CESARE'22

3rd Coordinating Engineering for Sustainability And Resilience
May 6th – May 9th, 2022, Irbid, Jordan
ISSN:2788-6204

MODULAR BUILDING CONNECTIONS: A REVIEW

Konstantinos Daniel Tsavdaridis[1], Dan-Adrian Corfar[2]

[1] Professor of Structural Engineering, School of Mathematics, Computer Science and Engineering, City, University of London, London, EC1V 0HB, UK
e-mail: konstantinos.tsavdaridis@city.ac.uk; web page: https://kostasdaniel.blogspot.com/

[2] PhD Candidate, School of Mathematics, Computer Science and Engineering, City, University of London, London, EC1V 0HB, UK
e-mail: Dan.Corfar@city.ac.uk

Keywords: Inter-Module Connections, Modular Building Systems, Demountability, Reusability, Multi-Attribute Ranking, Damage Control.

Abstract. *Recently the development of inter-module connections (IMCs) for steel modular building systems (MBSs) has gained traction with many researchers and engineers being in pursuit of universally performant connection systems. While numerous studies reviewed IMCs for hot-rolled steel MBSs, most of them focused on a limited number of connections and were inconsistent in naming conventions and classification methods, posing a challenge for the development of new and meaningful connections. The present study aims to provide a harmonised overview of the existing literature by proposing a unified nomenclature and a systematic classification based on the method of joining. A multi-attribute ranking system was developed and employed to identify "must-have" features for the development of future designs and key areas of improvement for existing configurations, serving as a useful decision-making tool for both researchers and practitioners concerned with this topic.*

1. INTRODUCTION

Modular Building Systems (MBSs) are a Modern Method of Construction (MMC) which adopts principles of Offsite Manufacturing (OSM) and Offsite Construction (OSC), delivering ready-to-install, fully finished structural modules; MBSs enable reduced manufacturing costs due to standardisation and mass production, speed of onsite construction guaranteed by straight-forward assembly sequences, and superior end-products delivered by better quality control and improved accuracy of production lines [1]. These innate advantages have bolstered the confidence to adopt steel MBSs in the high-rise construction sector, where corner-supported modules are typically preferred for the high buckling resistance of hot-rolled steel SHS columns and the planning freedom of unobstructed walls [2].

To date, several studies have investigated the structural behaviour of multi-storey and high-rise steel MBSs [3–7], reaching a consensus that inter-module connections (IMCs) are paramount in the structural performance of steel MBSs. In the past decade, the development of IMCs for hot-rolled steel MBSs has gained traction, putting researchers and engineers in pursuit of universally performant connection systems. This led to the development of a large and growing volume of proposed IMCs that introduced a pressing need for harmonisation of the literature to promote a well-structured development of future designs. While numerous studies reviewed IMCs for hot-rolled steel MBSs, even the most noteworthy of them [8–12] focused on a limited number of connections and were inconsistent in naming conventions and classification methods, posing a challenge for the development of new and meaningful connections.

The present study aims to provide a harmonised overview of the existing literature by proposing a unified nomenclature and a systematic classification based on the method of joining. The main advantages of this classification stem from its consistency all-throughout based on joint typologies and the scalability that supports its adoption and further expansion as new connections are proposed. Moreover, a new multi-attribute ranking system was developed and employed to identify "must-have" features and key areas of improvement for existing connections.

2. STATE-OF-THE-ART INTER-MODULE CONNECTIONS

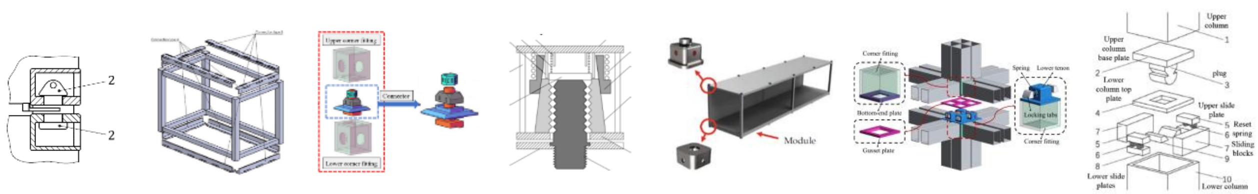
In the present section the wide and often tangled literature of IMCs for hot-rolled steel MBSs was systematically re-organised, drawing attention to the key features of these systems. IMCs were classified and labelled under three main categories, based on the main coupling method: locking devices (**LD01-07**), post-tensioned (**PT01-06**), and bolted joints (**CTC01-16, BTB01-12, FTF01-19**).

2.1. IMCs with locking devices

Seven innovative IMCs were identified in this category (Table 1**.** In general, these joints used either tool-driven or gravity-actioned mechanisms as showed in Figure 1.

