EPiC Series in Built Environment

Volume 5, 2024, Pages 193–201

Proceedings of 60th Annual Associated Schools of Construction International Conference

Modular Construction Safety Risk Mitigation

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The construction industry has witnessed a significant increase in the use of modular construction, given its ability to save time and reduce project costs. However, while modular construction is relatively safer than traditional construction methods, workers are still exposed to hazards that lead to injuries and fatalities. Few studies have focused on identifying the safety risks linked to the process of manufacturing, transporting, and installing modular structures. Therefore, the present study describes research on the safety risks associated with modular construction and the development of safety training resources. Specifically, this study focused on: (1) identifying safety risk factors and (2) developing training resources for mitigating these risk factors. The aim of the study was achieved through a detailed review of existing studies, a comprehensive analysis of archival data, interviews with safety professionals, and user assessment of training resources. The findings revealed that 70% of fatalities occur during the manufacturing phase of construction. Additionally critical safety risks identified included incidents such as falling loads, jack slippage incidents, lack of fall arrest systems implementation and equipment failures within construction projects. The study contributes to knowledge and practice by generating insight that could be used to improve the safety of workers in the modular construction industry.

Key Words: Modular construction, risk assessment, hazard identification, safety training, health and safety.

Introduction and Background

Modular construction has been an increasingly popular method of construction in recent years (Abdul Nabi & El-adaway, 2020), involves constructing buildings off-site using the same materials and standards as traditional construction, but with greater efficiency. In this process, modules are produced in controlled environments and then assembled on-site, ensuring both speed and high-quality standards. The types of modular construction include permanent buildings for long-term use, relocatable buildings, and structures made from diverse materials such as steel, wood, and concrete, each offering distinct benefits.

The modular construction industry is anticipated to have a market value of $271 billion by the end of 2030 (Straits Reserach, 2022), so it is evident that modular construction is on the rise. There are many factors why modular construction is being chosen over traditional construction methods. Modular building allows for better quality control because it greatly reduces the variability associated with construction (Innella et al., 2019). In addition, around 70 -80% of the work is completed in the

manufacturing plant which is less influenced by external environment (Fard et al., 2017). The ability to standardize products enhances the consistency and quality of products and helps reduce the total time and cost it takes to construct a building (Thai et al., 2020). It also allows for more efficient build times using manufacturing techniques and reduces delays associated with traditional methods (Innella et al., 2019).

Though modular construction seemingly provides safer working conditions by moving most construction tasks from construction sites to manufacturing plants, the nature of the required work could introduce new or exacerbates existing safety risks (Jeong et al., 2022). Workers are often required to be on top of modules as they are being manufactured, prepared for transport, and installed where there is potential to fall off the side or through the roof, especially if there are unsecure or loose parts (Jeong et al., 2022). An initial analysis of archived data conducted by Khan et al. (2022) indicates that the top two accident types in modular construction are fall from height and crush (struck-by) related accidents as shown in the Table 1. However, there is limited insight into the hazards associated with fall and struck-by accidents, root causes of these accidents, and safety risk mitigation strategies within the context of modular construction – especially during the manufacturing phase (Jeong et al., 2022; Khan et al., 2022). Such insight will help characterize safety risks during the modular construction (e.g., manufacturing phase) process and inform effective safety training aimed at improving workers' situational awareness.

Table 1.

Different types of accidents in modular construction (Khan et al., 2022).

Accident Type	No. of Accidents	Accidents %	No. of Fatalities	Fatality %
Crushed (Falling loads, etc.)	48	42%	38	57%
Fall from height	33	29%	15	22%
Falling Object	18	16%	10	15%
Caught	5	4%	0	0%
Other	10	9%	4	6%
Total	114	100%	67	100%

