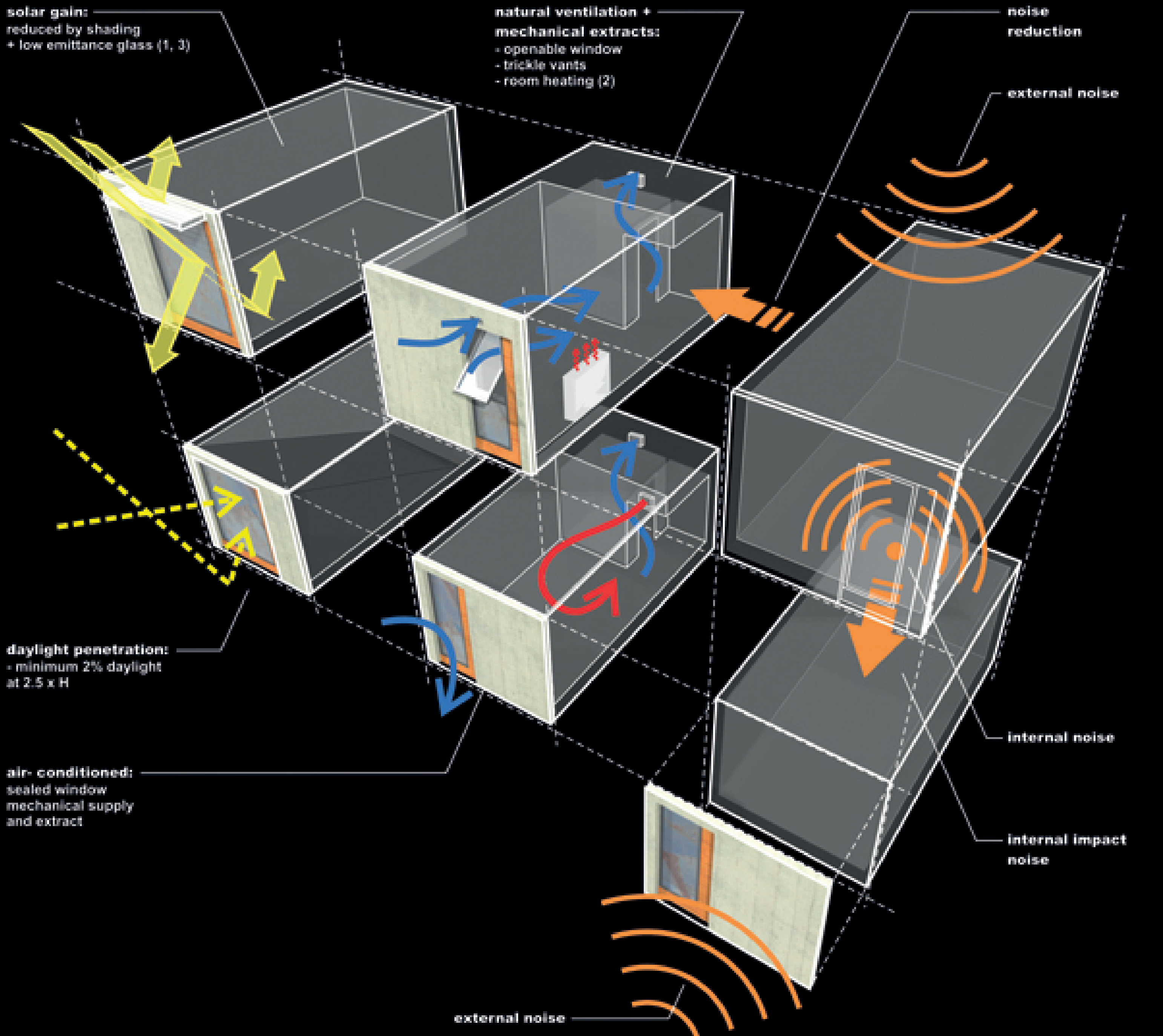

Modules are designed to carry and transfer vertical load (their own self-weight, the self-weight of modules above them, and the design live and imposed loads). They are also designed to resist horizontal wind loads, either transferring these to the foundations, core or other building elements with sufficient capacity to resist them. The transfer of wind loads to cores can be particularly useful in high multi-storey projects where the capacity of modules becomes a limiting factor for building height. As with any form of construction, modular construction needs an appropriate level of robustness to avoid progressive collapse.

The cumulative effects of tolerances between **modules** must be accommodated. Tolerances and accuracy are generally of a higher standard than in conventional construction, and special attention should be paid at interfaces (such as foundations and core elements) where the two sets of tolerances must be reconciled. To control overall building dimension variations, individual modules are usually designed to a small negative tolerance which, if required, can be made up on site.