ID code	Joint typology	ID code	Joint typology
LD01 [13]	Twistlock	LD05 [14]	Torque-activated pin device
LD02 [15]	Interlocking grooves	LD06 [16]	Self-locking spring-activated tabs
LD03 [17]	Rotary device and screwed nut	LD07 [18]	Self-locking spring-activated sliding blocks
LD04 [19]	Self-locking plug-in device		

Table 1 : IMCs with locking devices



LD01 **LD02** **LD03** **LD04** **LD05** **LD06** **LD07**

Figure 1. IMCs with locking devices

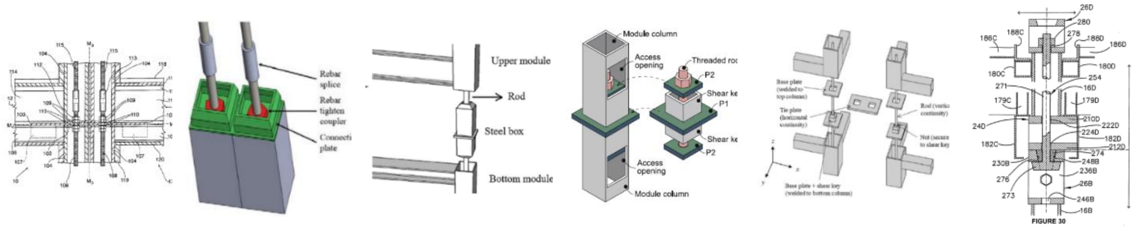
2.2. Post-tensioned (PT) IMCs

PT IMCs (Table 2) consisted of rods inserted through hollow sections (continuously throughout the full length of columns). When necessary, bar continuity was ensured by couplers or sleeve nuts, while nuts tightened the rods to connecting plates, which could also enhance the shear force transfer by various types of shear keys (Figure 2).

ID code	Joint typology	ID code	Joint typology
PT01 [20]	PT rods through SHS columns	PT04 [21]	PT rods coupled through shear keys
PT02 [22]	PT rods clamped through shear keys	PT05 [23]	PT rods coupled through shear keys
PT03 [24]	PT rods coupled through steel boxes	PT06 [25]	PT rods through SHS columns

Table 2 : Post-tensioned IMCs

ISSN:2788-6204



PT01 **PT02** **PT03** **PT04** **PT05** **PT06**

Figure 2. Post-tensioned IMCs

2.3. Bolted IMCs

Bolted IMCs were the most diverse type of IMCs, using common, easy-to-manufacture steel parts such as corner fittings, plates, bolts, screws, nuts, washers, and other components like pins, tenons, spigots, or rubber layers. Due to the multitude of existing configurations, these connections were further classified based on joint type.

2.3.1. Column-to-column (CTC) connections

The most common typology of bolted IMCs are CTC joints (Table 3) derived from classic splice joints for tubular sections, with plates which are welded to the ends of the hollow sections and clamped together by bolts (Figure 3).

ID code	Joint typology	ID code	Joint typology
CTC01 [26]	Vertical and horizontal plates	CTC09 [27]	Intermediate plates and interior bolts
CTC02 [28]	Up-down I beams	CTC10 [29]	Cruciform plate
CTC03 [30]	Cover plate with blind bolts	CTC11 [31]	Interlocking pins and connecting plates
CTC04 [32]	Bonded sleeve splice joint	CTC12 [33]	Connecting plates and resilient layers
CTC05 [34]	Connecting plate and access holes	CTC13 [35]	In-build tenon and side-plates
CTC06 [36]	Extended connection plate	CTC14 [37]	Shape-memory alloy (SMA) bolts
CTC07 [38]	Bolted intermediate plate	CTC15 [39]	Guiding tenons and internal steel pipes
CTC08 [40]	Overlaying extended endplates	CTC16 [41]	Interconnecting tube and nut