Despite the potential safety challenges inherent in modular construction, there is a scarcity of training materials focused on proactive practices to prevent falls and struck-by accidents in both permanent and temporary modular construction. While some existing training resources might be adaptable for safety management in modular construction, particularly during the installation phase, there is a notable lack of easily accessible resources that address the unique hazards faced by workers in this burgeoning market, especially during the manufacturing phase. Consequently, there is an urgent need to develop useful and engaging training materials to support workers' safety and health. As the industry grows, the exposure of workers to hazards intrinsic to modular construction increases, potentially leading to more injuries and fatalities. This expansion in modular construction activities is driving a heightened demand for workers and managers who are not only skilled but also knowledgeable about the specific safety risks associated with this type of construction (Abdul Nabi & El-adaway, 2020). Despite this need, there is a significant gap in the availability of contractors proficient in modular construction practices (Pervez et al., 2022; Thurairajah et al., 2023). Many existing construction firms, traditionally focusing on general construction, are now venturing into modular projects. However, this transition is fraught with challenges. Often, the safety management approaches used in general construction are inappropriately applied to modular construction, without fully considering the distinct characteristics of each method (Rocha et al., 2022; Thurairajah et al., 2023).

Therefore, efforts must be directed towards developing effective materials to train workers and employers to identify hazards associated with modular construction, perceive associated safety risks, learn hazard mitigation and accident prevention methods, and gain knowledge of safety best practices. These efforts will help large, medium, and small organizations in the modular construction industry to incorporate safety best practices into their safety management programs and apply effective strategies in projects to prevent potential catastrophic accidents, increase productivity, and save lives and assets. The overarching objectives of the present study are to (1) identify safety risk factors associated with modular construction and (2) develop safety training outline for mitigating these risk factors.

Research Methodology

This research aims to identify the risk factors associated with different phases of the modular construction and develop and evaluate safety training material. The present study implemented a two-step, multi-method research framework to achieve the research objectives. The overall research methodology flow is shown in Figure 1.

Objective 1: Identify modular construction safety risk factors. The research team implemented three data collection approaches to facilitate the identification of risk factors.

1. *Systematic Literature Review:* In our systematic literature review, we used databases like Google Scholar, Web of Science, and Scopus, focusing on keywords such as “Modular” OR “Prefabricated” OR “Offsite” AND “Construction”, and “worker” OR “Labor” AND “Risk” OR “Hazard” AND “Identification”. The selection was aimed at capturing a broad range of relevant grey and academic literature. Our inclusion criteria targeted recent English-language articles pertinent to modular construction, especially those addressing hazards in any phase of the construction process. We excluded articles that did not focus on hazards and safety issues in modular construction. The quality of sources was critically assessed based on their relevance, publication credibility, author expertise in modular construction, and the thoroughness of the hazard analysis, ensuring that our literature review was founded on reliable and pertinent sources for developing effective safety training materials.
    a. What are the hazards associated with modular construction?
    b. Which hazards are most critical (high impact and frequency)?
    c. How are these hazards controlled?
    d. What are the best practices commonly used to address safety issues?

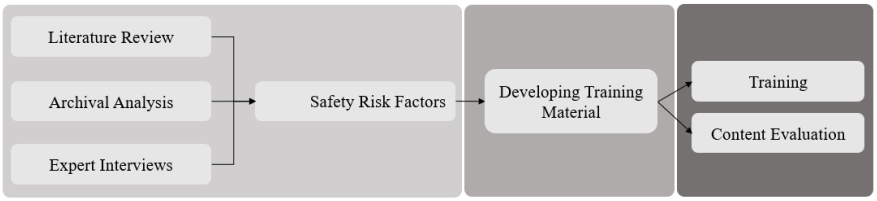

Figure 1. *Research methodology flow.*

2. *Archival Analysis:* Next, the study gathered information on mishaps and associated hazards in the modular construction sector by searching the Occupational Safety and Health Administration (OSHA) Fatality and Catastrophe Investigation Summaries database using terms like "modular", “off-site”, "prefabricated", "manufactured", and "mobile home." In addition, consider the Standard Industrial Classification (SIC) 245 categories to investigate accidents related to Wood buildings and mobile homes. These terms were entered into the database search to carefully

examine report summaries and abstracts for incidents of injuries and fatalities specifically linked to modular construction. The data was then analyzed and arranged to pinpoint the principal safety hazards within the modular construction field.

3. *Expert Interviews:* In our study, expert interviews were conducted using a semi-structured questionnaire to gather context-specific insights on modular construction risks and safety. Experts were selected from companies registered with the Modular Building Institute (MBI), ensuring a focus on experienced professionals in the industry. The interviews, conducted online, were recorded with participant consent, transcribed verbatim, and analyzed using thematic analysis. This approach allowed us to identify key themes and patterns, offering a comprehensive view of experts' perspectives. Ethically, we ensured participants understood the study's purpose and obtained their informed consent, maintaining confidentiality and anonymity, and allowing withdrawal from the study at any time without repercussions.