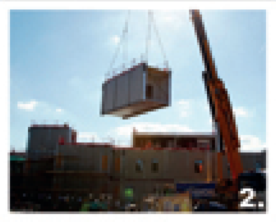

Photo courtesy of Yorkon Ltd

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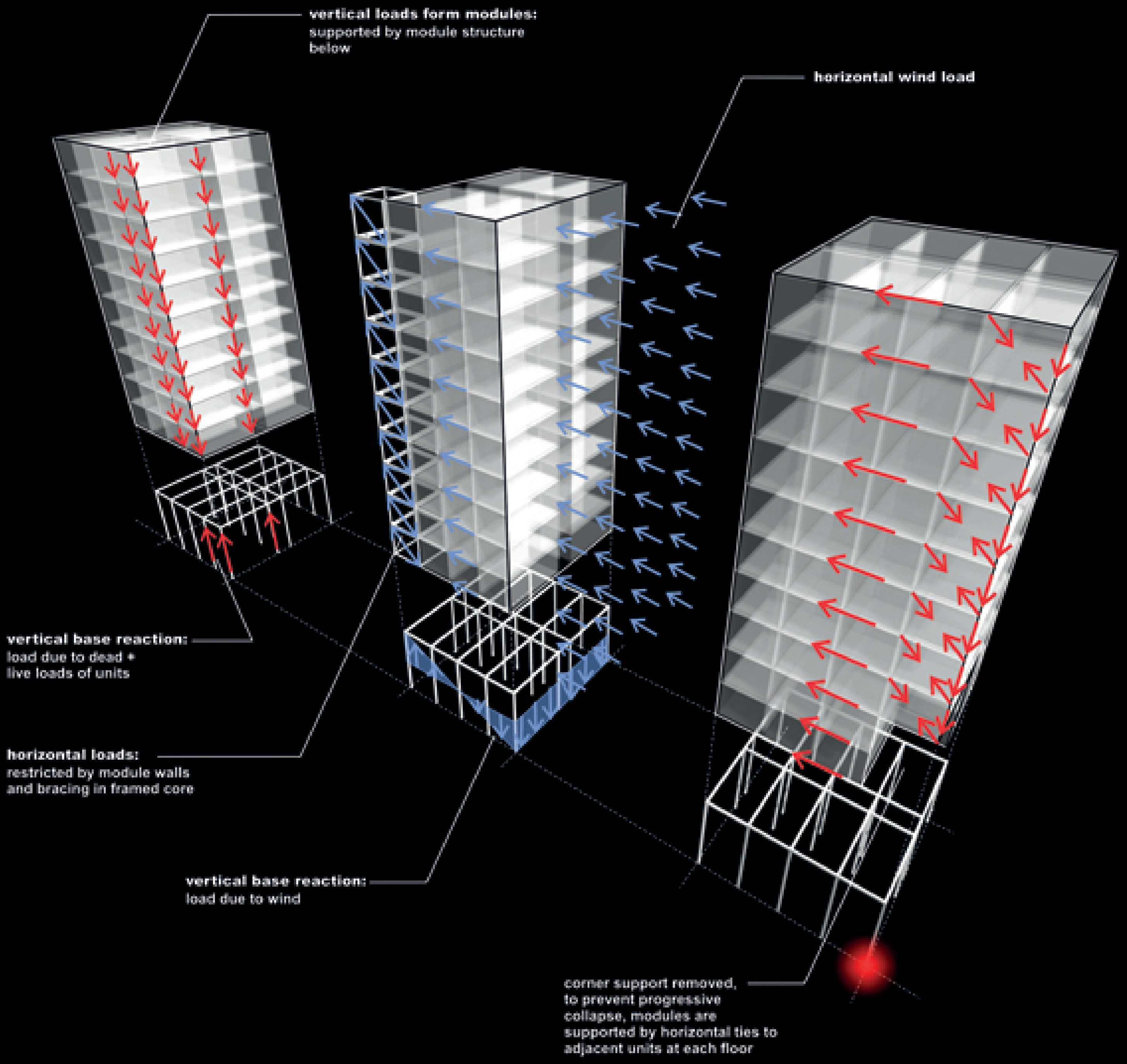


2·6

structural design

3.0 project planning

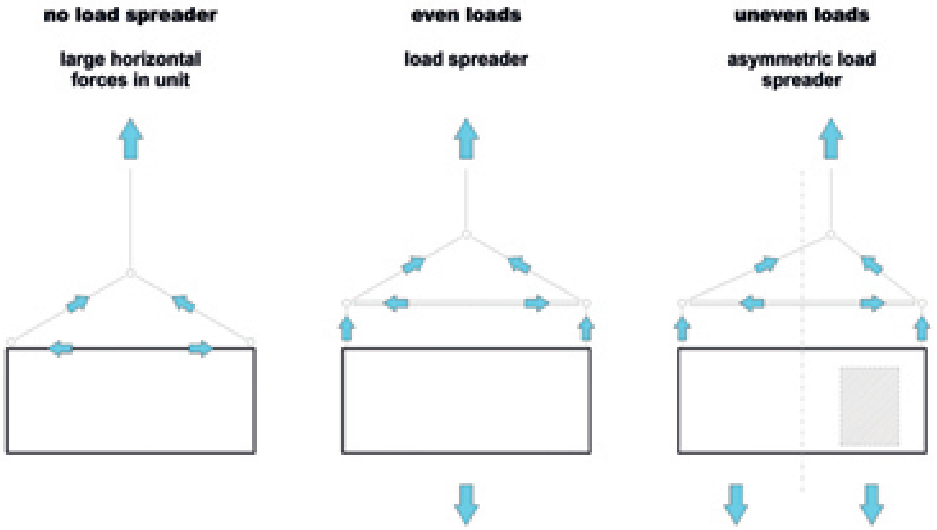
3.1 access & lifting

3.2 programming
traditional and offsite methods comparison

3.3 economic drivers
complex arrangements, modular and non-modular elements

Amongst other site related **benefits** modular construction offers significant reductions in site personnel, vehicle movements, waste and damage. It relies on fewer subcontractors and there is less programme risk, particularly as a result of poor weather conditions. Generally modular building sites are cleaner, safer and easier to manage.

Modular construction is particularly successful in tight urban sites where there is limited space to store materials, or secure sites with limited access such as on prisons, military camps, airports and research centres. Other sites where modular construction is particularly attractive include those in remote locations and sites with extreme weather conditions where working may be difficult and trades limited and expensive.