Table 3 : Column-to-columns bolted IMCs

ISSN:2788-6204

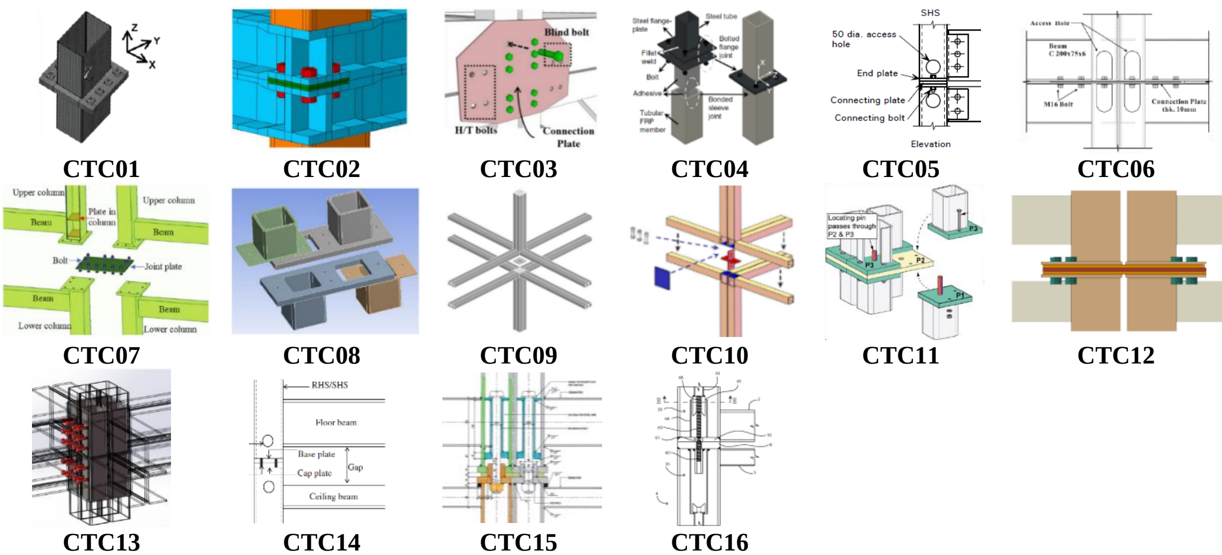


Figure 3. Column-to-column bolted IMCs

2.3.2. Beam-to-beam (BTB) connections

BTB connections relocate the joint between floor and ceiling beams (Table 4). The common elements employed in this type of connection are gusset plates of various geometries, engineered to closely fill the gaps between modules, optimising the unusable space between each of the floor and ceiling cassettes (Figure 4).

ID code	Joint typology	ID code	Joint typology
BTB01 [42]	Cruciform plate	BTB07 [43]	Interpenetrating tenon devices
BTB02 [44]	Connector plates	BTB08 [45]	Cross-shaped plug-in connector
BTB03 [46]	Steel gusset plates	BTB09 [47]	Bolted plug-in adapter with spring pins
BTB04 [22]	Bolted intermediate tenon plate	BTB10 [48]	Bolted gusset plates
BTB05 [49]	Cruciform socket-shaped tenon	BTB11 [50]	Plug-in tenon and high-strength and blind bolts
BTB06 [51]	Plug-in tenon device	BTB12 [52]	Bolted PFC double beam

Table 4 : Beam-to-beam bolted IMCs

ISSN:2788-6204

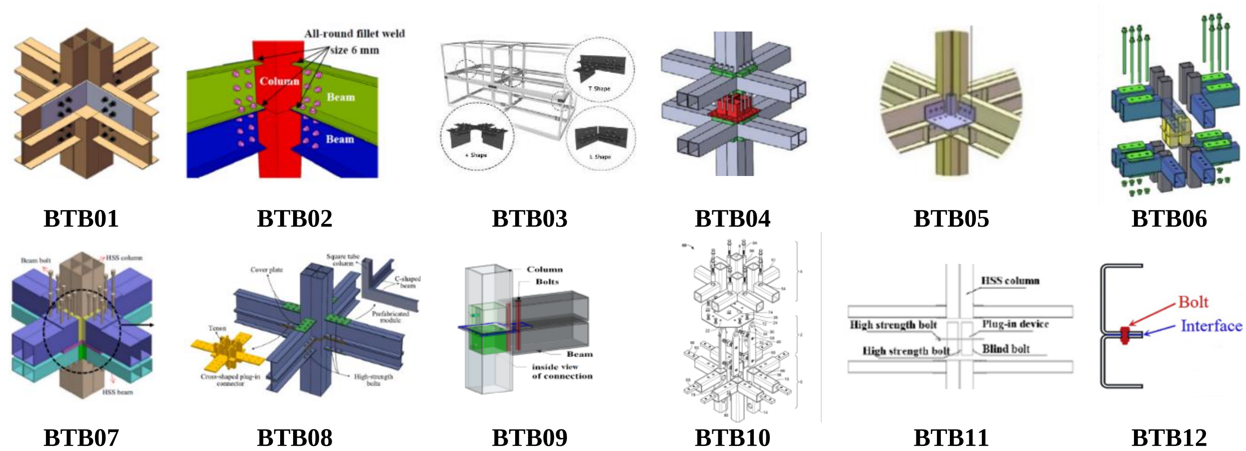


Figure 4. Beam-to-beam bolted IMCs

2.3.3. Fitting-to-fitting (FTF) connections

The third type of bolted IMCs stems from the common feature of engaging modules through corner fittings (Table 5). The shape of these cast corners ranges from the classic ISO design adopted from shipping containers to more refined and computationally optimised topologies (Figure 5).

ID code	Joint typology	ID code	Joint typology
FTF01 [53]	Steel hollow cube bracket	FTF11 [54]	Square pipe blocks with internal circular pipes
FTF02 [55]	Intermediate plate	FTF12 [56]	Gusset plates and locating pins
FTF03 [57]	Gusset plates and locating pins	FTF13 [25]	Bolted corner fittings
FTF04 [58]	Tie plates and spigots	FTF14 [59]	Vertical bolts through columns
FTF05 [60]	Tie plates and twist locks	FTF15 [61]	Corner fittings with internal threaded aperture
FTF06 [62]	Rubber isolator and steel clamps	FTF16 [63]	Corner fittings with rubber isolation
FTF07 [64]	Transverse clamps	FTF17 [65]	Bolted endplates and intermediate plates
FTF08 [64]	Cross-shaped clamp	FTF18 [66]	External bolts and positioning plate
FTF09 [64]	X-shaped clamp	FTF19 [67]	Cruciform plate and horizontal bolts
FTF10 [64]	Bolted corner fittings		