From these three research activities, we compiled a comprehensive list of safety risk factors specific to the modular construction industry. These risk factors were categorized and prioritized based on their frequency, severity, and preventability.

Objective 2: develop and test modular construction safety training materials. Using the information derived from objective 1, our research team embarked on the development of modular construction safety training materials. The design of these materials was underpinned by an iterative process that involved continuous refinement and adaptation to ensure relevance and effectiveness.

1. *Development of Training Material:* Leveraging the findings from our research, we developed tailored safety training materials. The creation of the training materials incorporated principles of iterative design and active learning. These materials were designed to address the identified risk factors through scenario-based learning activities.
2. *Pilot Training*: In our study, pilot training sessions for construction students were used to evaluate our safety training materials. These sessions aimed to enhance students' understanding of modular construction risks, with content including 3D animation videos to illustrate risks and preventive measures, and case studies for interactive learning. The training was delivered in a physical classroom setting, providing an immersive and engaging environment. The authors conducted a 'post-then-pre' survey design for evaluation, allowing students to first assess their knowledge post-training and then retrospectively evaluate their pre-training understanding, minimizing response-shift bias and accurately gauging the training's impact.

Results And Discussion

Modular Construction Risk Factors: Literature Review

Prefabricated construction encompasses intricate and interrelated processes, contributing to a higher frequency of safety incidents as compared to traditional construction (Tang et al., 2023). The cycle of prefabricated building is divided into three active stages/phases: The off-site manufacture, transportation, and hoisting and splicing on-site assembly (Khan et al., 2022). All the three phases are prone to many safety accidents, which identification can play a vital role in developing safety protocols and regulations.

Manufacturing Phase

Song et al. (2022) underscores the vulnerability inherent in the design stage, revealing a substantial risk due to inadequate safety considerations. Their research emphasizes the imperative of integrating robust

safety protocols from the project's inception. Transitioning to the manufacturing phase, Song et al., (2022) further illuminates the prevalence of quality defects in prefabricated components, accentuating the compounded risks associated with skill shortages and a pervasive lack of safety awareness among on-site and off-site workers. Expanding on this, Jeong et al. (2022) conducted a meticulous analysis of accidents in modular construction, revealing a startling 31% occurrence rate during the manufacturing process. Their findings delineate a spectrum of accidents, encompassing falls, collisions with falling objects, and other incidents, while pinpointing specific risk factors such as unstable work areas and improper equipment use. Additionally, Vithanage et al. (2022) highlighted the lack of collaboration among key stakeholders, particularly designers, stressing the need for heightened safety awareness within this pivotal cohort. In addition, advocates for a unified safety strategy that comprehensively addresses risks throughout the prefabricated construction process.

Transportation Phase

Transportation risk factors associated with modular construction were however found to include unsecured equipment and tools or objects, human mistake, dangerous situation, workers physical and mental state, adverse weather conditions, and large prefabricated components (Song et al., 2022). The delivery of oversized modules poses a greater and, in some cases, an urgent challenge, potential collision, lane straddling, wide turns and sophisticated turning analysis are sometimes the case (Zheng et al., 2023). Vithanage et al. (2022) added the lack of safety awareness and consideration within the transportation team to identify and evaluate risks in their workplace through lessons or informational sessions.

Installation Phase

Scholars suggest that hoisting and assembling of prefabricated units is the riskiest aspect of modular construction (Wang et al., 2022). In the construction phase, the installation process is the most hazardous activity accounting for 50% of all accidents (Jeong et al., 2022). Guo et al. (2013) adopted an interactive environment to stimulate the dismantling process associated with crane collapse (Fard et al., 2017) and operator being struck, collided or crushed during dismantling of the plant. The authors however indicated that higher risks exist when working with tower cranes than mobile cranes. Using the HFACS-PH model, Song et al. (2022) asserts that a significant number of lifting accidents occur during the installation phase including falling from a height, connection failure, pinch, mechanical failures, hoisting load dumping, hoisting load falling off, collapse, object strike, lifting injury and vehicle transportation injuries, and mechanical injury. These accidents arise from unsafe leadership behaviors, organizational influences, conditions predisposing accidents, and the external environment (Wang et al., 2022). In addition, Wang et al. (2022) added that miscommunication between operator and ground worker are identified as critical risk factors.