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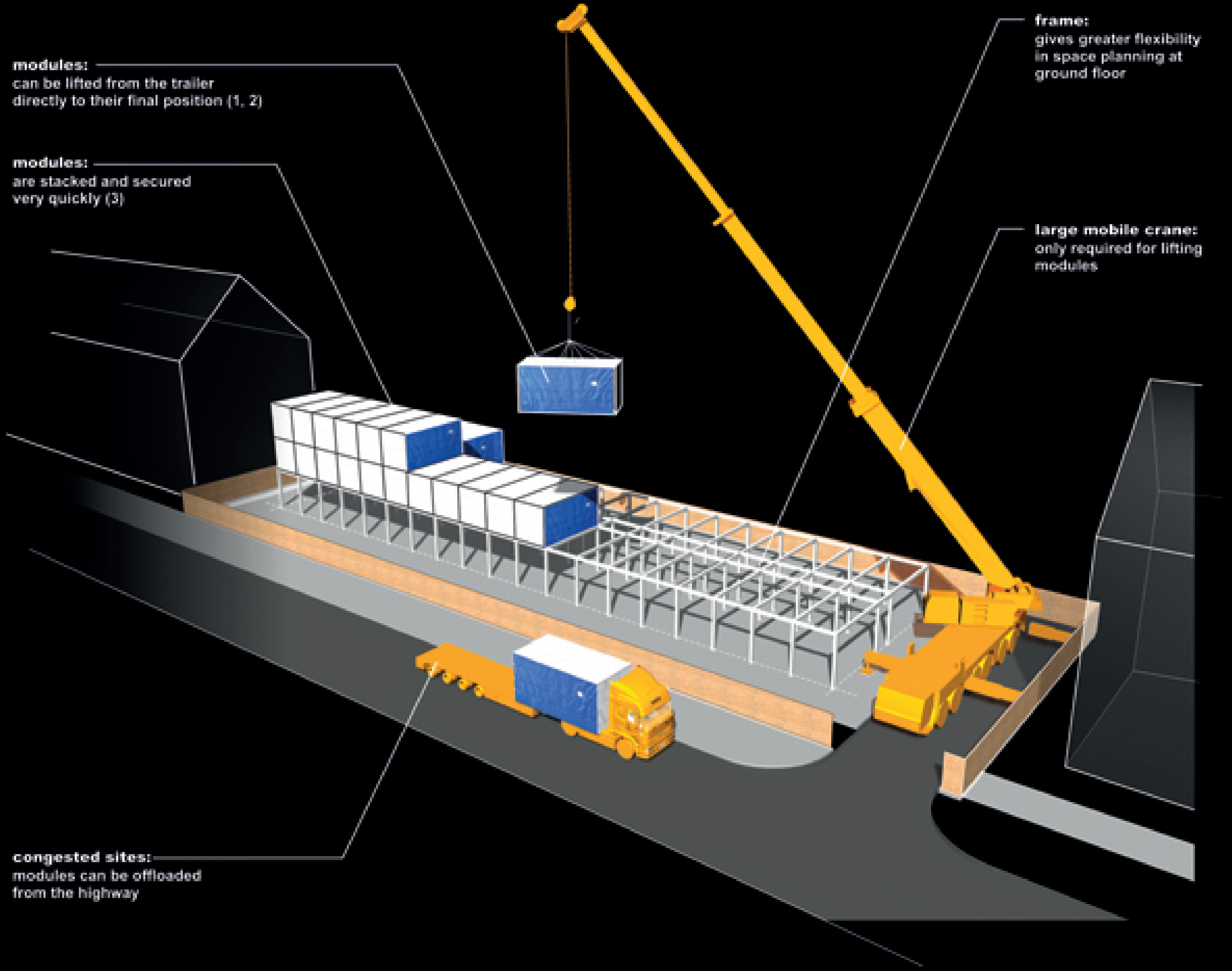


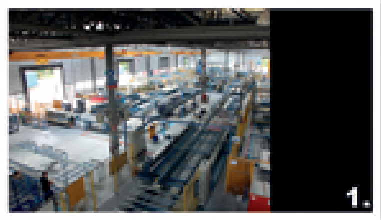
access & lifting

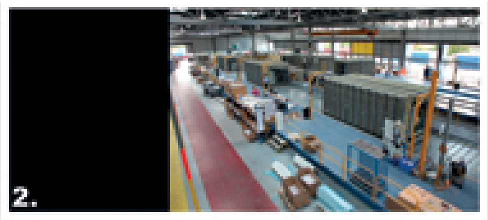
Modular construction can significantly reduce build programmes. For example, where sites have limited access and short working hours, as may occur in tight urban locations, build programmes may be reduced by **50%** in comparison with conventional construction.

To maximize the advantages of modular construction manufacturers should be involved relatively early in the design process. Key factors to be considered may include dimensional coordination of layouts, storey heights and floor and wall thicknesses, and building services coordination.

Pre-production **prototyping** allows the overall design and detailing of modular units to be optimised. Early sign-off of designs allows manufacturers to prepare material supplier frameworks and programme production efficiently.

Production commonly starts during site enabling works so that finished modules can be delivered as soon as groundworks are complete. Finished modules may be stored at the manufacturing plant ready for efficient delivery to site where ideally they are hoisted into position directly from the lorry.