Table 5 : Fitting-to-fitting bolted IMCs

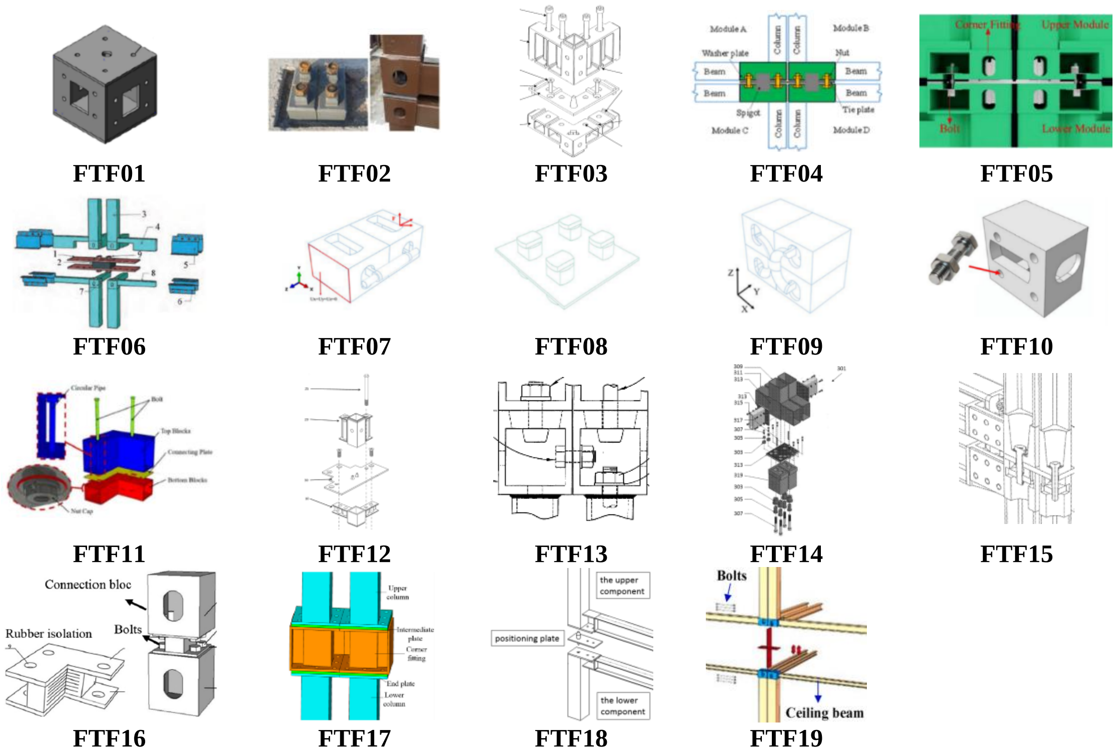


Figure 5. Fitting-to-fitting bolted IMCs

3. MULTI-ATTRIBUTE RANKING OF IMCS

3.1. The framework of the proposed scoring system

The scoring system (Table 6) was based on the same three core criteria used by Srisangeerthanan et al. [12], namely, structural, manufacturing and constructional performance attributes, while the scale and marking criteria were fully re-configured by adopting a more holistic perspective based on qualitative analysis. Additionally, characteristics such as design resilience through re-centring and energy dissipation, reusability and design flexibility were not explicitly considered in the metrics of the previous study and were thus included in the present review. Scoring for all attributes was done on 3-point rating scales, except for the vertical and horizontal load transfer (VH) attribute where a 0-1 integer scale was adopted based on whether a connection met or not the criterium. The maximum possible score for a system was 25 points, while the minimum a connection could score was 8.

In lack of consistent quantitative data about the designs considered, a qualitative approach based on visual inspection combined with engineering knowledge and intuition was adopted in the characterisation of the connection systems. Weightings were kept equal to ensure an overall level of impartiality. Nevertheless, it is believed that through the scoring metrics proposed herein a practical, comprehensive, and scalable multi-attribute ranking system was achieved, which could be used as is or tailored by researchers and practising engineers for other specific objectives.

ISSN:2788-6204

A. Structural performance metrics		
Metric	Score	Description
VH	0	Does not meet the requirement
	1	Meets the requirement
DR	1	Low energy dissipating capability, no self-centring
	2	Moderate energy dissipating capability, moderate or no self-centring
	3	Good energy dissipating capability, self-centring
FD	1	Limited scaling opportunities
	2	Moderate scaling opportunities
	3	Good scaling opportunities
B. Constructional performance metrics		
Metric	Score	Description
DfA	1	Complex: no self-aligning features, large number of tasks, difficult access, complex tooling
	2	Moderate: self-aligning features, moderate number of tasks, moderate access, moderate tooling
	3	Lean: efficient self-aligning features, small number of tasks, easy access, simple tooling
DfD	1	Difficult to disassemble
	2	Easy to disassemble and parts of the assembly need to be replaced
	3	Easy to disassemble and parts of the assembly can be reused
TC	1	Limited tolerance control
	2	Moderate tolerance control
	3	Good tolerance control
C. Manufacturing performance metrics		
Metric	Score	Description
JC	1	Numerous parts; complex geometry; complex manufacturing sequences; difficult to mass-produce;
	2	Moderate number of parts; reasonable geometry; moderate manufacturing sequences; reasonable to mass-produce
	3	Small number of parts; Easy-to-manufacture geometry; easy to mass-produce;
EI	1	Difficult integration of connection parts into final joint (e.g., welding of complex parts)
	2	Reasonable integration of connection parts into final joint (e.g., fastening)
	3	Simple joint configuration (e.g., no post-manufacturing integration required or fast procedures such as inter-locking)
EP	1	Demanding pre-attachment process (e.g., welding of additional components to finished modules)
	2	Reasonable pre-attachment process (e.g., fastening of additional components to finished modules, drilling holes)
	3	Easy pre-attachment process (e.g., no additional components required, or connection parts are already integrated into module framing i.e., corner fittings)
Notes: VH - Vertical and horizontal connectivity; DR – Design resilience; DF – Design flexibility; DfA – Design for Assembly; DfD – Design for Disassembly; TC – Tolerance control; JC – Joint complexity; EI – Ease of integration; EP – Ease of pre-assembly		