Modular Construction Risk Factors: Archival Analysis

In this study, the authors considered archival analysis for SIC 245 (SEC, 2021), which includes mobile homes and prefabricated wood buildings. The authors analyzed 71 documented accidents from the OSHA Accident database over a 20-year period (2002-2022)(OSHA, 2023), and these documents revealed 26 fatalities (total number of incidents (n)=71). Hospitalizations occurred in 38 cases, overshadowing the 7 non-hospitalized injuries. The manufacturing phase saw the majority of these accidents (52, with 18 fatalities), outpacing the installation phase (17 accidents, 7 fatalities) and the transportation phase (2 accidents, 1 fatality) as shown in Figure 2. The data indicates that the most perilous incidents in mobile house construction involve being crushed by falling loads (11 accidents, 7 fatalities) and saw-related accidents (17 accidents, 1 fatality), with falls from a height also presenting

significant risks (8 accidents, 4 fatalities). Other causes included jack and crane failures or being pinned between objects. Fractures were the most frequent injury type (27 cases), followed by amputations (15). This archival data delivers crucial insights for the modular construction sector, highlighting urgent areas for safety enhancement and preventive action.

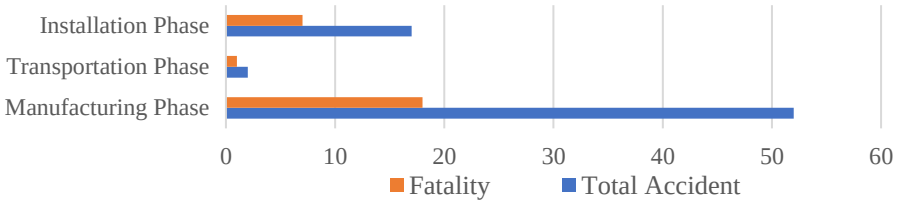

Figure 2. *Summary of accidents and fatalities (n=71).*

Modular Construction Risk Factors: Interviews

As part of our comprehensive analysis on the development of safety training materials for the modular construction industry, we conducted interviews with six experts from various sectors involved in modular construction: one from the precast/prestressed concrete sector, three specializing in the manufacturing and installation of mobile homes, and two involved in industrial modular systems. A unanimous view among the experts is that the manufacturing phase poses more significant risks compared to other phases of modular construction.

Figure 3 illustrates the prevalence of different types of accidents in the modular construction industry, with crushed accidents and falls from height being the most frequently reported. These incidents are attributed to various risk factors as identified through literature review, archival analysis, and expert interviews. For falls from height, the contributing factors include falls from ladders, scaffolds, openings, mobile equipment, and roofs, often due to issues like lack of anti-slip systems, poor installation, missing guardrails, and lack of monitoring. Crushed accidents are mainly due to crane overturns, operations, overloading, being caught in or between equipment, falling loads, and hydraulic jack failures, with root causes such as sudden movements of structures, failure of outriggers, and safety barriers missing as shown in Figure 4. This data provides critical insight into the specific hazards that need to be addressed to improve worker safety in modular construction.

Next, the experts identified and stressed the need for safety training materials tailored to the modular construction industry. Following multiple interviews, the experts indicated that the training should encompass detailed modules as shown in Figure 4.

Participant Background. The modular construction safety training program was pilot tested in two construction safety classes consisting of 62 participants. Most of the participants had construction experience. The assessment focused on participants' knowledge and overall perception of the training materials.