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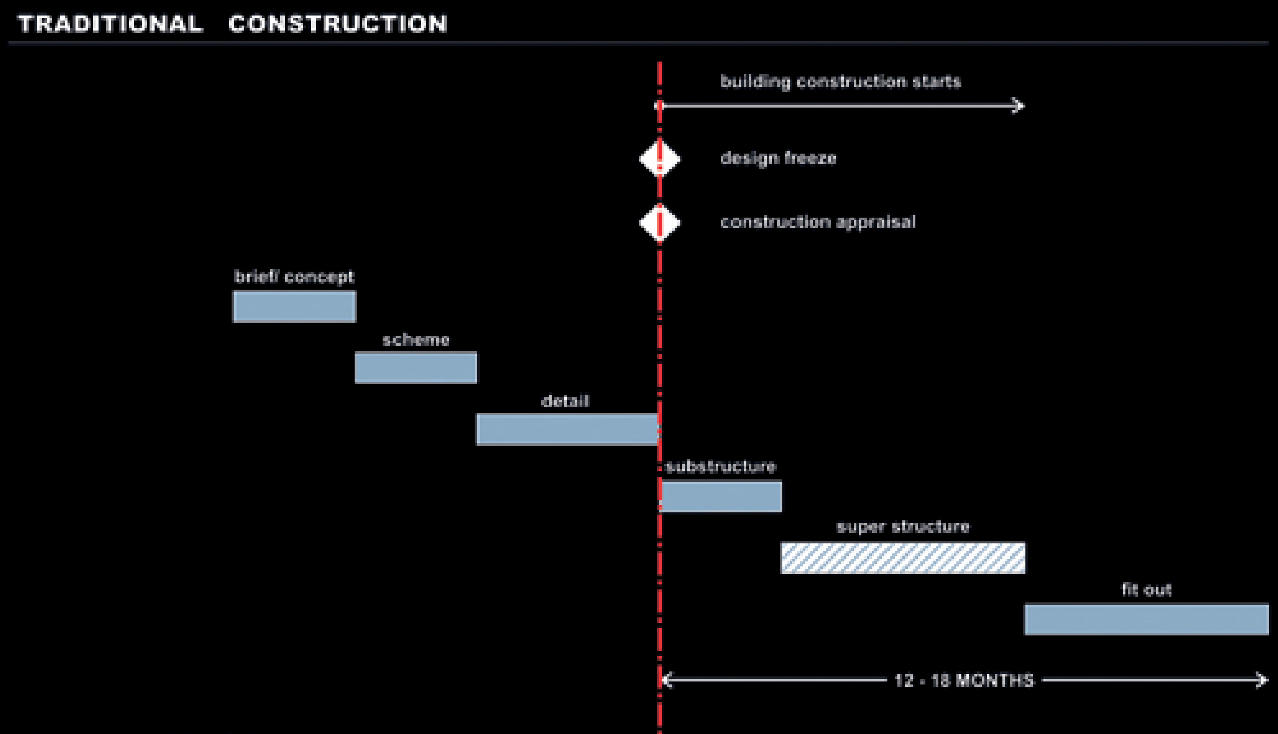
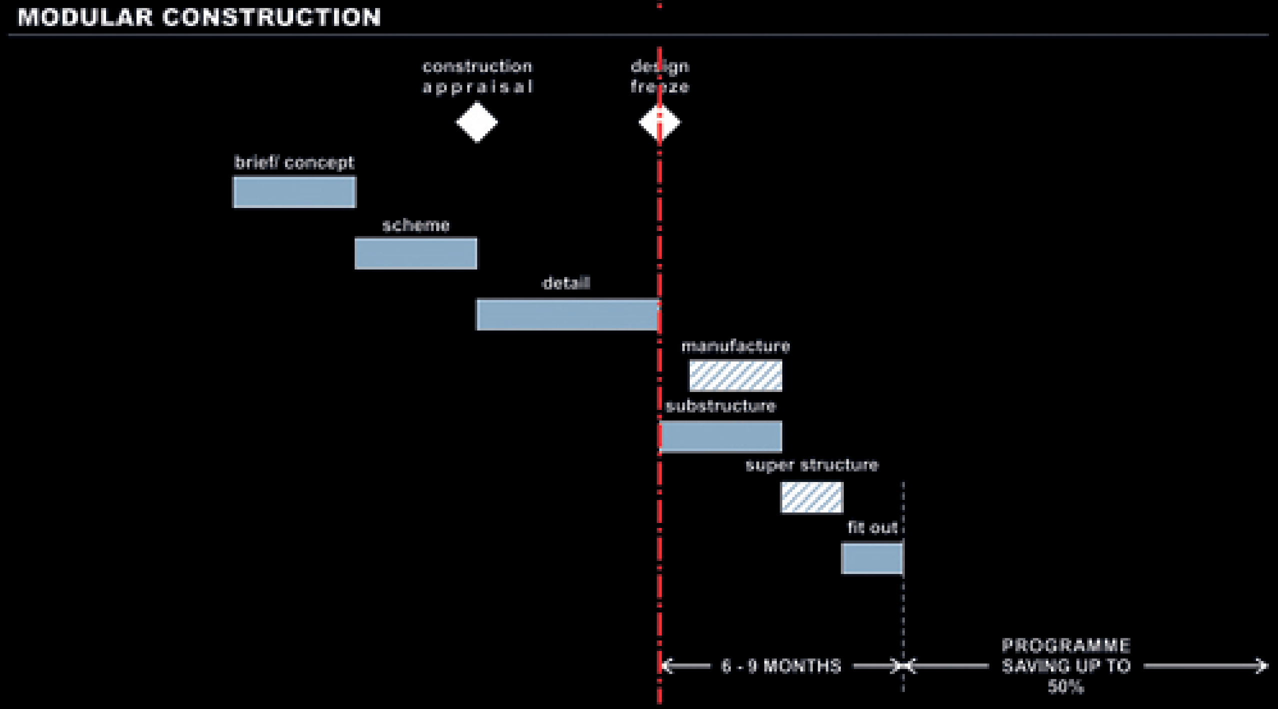
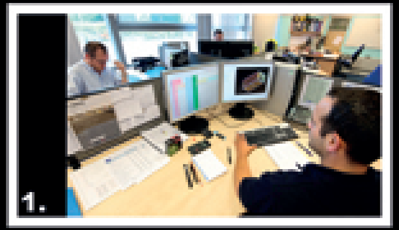




programming

From a **manufacturers** perspective the capital investment required to set up and operate a modular production facility is relatively high, but the operational efficiencies combined with the net cost reductions associated with site operations, reduced defects and wastage, mean that the costs that the manufacturer can tender are highly competitive with those of conventional construction.

Clients benefit from significant quality improvements and early delivery of buildings such that their asset value and business benefits can be realised much sooner than might otherwise be possible. Clients also benefit from improved reliability in the procurement process reducing risks of cost overruns and reduced operational costs associated both with maintenance and building energy costs.