Table 6 : Description of the proposed scoring system

4. APPLICATION OF THE PROPOSED SCORING SYSTEM

The multi-attribute rankings presented herein were used to determine the highest-scoring IMCs for each performance category, revealing the most promising IMCs per attribute as well as the best-performing system for each type of connection.

4.1. Overall ranking

In this section the discussion focused on the highest overall scoring IMCs and their bespoke characteristics, illustrated in Figure 6, while complete data, plots and scoring method for each metric are available in the full review study [68].

Overall, the highest scoring systems were **FTF06** and **FTF11** joints with totals of 21 points each. **FTF06** scored best in metrics such as DR, DF, DfD and TC due to its flexible, resilient, and demountable configuration. The only improvements could be reducing the number of bolts which require on-site tensioning, while manufacturing complexity of the lead-rubber bearing may be mitigated by using a high damping rubber bearing instead.

The next four joints were **FTF19**, **FTF12**, **FTF03**, and **BTB09**, coming second with totals of 20 points. These joints displayed well-balanced scores for all metrics, demonstrating robust IMCs which could be improved in terms of resilience, reuse opportunities or complexity of fabrication.

Next two IMCs scored 19 points each, achieving medium scores in almost all metrics. The **CTC11** system highlighted the efficiency of common and easy to manufacture features such as interlocking pins and bolted endplates, while adding means of energy dissipation and damage control would help improving its resilience and demountability. Connection **CTC12** had an efficient configuration made of common parts with good energy dissipation provided by the rubber layers, yet the inclusion of self-aligning features and mitigating the difficulties in repairing or replacing the damaged endplates after an earthquake could be considered for improving its structural and constructional metrics.

In the end, it must be noted that the purpose of the ranking discussed above was not to suggest that one IMC would be better than all the others, as there is no fit-for-all solution in multi-dimensional problems like that of assessing the performance of IMCs. As the discussion demonstrates, the proposed framework is useful in revealing key features which make efficient designs both in terms of structural, constructional, and manufacturing aspects, while it also uncovers areas which require improvement, serving as a good starting point for future research directions.

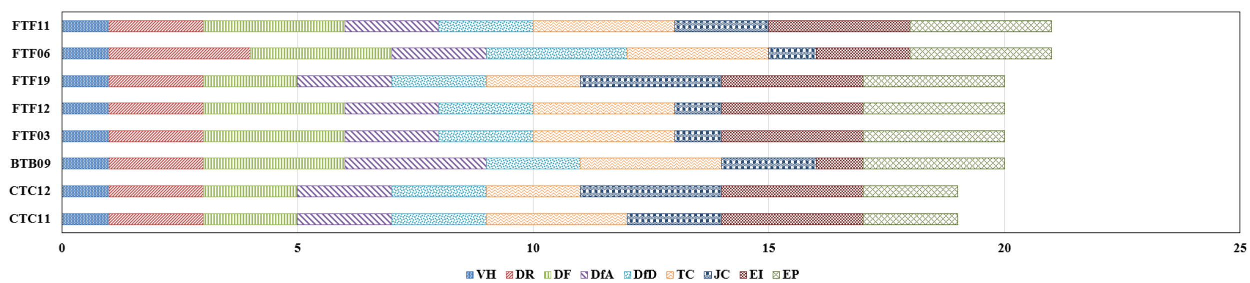


Figure 6. Overall ranking of IMCs

5. CONCLUDING REMARKS

This study provided a harmonised overview of the relevant literature, having reviewed, classified, and indexed sixty IMCs using a unified nomenclature and a systematic and consistent classification system based on joint typology.

A new multi-attribute ranking method was developed using a qualitative approach, holding a certain degree of subjectivity. Nevertheless, the adoption of the proposed multi-attribute ranking system can facilitate future designs, as well as enhance existing connections in low-scoring areas, serving as a useful decision-making tool for both researchers and practitioners concerned with this topic.

The multi-attribute ranking system revealed that the use of corner fittings, bolted joints, self-aligning/locating parts, and damage control devices were all must-have features for IMCs with all-round performance.

More focus should be put on addressing the hindered demountability and reuse opportunities caused by the lack of seismic resilience. The viscoelasticity of elastomers and superelasticity of SMAs were noteworthy recommendations in the future research of smart and resilient IMCs for steel MBSs.

