MODCONS Project Brochure

Modular Construction Research

MODCONS is a project funded by the European Commission under the Framework 7 programme to support Small and Medium Sized Enterprises (SMEs). MODCONS is aimed at developing and extending the use of modular construction systems in the residential building sector in the participating countries of Spain, Finland, Portugal, UK and beyond. The work has involved physical testing, structural modelling, architectural and sustainability studies, and preparation of design guidance in accordance with European standards and Eurocodes.

The project started in January 2013 and was completed in November 2015.

Project Partners

The project partners for MODCONS are:

- **SCI (The Steel Construction Institute)**, based in UK, SCI is the leading, independent provider of technical expertise and disseminator of best practice to the steel construction sector.
- **FutureForm / Renascent**, a UK based modular system supplier, manufacturer and developer.
- **HTA Design**, a leading architectural practice which is a specialist in the housing and residential sector.
- **Technical University of Tampere**, second largest University of technology in Finland.
- **Tecnalia**, a materials-based research organization in the Basque country, Spain.
- **AST,** an engineering company based in Spain active in the development of projects through the use of simulation technology.
- **IA3,** a Spanish engineering company specialized in the study, control and measurement of noise and vibration.
- **Cool Haven,** a Portuguese company focused on development and manufacture of a new modular construction system.
- **University of Coimbra**, a Portuguese University. Established in 1290, it is one of the oldest universities in the world.

Background

The project was one of a few awarded by FP7 for support to SMEs in the construction sector, and it was considered to be innovative in terms of the off-site nature of the construction technology and also the need to develop application rules in Eurocodes and also for CE marking. Modules are highly manufactured products which act as three-dimensional ‘building blocks’ and require a different discipline of design from the linear or planar elements with which designers are generally more familiar. Modular construction can be used for buildings up to 25 storeys, as evidenced by recent projects, and for this scale of construction, questions of stability, robustness, fire resistance, and in some European regions, seismic resistance, are important.

Lifting of a module during construction of a residential building in Finland
(Image courtesy of NEAPO)

Construction of a modular hotel in south London
(Image courtesy of FutureForm)

Modular office / residential building in Portugal
(Image courtesy of CoolHaven)

Work Package 1: Structural Design and Physical Testing

Scope

The scope of work in WP1 concentrated on the preparation of application rules for design in modular construction using steel technologies, which takes account of the nature and practicality of the construction system. The application rules are based on the principles of Eurocode 3 for steel structures, Eurocode 1 for loading (actions) and EN 1090 - Execution of steel structures. This was based on physical tests and use of supporting finite element analyses (FEA) of the tested systems.

Tasks

The scope of work in WP1 was divided into the following tasks:

- Finite element analyses of modules under various actions and support conditions.
- Tests on light steel walls in modular construction in compression and shear.
- Module connection tests.
- Full-scale module tests and analysis.
- Structural guidance for modular systems.

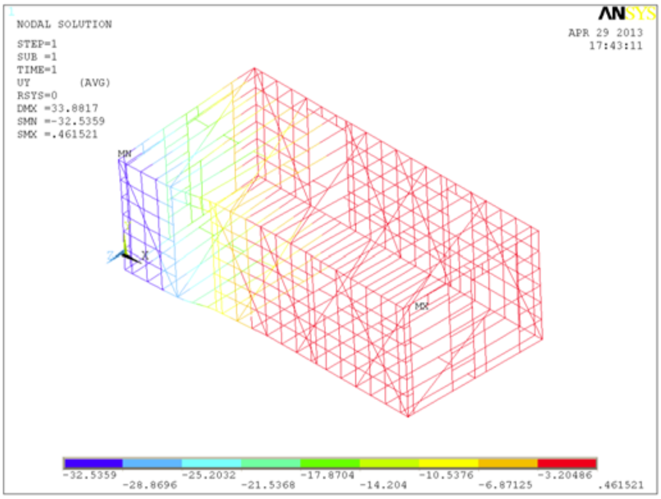

Figure 1 Finite element analysis of module with support around one corner removed

2D and 3D modelling of modules was carried out to determine the distribution of stresses under different support conditions. The support conditions were selected to reflect possibilities of accidental actions i.e. structural robustness.

Wall tests were carried out to determine the influence of boards on the wall resistance in compression and shear (racking). Various board combinations were investigated.