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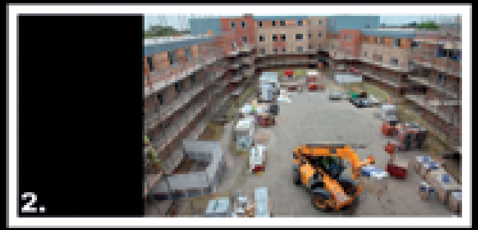

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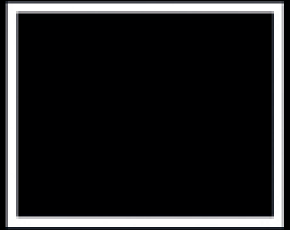
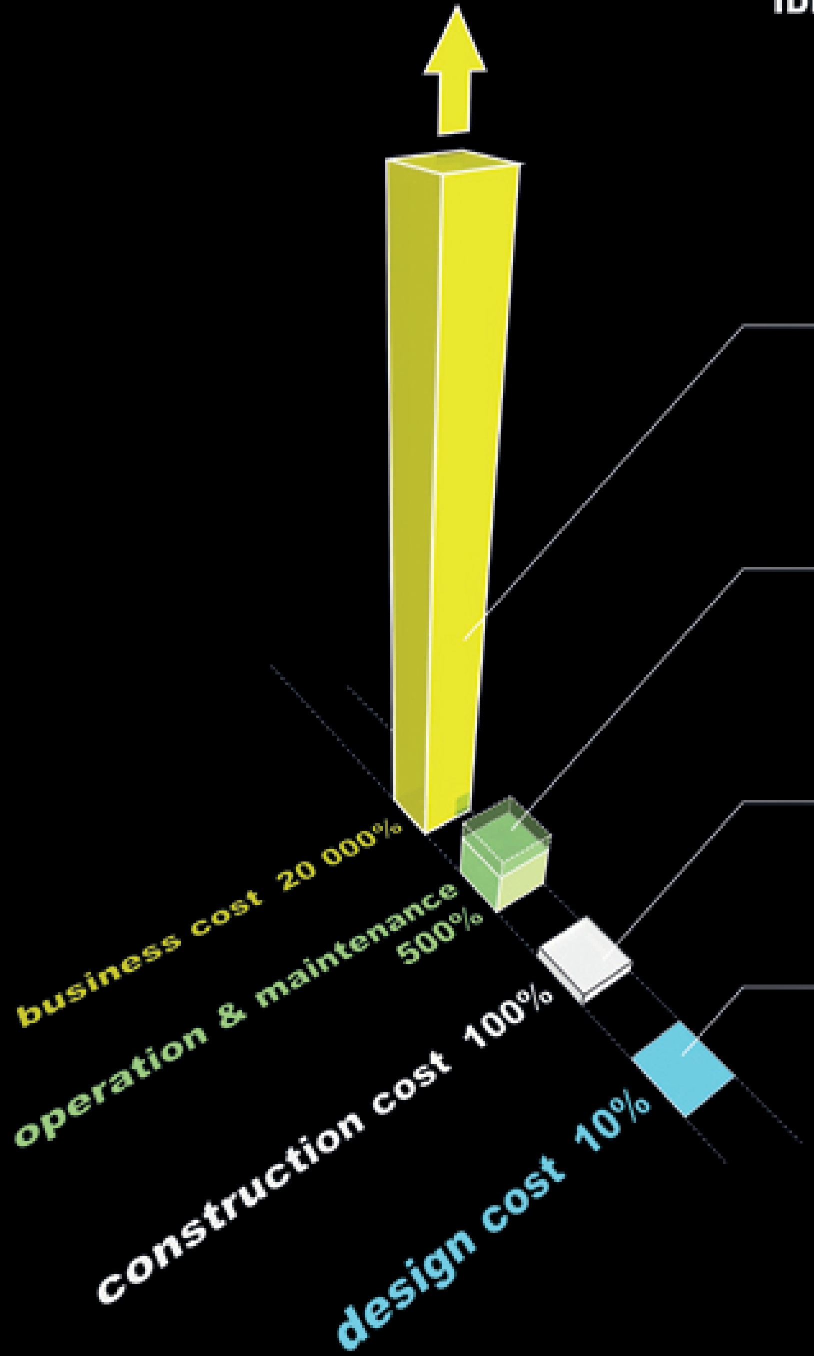


3.

IDENTIFYING VALUE IN BUILDINGS



business cost 20 000%
business costs are significantly greater than capital costs. Early programme completion and an appropriate building can have a significant effect on business profits.

operation & maintenance 500%
higher quality build achieved through modular construction has been shown to reduce operation and maintenance costs (3)

construction cost 100%
greatest benefits of manufacture are maximised through larger scale projects and standardisation (2)

design cost 10%
design costs may be lower for standardised designs using modular construction (1)

3.3 economic drivers

4.0 case studies

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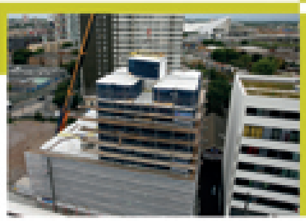

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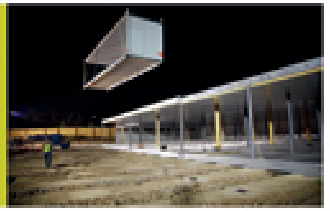


4.

4.1 mansfield hall, reading

4.2 colchester general hospital, essex

4.3 travelodge hotel in stratford, london

4.4 eco-store for tesco in southam

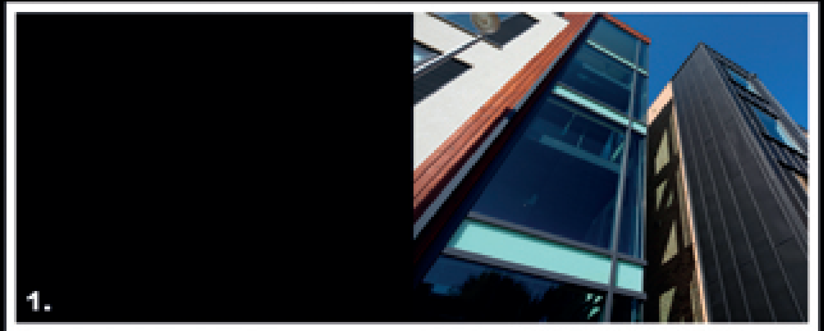
Mansfield Hall, Student Accommodation in Reading, Berkshire

Following a design competition Rio Architects was commissioned by Unite Group plc to design this student accommodation adjacent to Reading University's London Road Campus within a Conservation area.