REFERENCES

[1] Goodier, C and Gibb, A. (2007), "Future opportunities for offsite in the UK", *Construction Management and Economics*, Vol. 25, pp. 585-595.

[2] Lawson, R.M., Ogden, R.G. and Goodier, C. (2014), *Design in Modular Construction*, CRC Press, Oxon.

[3] Lacey, A.W., Chen, W., Hao, H. and Bi, K. (2018), "Structural response of modular buildings – An overview", Journal of Building Engineering, Vol. 16, pp. 45–56.

[4] Ferdous, W., Bai, Y., Ngo, T.D., Manalo, A. and Mendis, P. (2019), "New advancements, challenges and opportunities of multi-storey modular buildings – A state-of-the-art review", *Engineering Structures,* Vol. 183, pp. 883–893.

[5] Thai, H.-T., Ngo, T. and Uy, B. (2020), "A review on modular construction for high-rise buildings", *Structures,* Vol. 28, pp. 1265–1290.

[6] Ye, Z., Giriunas, K., Sezen, H., Wu, G. and Feng, D.-C. (2021), "State-of-the-art review and investigation of structural stability in multi-story modular buildings", *Journal of Building Engineering*, Vol. 33, article no: 101844.

[7] Wang, Z. and Tsavdaridis, K.D. (2022), "Optimality criteria-based minimum-weight design method for modular building systems subjected to generalised stiffness constraints: A comparative study", *Engineering Structures*, Vol. 251, article no: 113472.

[8] Deng, E.-F., Zong, L., Ding, Y., Zhang, Z., Zhang, J.-F., Shi, F.-W., Cai, L.-M. and Gao, S.-C. (2020), "Seismic performance of mid-to-high rise modular steel construction - A critical review", *Thin-Walled Structures*, Vol. 155, article no: 106924.

[9] Chen, Z., Khan, K., Khan, A., Javed, K. and Liu, J. (2021), "Exploration of the multidirectional stability and response of prefabricated volumetric modular steel structures", *Journal of Constructional Steel Research*, Vol. 184, article no: 106826.

[10] Lacey, A.W., Chen, W., Hao, H. and Bi, K. (2019), "Review of bolted inter-module connections in modular steel buildings", *Journal of Building Engineering,* Vol. 23, pp. 207–219.

[11] Li, Z., Tsavdaridis, K.D. and Gardner L. (2021), "A Review of Optimised Additively Manufactured Steel Connections for Modular Building Systems", *Industrializing Additive Manufacturing - Proceedings of AMPA2020*, pp. 357–373.

[12] Srisangeerthanan, S., Hashemi, M.J., Rajeev, P., Gad, E. and Fernando, S. (2020) "Review of performance requirements for inter-module connections in multi-story modular buildings", *Journal of Building Engineering,* Vol. 28, article no: 101087.

[13] BSI (2017), *Series 1 freight containers - Handling and securing*, BSI, London.

[14] Srisangeerthanan, S., Hashemi, M.J., Rajeev, P., Gad, E. and Fernando, S. (2021), "Fully-Modular Buildings Through a Proposed Inter-module Connection", *Proceedings of the 10th International Conference on Structural Engineering and Construction Management (ICSECM 2019),* pp. 303–312.

[15] Sharafi, P., Mortazavi, M., Samali, B. and Ronagh, H. (2018), "Interlocking system for enhancing the integrity of multi-storey modular buildings", *Automation in Construction*, Vol. 85, pp. 263–272.

[16] Chen, Z., Wang, J., Liu, J. and Khan, K. (2021) "Seismic behavior and moment transfer capacity of an innovative self-locking inter-module connection for modular steel building", *Engineering Structures,* Vol. 245, article no: 112978.

[17] Chen, Z., Liu, Y., Zhong, X. and Liu, J. (2019), "Rotational stiffness of inter-module connection in mid-rise modular steel buildings", *Engineering Structures*, Vol. 196, article no: 109273.

[18] Liu, J., Chen, Z. and Wang, J. (2020), *Sliding Block Type Modular Building Self-Locking Connection Node (in Chinese)*, CN 111287331 A.

[19] Dai, X.-M., Zong, L., Ding, Y. and Li, Z.-X. (2019), "Experimental study on seismic behavior of a novel plug-in self-lock joint for modular steel construction", *Engineering Structures*, Vol. 181, pp. 143–164.

[20] Farnsworth, D. (2016), *Modular building unit connection system*, US9366020B2.

[21] Lacey, A.W., Chen, W., Hao, H., Bi, K. and Tallowin, F.J. (2019), "Shear behaviour of post-tensioned inter-module connection for modular steel buildings", *Journal of Constructional Steel Research,* Vol. 162, article no: 105707.