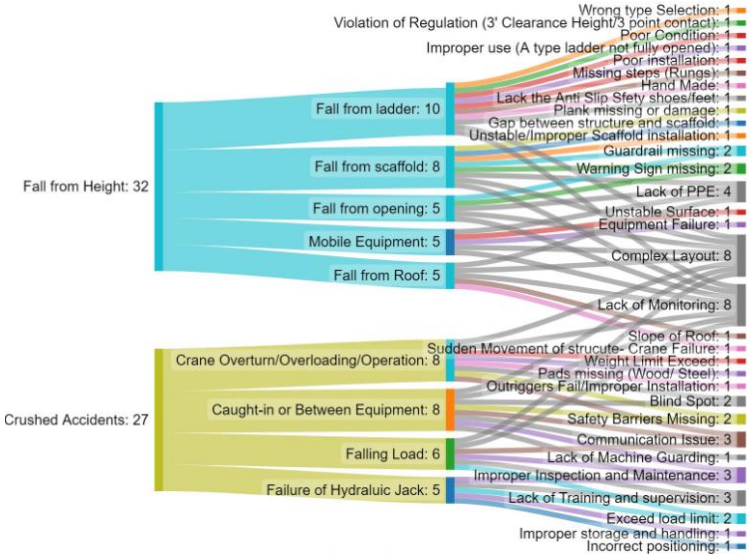

Figure 3. *List of potential risk factors.*

Figure 4. *Safety training program contents suggested by experts.*

Training Material Assessment

Content Evaluation Assessment

The participants indicated that the Modular Construction Safety training is highly effective, receiving strong ratings from participants. Key highlights include its precise content with a 4.82 rating (on a five-point scale), relevant and understandable material rated at 4.44 and 4.81, and effective coverage of

workplace hazards with a 4.77 rating. The training's structure and presentation methods were well-received, scoring an average of 4.44, and supplemental materials like 3D animations and handouts were beneficial, rated at 4.56. The duration and session lengths were optimal, earning a 4.42 rating, while interactive components scored 4.10, suggesting some room for improvement.
Feedback highlighted the importance of visual aids (3D animation work) and the need for more engagement and interactivity. The overall response was very positive, with a recommendation rating of 4.44. The training notably impacted participants' personal safety practices, which they intend to improve, as reflected in a 4.68 rating.

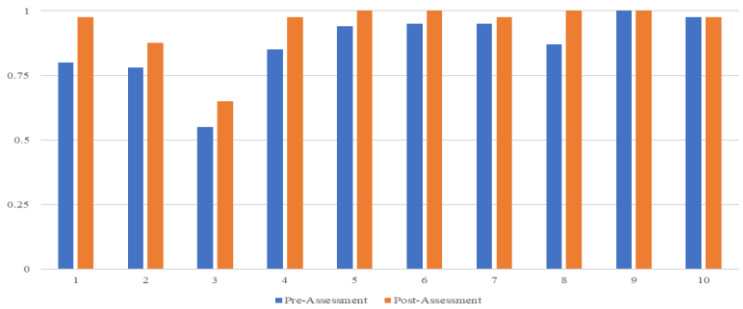

Figure 5. *Post-then Pre-Assessment Results*

As illustrated in Figure 5, the training markedly enhanced participants' understanding of risks in crane operation limitation, hydraulic jack safety, and other key areas within modular construction. Data from post and pre-training surveys revealed significant improvements, including a 12.82% increase in comprehension of crane operator responsibilities as per OSHA standards, and a 5.13% improvement in hydraulic jack failure awareness. There was also a notable enhancement in understanding the safety of jacks under load and mitigating pinned-between hazards, with a 10.26% improvement. The training effectively addressed nuanced safety concerns, leading to substantial advancements in preventing jack-related failures and accidents. Participants demonstrated near-perfect knowledge in safely storing materials and showed a strong intent to apply these safety practices. These outcomes underscore the training's thoroughness and the participants' active engagement with the content, particularly in managing risks associated with lifting modular units and adhering to design capacity in modular construction.

Conclusion, Limitation and Future Studies

This study identifies crucial safety risks in modular construction such as falling heavy loads, inadequate training, equipment misuse, jack slippage and developed targeted training to address these. Comprehensive research methods, including literature review, archival data, and expert interviews, pinpointed manufacturing as the phase most susceptible to accidents, leading to training enhancements on crane operations, rigging, and PPE use, among others. Pilot training sessions with construction students demonstrated the materials' effectiveness in improving safety knowledge and practices, although the study's focus on wood structures and its testing on students rather than professionals suggest a need for broader application in the future.

The research advocates for a shift towards immersive Virtual Reality (VR) training, proposing the use of platforms like Unity for realistic hazard simulations. Future recommendations include diversifying

training content to encompass various construction materials and expanding expert consultations to address the full spectrum of risks in modular construction.