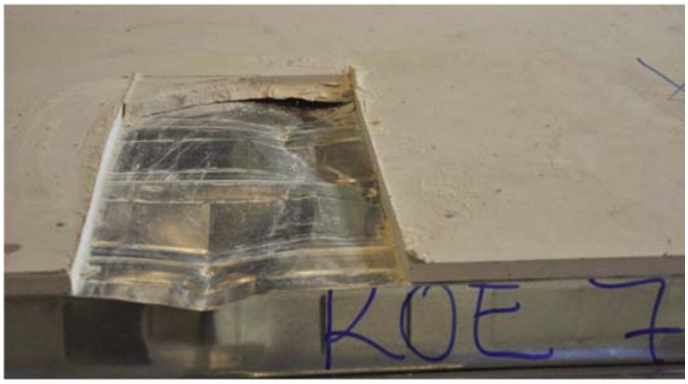

Figure 2 Testing of light steel wall subject to compression with plasterboard attached

Figure 3 Testing of light steel wall subject to shear with timber board attached

Connection tests were carried out to determine the systems performance in relation to transfer of horizontal forces.

Results and Conclusions

The loss of a corner support is the critical case, especially where there are significant openings in the side walls.

Modules can redistribute actions and remain stable (with significant distortion) when the corner support is removed.

Lining materials (boards) provide a significant enhancement (20% to 40%) to the module stiffness.

Plasterboard attached to light steel sections can improve compression resistance by up to a factor of two.

With appropriate horizontal bracing, significant tie forces can be transferred by connection details (i.e. at the module corners).

Eurocode 3 with supporting test data (which is system specific) can be used for the structural design of modular systems and buildings.

Work Package 2: Architectural Themes and Building Typologies

Scope

The scope of WP2 was to develop a diverse range of innovative typologies for modular residential buildings. An important task was to understand future demands and therefore to create building typologies that respond to these needs. The building typologies also take account of the structural characteristics investigated in WP1. This involved close participation of architectural practices experienced in modular construction. The scope of work has developed residential building typologies using modular construction, which take account of; the construction system, spatial requirements, Regulations and planning standards in various countries, such as fire safety, circulation space and disabled access.

Tasks

The scope of work in WP2 was divided into the following tasks:

- Modular system for European residential market.
- Building typologies and apartment arrangements using modular construction.
- Building typologies for high-rise buildings.
- Building typologies for mixed-use buildings.
- Architectural guidance on the developed systems.

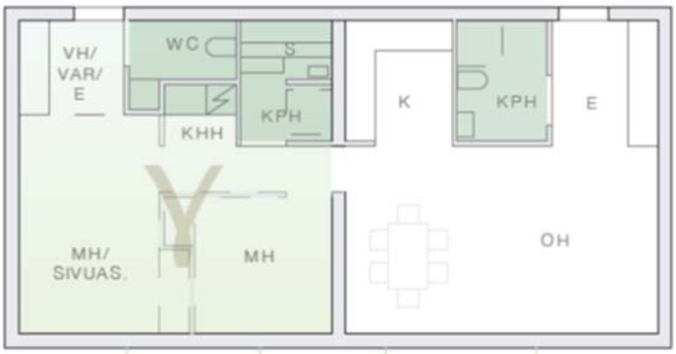

Figure 4 One possible module layout

The regulatory requirements in the participating countries were investigated to determine how these may impact the architectural solution. Other restrictions such as size limits for road transport were also investigated.

Modular building solutions were examined for all types of residential buildings; low-rise, medium-rise and high-rise.

Energy efficiency is relatively straight forward to achieve with modular buildings due to the quality control of production and double skin insulated construction.

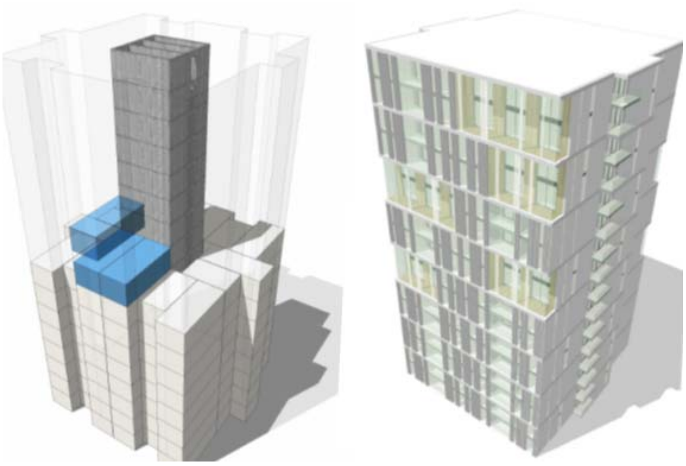

Figure 5 Modular system layout for high-rise buildings

Figure 6 Modular hotel demonstrating use for a mixed-use building

Minimum space criteria and fire escape routes affect the architectural layout of all buildings, particularly for mixed-use buildings where fire requirements may vary.