The Mansfield Halls consists of seven buildings five storeys high, and the 772 whole room modules were installed by modular contractor LightSpeed Construction Ltd in 12 weeks at a rate of 13 modules per day.

The main contractor was Mansel, structural engineers BWB Consulting, and the overall build cost was £22m of which the modular package contract value was £8.7m. The standard bedroom module size was 5550x2600 and shared kitchen modules 6675x3340. The 605 bed scheme is clad externally with traditional materials to reflect the character of the conservation area. Rio won the support of CABE and English Heritage in securing a planning approval on appeal in 2009.

Case Study courtesy of LightSpeed Construction Ltd, formerly known as Unite Modular Solutions Ltd.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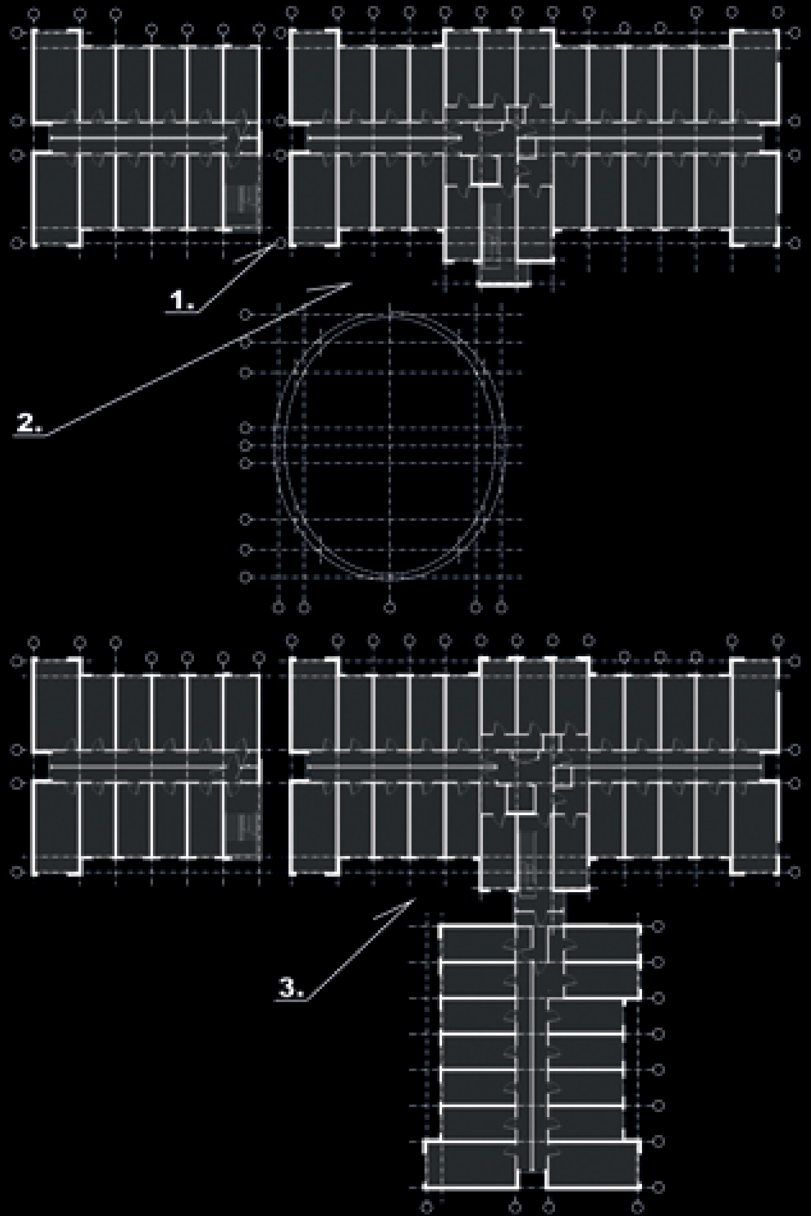

4.1 mansfield hall, reading

Colchester General Hospital, Essex

Tangram Architects together with contractor Kier Eastern used Yorkon's offsite approach to produce a new purpose-designed facility that includes 68 inpatient beds, consultation and treatment rooms, nurses' stations, two isolation beds, administrative offices, a school room, children's dining room, utility room, stores and ancillary rooms. The building was manufactured as part of Yorkon's £10m contract. The modules were fitted out offsite which reduced the construction time on site to 10 months.

The building was installed in two phases to allow the existing ward building to be used until just days before the second phase modules arrived on site. The shape and constrained nature of the site demanded a very complex modular layout, which had to take into account the short window for construction.

The building creates a strong image for the hospital with its striking architectural lines that feature deeply articulated facades finished in a palette of materials including white render, vertical bands of rainscreen cladding and curtain walling.

148 steel framed modules up to 14m long and 3.3m wide, each weighing up to 12 tonnes were delivered and installed in just 17 days.

The units were partially fitted out off site, including internal partitioning and first fix M&E services. The project was the first to use the Yorkon pre-installed concrete floor throughout. The building has achieved a BREEAM rating of 'very good' (targeted).

Case Study courtesy of Yorkon Ltd.