References

Abdul Nabi, M., & El-adaway, I. H. (2020). Modular Construction: Determining Decision-Making Factors and Future Research Needs. *Journal of Mang. in Engr.*, *36*(6), 04020085.

Fard, M. M., Terouhid, S. A., Kibert, C. J., & Hakim, H. (2017). Safety concerns related to modular/prefabricated building construction. *International Journal of Injury Control and Safety Promotion*, *24*(1), 10–23. https://doi.org/10.1080/17457300.2015.1047865

Guo, H. L., Li, H., & Li, V. (2013). VP-based safety management in large-scale construction projects: A conceptual framework. *Automation in Construction*, *34*, 16–24.

Innella, F., Arashpour, M., & Bai, Y. (2019). Lean Methodologies and Techniques for Modular Construction: Chronological and Critical Review. *Journal of Construction Engineering and Management*, *145*(12), 04019076. https://doi.org/10.1061/(asce)co.1943-7862.0001712

Jeong, G., Kim, H., Lee, H. S., Park, M., & Hyun, H. (2022). Analysis of safety risk factors of modular construction to identify accident trends. *Journal of Asian Architecture and Building Engineering*, *21*(3), 1040–1052. https://doi.org/10.1080/13467581.2021.1877141

Khan, M., Nnaji, C., Mccrary, E., & Awolusi, I. (2022). Worker Safety in Modular Construction: Investigating Accident Trends, Safety Risk Factors, and Potential Role of Smart Technologies . *The 9th International Conference on Construction Engineering and Project Management*, *August*. https://www.researchgate.net/publication/363046910

OSHA. (2023). *Fatality and Catastrophe Investigation Summaries | Occupational Safety and Health Administration*. https://www.osha.gov/pls/imis/accidentsearch.html

Pervez, H., Ali, Y., Pamucar, D., Garai-Fodor, M., & Csiszárik-Kocsir, Á. (2022). Evaluation of critical risk factors in the implementation of modular construction. *PLoS ONE*, *17*(8 August), 1–27. https://doi.org/10.1371/journal.pone.0272448

Rocha, P. F., Ferreira, N. O., Pimenta, F., & Pereira, N. B. (2022). Impacts of Prefabrication in the Building Construction Industry. *Encyclopedia*, *3*(1), 28–45.

SEC. (2021). *Division of Corporation Finance: Standard Industrial Classification (SIC) Code List*. https://www.sec.gov/corpfin/division-of-corporation-finance-standard-industrial-classification-sic-code-list

Song, Y., Wang, J., Liu, D., & Guo, F. (2022). Study of Occupational Safety Risks in Prefabricated Building Hoisting Construction Based on HFACS-PH and SEM. *International Journal of Environmental Research and Public Health*, *19*(3). https://doi.org/10.3390/ijerph19031550

Straits Reserach. (2022). *Modular Construction Market: Information by Type(Permanent, Re-locatable), Material (Steel, wood, Concrete), and Regain - Forecast till 2030*. https://straitsresearch.com/report/modular-construction-market

Tang, S., Zhu, K., & Guo, P. (2023). Research on Quantitative Assessment and Dynamic Reasoning Method for Emergency Response Capability in Prefabricated Construction Safety. *Buildings*.

Thai, H. T., Ngo, T., & Uy, B. (2020). A review on modular construction for high-rise buildings. *Structures*, *28*(October), 1265–1290. https://doi.org/10.1016/j.istruc.2020.09.070

Thurairajah, N., Rathnasinghe, A., Ali, M., & Shashwat, S. (2023). Unexpected Challenges in the Modular Construction Implementation: Are UK Contractors Ready? *Sustainability)*, *15*(10).

Vithanage, S. C., Sing, M., Davis, P., & Pillay, M. (2022). Systematic review on the identification of safety risks in off-site manufacturing (OSM). *Journ. of Engr., Des. and Tech.*, *20*(4), 935–964.

Wang, J., Guo, F., Song, Y., Liu, Y., Hu, X., & Yuan (2022). Safety Risk Assessment of Prefabricated Buildings Hoisting Construction: Based on IHFACS-ISAM-BN. *Buildings*, *12*(6), 1–22.

Zheng, Z., Pan, M., Yang, & Pan (2023). Motion planning for efficient and safe module transportation in modular integrated construction. *Computer-Aided Civil & Infra. Engr.*, *38*(5), 580–600.