Results and Conclusions

A significant consideration for modular construction is that modules must be of an appropriate size for transportation, a practical limit is 4.3m wide.

Modules can be used effectively for modification of existing buildings e.g. roof top extensions.

Modular systems can be used for all types of residential building, and 75% of all buildings in Europe are used for domestic purposes.

With inventive architectural design, modular construction is extremely versatile and satisfies all the requirements of modern buildings.

Work Package 3: Seismic Design of Modular Buildings

Scope

In WP3 various scenarios and intensities of seismic events have been considered which have been modelled statically by progressive 'failure' of the connections between the modules.

Dynamic models have been performed to establish the natural frequency of the assembly of modules taking account of the 'spring' connections. The compatibility of equivalent static and dynamic models has been investigated in order to develop design rules for the stability of modular buildings in seismic action.

Strategies to prevent collapse of modular buildings in severe seismic events have been evaluated. In high-rise buildings, stiff braced cores and floors can be introduced, so that progressive failure of a large number of modules is prevented.

Tasks

The scope of work in WP3 was divided into the following tasks:

- Finite element analyses (FEA) to Eurocode 8 and dynamic modelling of modular buildings.
- Finite element modelling of mixed use buildings.
- Strategies for seismic design of modular buildings.

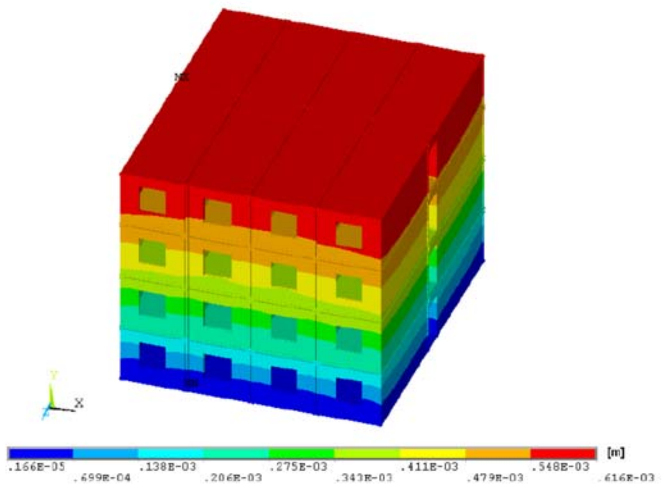

Figure 7 Low-rise building subject to horizontal actions

Many different building types were modelled with finite element analysis (FEA) and subjected to seismic horizontal loading. Modular buildings with 4, 8 and 12 storeys were considered. Structures with podiums at the ground floor level and independent bracing were considered.

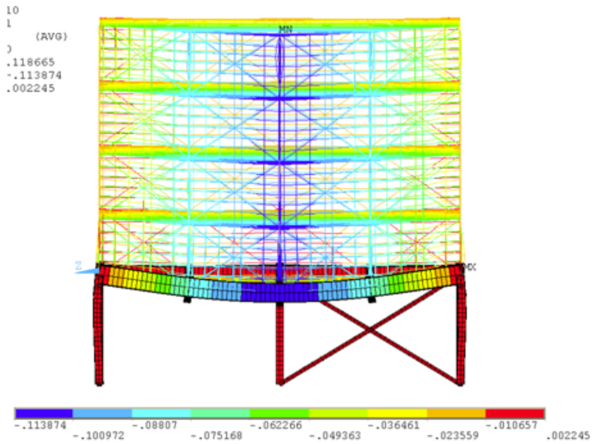

Figure 8 FEA of modules supported on a podium structure in a mixed-use development

A building core changes the load transfer between the modules and to the core as shown in Figure 9.