[22] Pang, S.D., Liew, J.Y.R., Dai, Z. and Wang, Y. (2016), "Prefabricated Prefinished Volumetric Construction Joining Techniques Review", *Modular and Offsite Construction (MOC) Summit,* Edmonton, Alberta, Canada, 29 September – 01 October 2016, pp. 249-256.
[23] Chua, Y.S., Liew, J.Y.R., and Pang, S.D. (2018), "Robustness of Prefabricated Prefinished Volumetric Construction (PPVC) High-rise Building", *12th international conference on 'Advances in Steel-Concrete Composite Structures (ASCCS),* Valencia, Spain, 27-29 June 2018, pp. 913-919.
[24] Sanches, R., Mercan, O. and Roberts, B. (2018), "Experimental investigations of vertical post-tensioned connection for modular steel structures", *Engineering Structures,* Vol. 175, pp. 776–789.
[25] Epaminondas, K. (2016), *Unitised Building System,* AU2016206222B2.
[26] Styles, A.J., Luo, F.J., Bai, Y. and Murray-Parkes, J.B. (2016), "Effects of joint rotational stiffness on structural responses of multi-storey modular buildings", *Proceedings of the International Conference on Smart Infrastructure and Construction (ICSIC),* Cambridge, UK, 27-29 June 2016, pp. 457–462.
[27] Wang, Y., Xia, J., Ma, R., Xu, B. and Wang, T. (2019), "Experimental Study on the Flexural Behavior of an Innovative Modular Steel Building Connection with Installed Bolts in the Column", *Applied Sciences,* Vol. 9, article no: 3468.
[28] Chen, C., Cai, Y.Q. and Chiew, S.P. (2014), "Finite Element Analysis of Up-down Steel Connectors for Volumetric Modular Construction", *12th International Conference on Steel, Space and Composite Structures,* Prague, Czech Republic, 28-30 May 2014, pp. 173–179.
[29] Deng, E.-F., Zong, L., Ding, Y., Dai, X.-M., Lou, N. and Chen, Y. (2018), "Monotonic and cyclic response of bolted connections with welded cover plate for modular steel construction", *Engineering Structures,* Vol. 167, pp. 407–419.
[30] Cho, B.-H., Lee, J.-S., Kim, H. and Kim, D.-J. (2019), "Structural Performance of a New Blind-Bolted Frame Modular Beam-Column Connection under Lateral Loading", *Applied Sciences,* Vol. 9, article no: 1929.
[31] Lacey, A.W., Chen, W., Hao, H. and Bi, K. (2019), "New interlocking inter-module connection for modular steel buildings: Experimental and numerical studies", *Engineering Structures,* Vol. 198, article no: 109465.
[32] Qiu, C., Bai, Y., Zhang, L. and Jin, L. (2019), "Bending Performance of Splice Connections for Assembly of Tubular Section FRP Members: Experimental and Numerical Study", *Journal of Composites for Construction*, Vol. 23, article no: 04019040.
[33] Sendanayake, S.V., Thambiratnam, D.P., Perera, N., Chan, T. and Aghdamy, S. (2019), "Seismic mitigation of steel modular building structures through innovative inter-modular connections", *Heliyon*, Vol. 5, article no: e02751.
[34] SCI (2007), *Building Design Using Modules*, SCI, Berkshire.
[35] Ma, R., Xia, J., Chang, H., Xu, B. and Zhang, L (2021), "Experimental and numerical investigation of mechanical properties on novel modular connections with superimposed beams", *Engineering Structures,* Vol. 232., article no: 111858.
[36] Choi, K.-S., Lee, H.-C. and Kim, H.-J. (2016), "Influence of Analytical Models on the Seismic Response of Modular Structures", *Journal of the Korea Institute for Structural Maintenance and Inspection*, Vol. 20, pp. 74–85.
[37] Sultana, P. and Youssef, M.A. (2018), "Seismic Performance of Modular Steel-Braced Frames Utilizing Superelastic Shape Memory Alloy Bolts in the Vertical Module Connections", *Journal of Earthquake Engineering*, Vol. 24, pp: 628–652.
[38] Yang, H. (2020), "Performance analysis of semi-rigid connections in prefabricated high-rise steel structures. *Structures,* Vol. 28, pp. 837–846.
[39] Chain, P. (2018), "Pre-fabricated Pre-finished Volumetric Construction (PPVC) in Singapore: NTU Case Studies (Residential Halls)".
[40] Gunawardena, T. (2016), *Behaviour of Prefabricated Modular Buildings Subjected to Lateral Loads*, The University of Melbourne.
[41] O'Brien, J.A. (2019), *Structural Module with Vertical Ties,* WO2019219286A1.
[42] Park, K.-S., Moon, J., Lee, S.-S., Bae, K.-W. and Roeder, C.W. (2016), "Embedded steel column-to-foundation connection for a modular structural system", *Engineering Structures*, Vol. 110, pp. 244–257.

[43] Khan, K. and Yan, J.-B. (2020), "Finite Element Analysis on Seismic Behaviour of Novel Joint in Prefabricated Modular Steel Building", *International Journal of Steel Structures*, Vol. 20, pp. 752–765.

[44] Lyu, Y.-F., Li, G.-Q., Cao, K., Zhai, S.-Y., Li, H., Chen, C. and Wang, Y.-Z. (2021), "Behavior of splice connection during transfer of vertical load in full-scale corner-supported modular building", *Engineering Structures,* Vol. 230, article no: 111698.

[45] Zhang, G., Xu, L.-H., Li and Z.-X. (2021), "Development and seismic retrofit of an innovative modular steel structure connection using symmetrical self-centering haunch braces", *Engineering Structures*, Vol. 229, article no: 111671.