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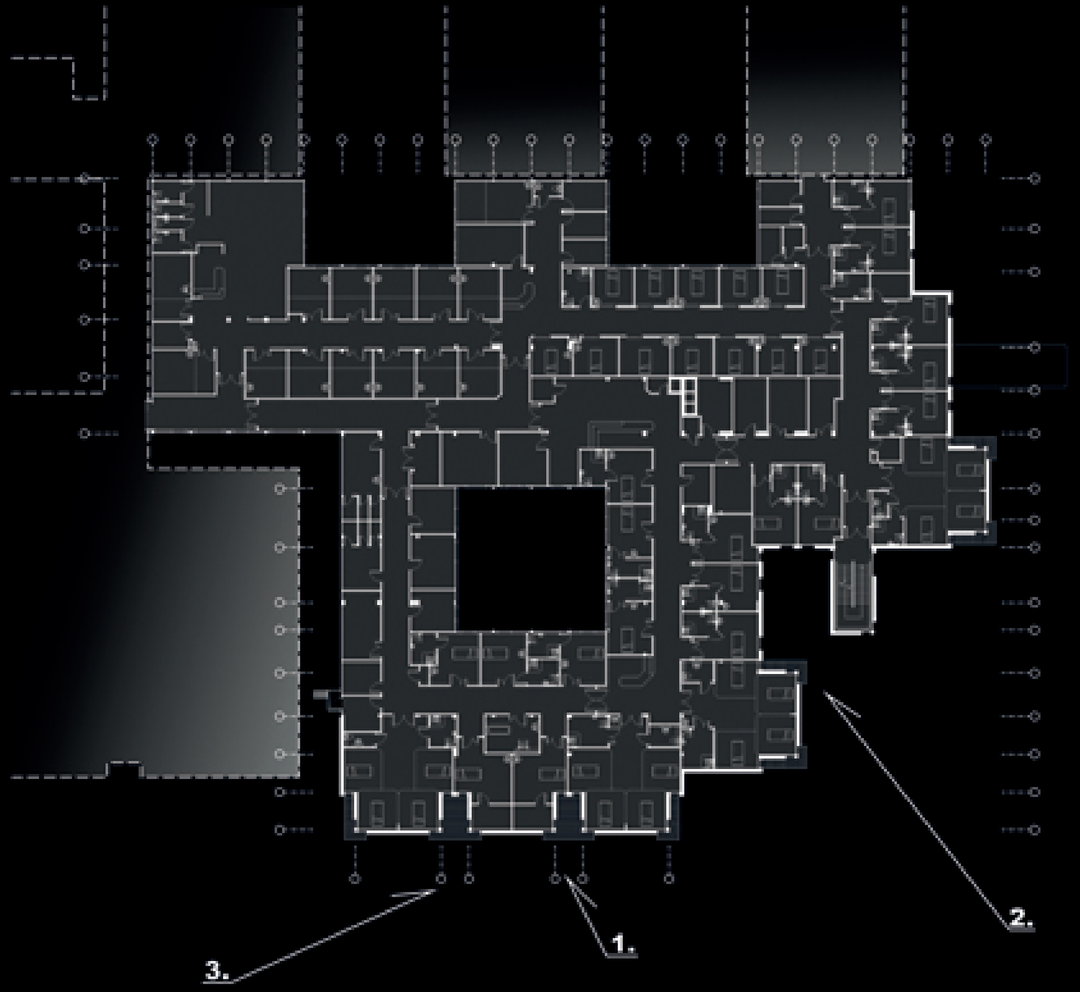


4·2

colchester hospital

Travelodge Hotel in Stratford, London

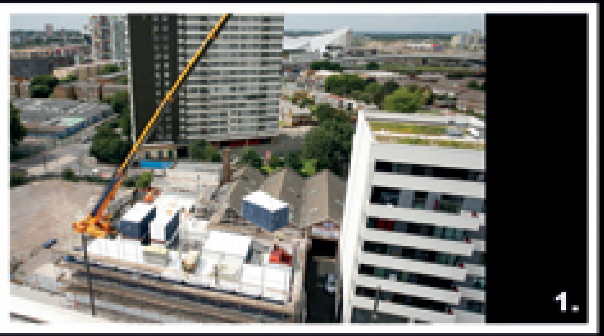
This new Travelodge hotel development at the entrance to the Olympic Park in Stratford, London is an 11-storey building containing 229 modules to create 188 bedrooms. Red 4 Architects opted for a fully modular approach from the first to 11th floors of the hotel, using modular contractor LightSpeed Construction Ltd to meet the strict programme timescale that ensured the hotel was completed in plenty of time for the 2012 Olympic Games.

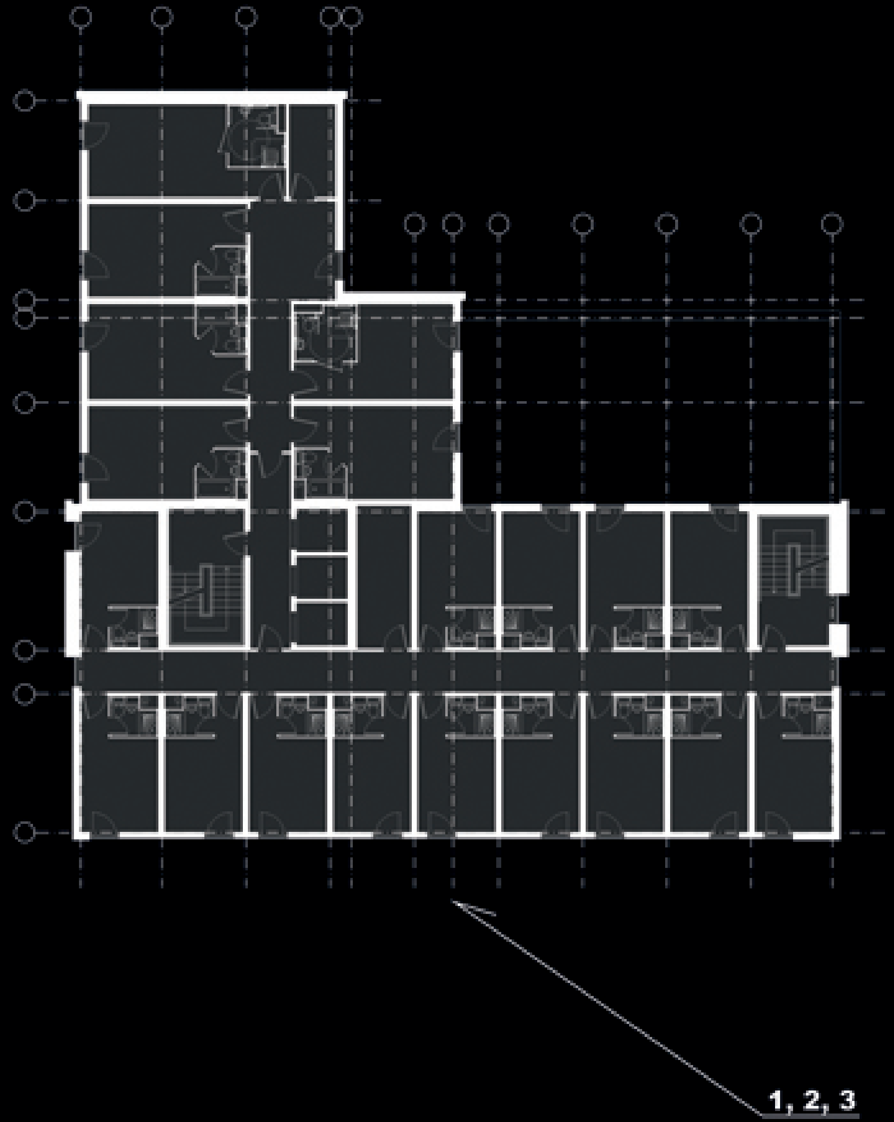
The main contractor was Bower and Kirkland, structural engineer HSP Consulting, and the overall build cost was £7.7m of which the modular contract value was £3.1m.