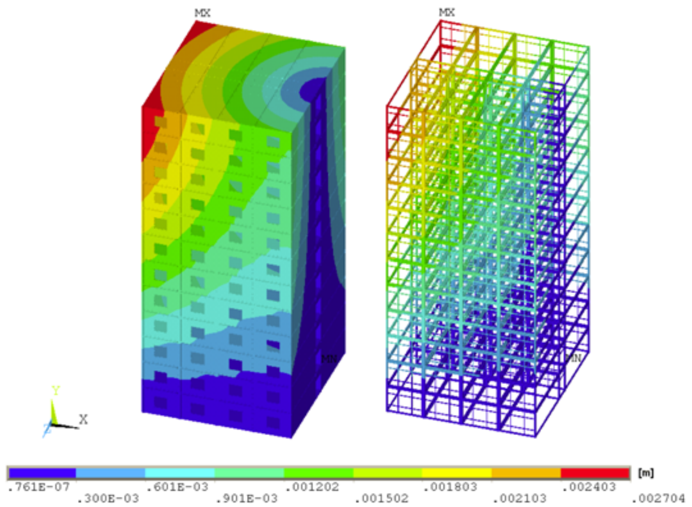

Figure 9 FEA of high-rise modular building with support from a stiff core

Results and Conclusions

Structures with modules supported on a podium structure perform very well in seismic events, even if one column of the podium is assumed to be ineffective.

High rise buildings generally require a separate bracing system or concrete core, which changes the load transfer between the modules.

Pre-stressed bolted connections between modules can be twice as effective for energy absorption during seismic loading.

Modules with structural hollow section rigid frames perform well in seismic events.

Work Package 4: Sustainable Design of Modular Buildings

Scope

The scope of WP4 was to consider the sustainability of modular systems by:

- Quantification of the sustainability benefits of the construction process, based on measures such as; site impacts and disruption to the neighbourhood, safety, transport, waste reduction and recycling, use of recycled materials etc.
- Quantification of the operational energy benefits of modular construction and particularly comparison of design versus as-built operational energy use and other performance measures, such as over-heating and effective ventilation.
- Embodied carbon comparisons and the effective integration of renewable energy technologies in modular construction, which may be part of the module or attached to the modules.

Tasks

The scope of work in WP4 was divided into the following tasks:

- Sustainability benefits of modular construction.
- Energy performance of modular buildings.
- LCA embodied carbon and use of renewable energy technologies.

Figure 10 Modular residential building in west London designed for high energy efficiency

Extensive research was carried out into the sustainability benefits of modular construction this included the factory based activities and the following site based activities.

The energy performance of a modular development was monitored and the data analysed. The variation of energy use was highly dependent upon occupier behaviour. The average use was within the design prediction.

Embodied carbon comparison of modular and traditional build was carried out. This showed a light steel modular system has 20% lower embodied carbon than an equivalent concrete frame.

Figure 11 Re-use of modular house with good sustainability credentials

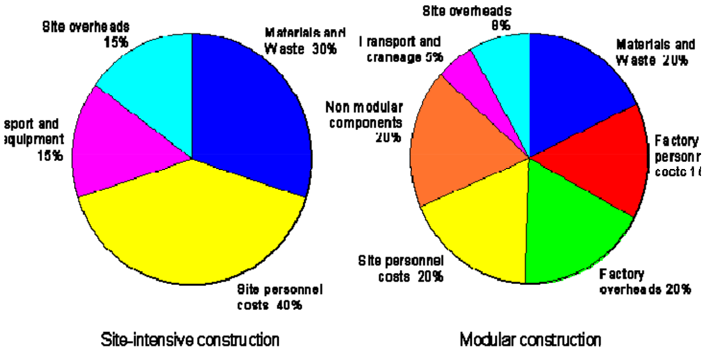

Figure 12 Comparison of breakdown of costs of site-intensive and modular construction

Results and Conclusions

The sustainability benefits of modular construction are:

- Increased speed of construction (50% faster than concrete frame construction).
- Reduced site management cost.
- Improved safety (5 times safer than fully on-site construction).
- Reduced waste and landfill charges, and more opportunities for recycling.
- Higher productivity (fewer personnel on site).
- Reduced disruption to the locality by noise and traffic with fewer deliveries of materials.
- Renewable energy systems can be integrated.

Modular construction is significantly different to traditional construction and therefore it is important that the main contractor on the project is experienced with modular construction.

Work Package 5: Acoustic Design of Modular Buildings

Scope

The objective of WP5 was to prove the acoustic characteristics of the modular systems in compliance with basic regulatory requirements, and then to achieve 3 and 5 dB improvements in acoustic insulation based on the double layer nature of modular systems. This was done by examination of the details of the modular systems in terms of control of airborne and impact sound transfer, taking into account the module to module connections. Laboratory measurements of the acoustic performance of modules relative to adjacent modules. The field performances of modular buildings was evaluated in relation to laboratory measurements, and significant differences investigated.