[46] Lee, S., Park, J., Kwak, E., Shon, S., Kang, C. and Choi, H. (2017), "Verification of the Seismic Performance of a Rigidly Connected Modular System Depending on the Shape and Size of the Ceiling Bracket", *Materials,* Vol. 10, article no: 263.

[47] Nadeem, G., Safiee, N.A., Abu Bakar, N., Abd Karim, I. and Mohd Nasir, N.A. (2021), "Finite Element Analysis of Proposed Self-Locking Joint for Modular Steel Structures. *Applied Sciences*, Vol. 11, article no: 9277.

[48] Bowron, J. (2020), *Locating Pin Assembly For A Modular Frame,* WO2020010463A1.

[49] Deng, E.-F., Yan, J.-B., Ding, Y., Zong, L., Li, Z.-X. and Dai, X.-M. (2017), "Analytical and numerical studies on steel columns with novel connections in modular construction", *International Journal of Steel Structures*, Vol. 17, pp. 1613–1626.

[50] Li, Y.M. (2019), *Mechanical Behavior Study on the New Bolted Joint of Modular Steel Structure*, Tianjin University.

[51] Chen, Z., Liu, J. and Yu, Y. (2017), "Experimental study on interior connections in modular steel buildings", *Engineering Structures*, Vol. 147, pp. 625–638.

[52] Xu, B., Xia, J., Chang, H., Ma, R. and Zhang, L (2020), "Flexural behaviour of pairs of laminated unequal channel beams with different interfacial connections in corner-supported modular steel buildings", *Thin-Walled Structures*, Vol. 154, article no: 106792.

[53] Hwan Doh, J., Ho, N.M., Miller, D., Peters, T., Carlson, D. and Lai, P (2017), "Steel Bracket Connection on Modular Buildings", *Journal of Steel Structures & Construction*, Vol. 2, article no: 1000121.

[54] Lee, J.-S., Lee, H.-D., Shin, K.-J., Kim, H.-J. and Lee, K.-M. (2021), "Structural Performance Evaluation of Modular Connections Using Developed Blocks", *International Journal of Steel Structures*, Vol. 21, pp. 1250-1259.

[55] Yu, Y. and Chen, Z. (2018), "Rigidity of corrugated plate sidewalls and its effect on the modular structural design", *Engineering Structures*, Vol. 175, pp. 191–200.

[56] Bowron, J., Gulliford, J., Churchill, E., Cerone, J. and Mallie, J. (2014), *Modular Building Units, And Methods Of Constructing And Transporting Same*, WO2014127472A1.

[57] Bowron, J. (2021), *Structural Modular Building Connector*. US10947716B2.

[58] Shan, S. and Pan, W. (2020), "Structural design of high-rise buildings using steel-framed modules: A case study in Hong Kong", *The Structural Design of Tall and Special Buildings*, Vol. 29, article no: e1788.

[59] Miller, R. (2019), *Prefabricated Modular Buildings*. WO2019023604A1.

[60] Shi, F., Wang, H., Zong, L., Ding, Y. and Su, J. (2020), Seismic behavior of high-rise modular steel constructions with various module layouts", *Journal of Building Engineering*, Vol. 31., article no: 101396.

[61] Parkhouse, L., Vittadini, A., Clark, M.C.J., Andreatta, S. and Saby, V.M.C. (2021), *Connection Node For Modular Building Structures*, US10907342B1.

[62] Wu, C.X., Yang, Y., Wu, C.Y., Yang, T. and Xu, X. (2019), "Research on seismic behaviour analysis of shock absorbing structure and connecting joints of container assembly structures", *Steel Construction*, Vol. 34, pp. 1-8+73.

[63] Chen, Z., Chen, S., Zhou, T. and Liu, J. (2019), *A Rubber Isolation System between Columns of Steel Modular Building (in Chinese)*. CN 110397176 A.

[64] Feng, R., Shen, L. and Yun, Q. (2020), "Seismic performance of multi-story modular box buildings", Journal of Constructional Steel Research, Vol. 168., article no: 106002.

[65] Chen, Z., Zhong, X., Liu, Y., Liu, J. and Guo, N. (2020), "Numerical study on modular slab–column steel structure based on simplified integrated floor", *Advances in Structural Engineering*, Vol. 23, pp. 1195–1208.

[66] Hu, Q., Lin, B., Xie, Y. and Chen, W. (2020), "Study on Mechanical Performance of Connection jointsIn Novel Modular Steel Structure Buildings", *IOP Conference Series: Earth and Environmental Science*, Vol. 605, article no: 012015.

[67] Lian, J.-Y., Deng, E.-F., He, J.-M., Cai, L.-M., Gao, S.-C. and Zhou, J.-J. (2021), "Numerical analysis on seismic performance of corner fitting connection in modular steel building", *Structures*, Vol. 33, pp. 1659–1676.

[68] Corfar, D.-A., Tsavdaridis, K.D. (2022), "A comprehensive review and classification of inter-module connections for hot-rolled steel modular building system", *Journal of Building Engineering*, Vol. 50, article no: 104006.