Modules were installed at a rate of 10 per day over an eight week construction programme.

Module sizes for double room with shower pod were 5380x3150, and the largest module used was 9547x3730. Lift and stair modules were also installed. The tight footprint of the site meant it would have been difficult to build using traditional forms of construction. Manufacturing the modules offsite ensured they could be delivered just in time and without the need for storage space on site.

Case Study courtesy of LightSpeed Construction Ltd, formerly known as Unite Modular Solutions Ltd.





4-3

travelodge hotel

Eco-store for Tesco in Southam, Warwickshire

Tesco utilised the Yorkon off-site approach to deliver a 20,000sqft retail space with uninterrupted spans of 28m in a build programme that was reduced by eight weeks compared with conventional site-based construction. Architects were the Saunders Partnership and main contractors RG CARTER.

24 hour shifts at the Yorkon production centre ensured that the 70 steel framed store modules were manufactured and partially fitted out and craned into position in time for the opening deadline and on budget.

The eco-store features roof-mounted photovoltaic panels, good natural lighting, sun pipes to internal spaces, rainwater harvesting, timber cladding from sustainable sources and air-scoops to enhance natural ventilation.

Internal columns were reduced by 50% to achieve clear internal spans of 28m. The store design also includes back-of-house staff facilities and office accommodation on the first floor.

Special features developed by Yorkon for retail stores are factory installed high performance concrete floors with optional high specification floor finishes, wide range of cladding and glazing options including full height shop front glazing, and modules up to 15m long and 3.3m wide.

Case Study courtesy of Yorkon Ltd.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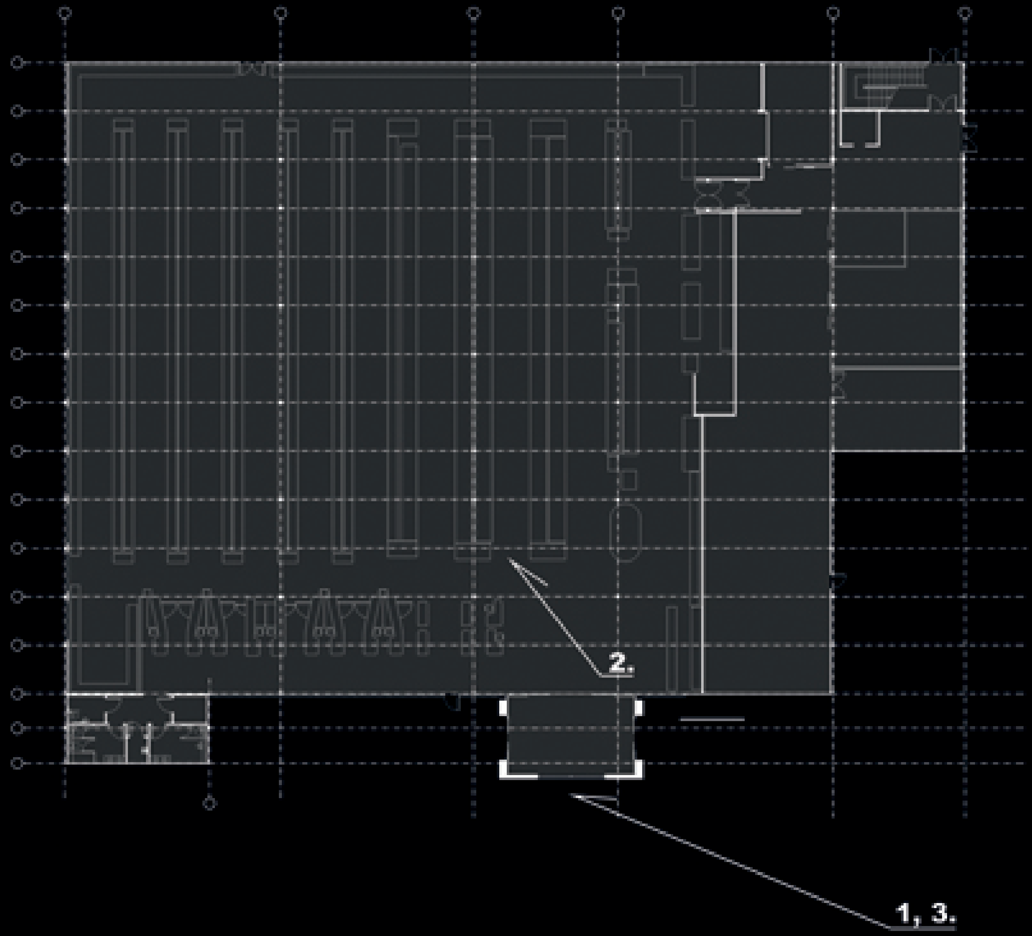

4.4

eco-store for tesco

5.0

credits

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RIBA assessed CPD Material

Core Curriculum topics
- External management: clients, users and delivery of services
- Procurement and contracts
- Designing and building it: structural design, construction, technology and engineering