Tasks

The scope of work in WP5 was divided into the following tasks:

- Defining the requirements for acoustic design of a modular building.
- Laboratory measurement of acoustic performances of lightweight elements.
- Acoustic design of junctions between elements by tests on module junctions.
- Field tests on real buildings for acoustic performance of modular buildings.

Figure 13 Preparation of wall panel for acoustic testing

Acoustic requirements for modular residential buildings in various parts of Europe were investigated. The methods allowed for demonstration of compliance were also examined.

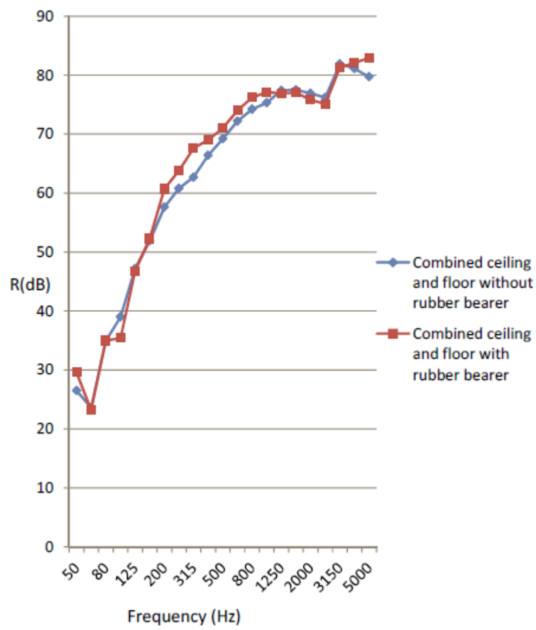

Figure 14 Sound insulation results for test of floors

Test Result	Airborne $D_{nTw} + C_{tr}$	Impact L_{nTw}
Floor	58dB > 45dB	50dB < 62dB
Walls	57dB > 45dB	NA

Figure 15 Results of wall and floor tests compared to required performance

Laboratory testing of floors, walls and connections was carried out, some of the results are shown in Figure 14 and Figure 15.

Results and Conclusions

Different parts of Europe demand different levels of sound insulation between rooms.

Modular construction systems provide the required level of acoustic performance by at least 5dB.

Flanking sound at junctions is reduced by the discontinuous nature of the connections in modular construction.

The number, type and thickness of boards used for wall and ceiling linings contribute significantly to the level of sound insulation achieved.

The modular system studied achieved excellent acoustic performance in laboratory testing and demonstrated by field testing of completed buildings.

Work Package 6: Dissemination and Exploitation

Scope

The objective of WP6 was to publicise the information obtained from the project in terms of: architectural information describing the building typologies and details for high-rise and mixed use buildings, structural design guidance on high-rise and mixed use buildings to Eurocode 3, seminars to present the results of the project, case studies on buildings using the developed technologies and sustainability guidance on modular construction.

Tasks

The scope of work in WP6 was divided into the following tasks:

- Seminars to promote the development of modular systems.
- Case studies on high-rise modular projects.
- Participation in sectorial fairs and shows.
- Production of project website.
- Submission of articles for technical publications.
- Creation of video clips on modular construction.
- Issue of a Wikipedia page on the project.
- Conformity of the developed systems with regulatory requirements.
- Production of a project brochure.

Figure 16 Covers from 2 case studies produced in the project

A project website has been created and is available at www.modcons-research.eu. The website includes many of the dissemination outputs from the project, such as case studies, video clips, presentations and brochures.

A total of 8 case studies have been created and can be viewed on the website. Video links are also available from the website.

Figure 17 MODCONS website – www.modcons-research.eu

A guide to the architectural design of modular buildings has been produced to give an overview of what can be achieved with modular systems.

Figure 18 Extract page from the architectural guidance

Magazine articles and technical papers have been produced and more are planned.

Results and Conclusions

All of the tasks listed have been achieved. Some of the publication related activities will take some time to be made public. Updates on these activities will be communicated through the project website and direct communication from the project partners.

Sources of Information

Reports and publications

Many reports have been produced during the course of the MODCONS project. These reports detail the specific research carried out on the proprietary modular systems examined during the project. Therefore, the contents is commercially important for those companies.

The MODCONS website is the most appropriate source of public information coming from the project.

Alternatively, contact details are provided for the companies involved with the MODCONS project and these may be contacted for more information if required.

Contact Details

SCI (The Steel Construction Institute)
http://www.steel-sci.com/

FutureForm / Renascent
http://www.futureformltd.com/

HTA Design
http://www.hta.co.uk/

Technical University of Tampere
http://www.tut.fi/en/home

Tecnalia
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