COMPARATIVE ANALYSIS OF ACCIDENT RISKS: TEMPORARY STRUCTURES VERSUS STABLE INDUSTRIAL SPACES

N. MERLOI (ENE) - National University of Science and Technology POLITEHNICA Bucharest, Bucharest, Romania , nicoleta.ene86@gmail.com
D.F. NIȚOI - National University of Science and Technology POLITEHNICA Bucharest, Bucharest, Romania
M.N. MARINESCU - National University of Science and Technology POLITEHNICA Bucharest, Bucharest, Romania
C.I. ENACHE - National University of Science and Technology POLITEHNICA Bucharest, Bucharest, Romania
A. TRIFU - National University of Science and Technology POLITEHNICA Bucharest, Bucharest, Romania
C. VÎNTURIȘ - National University of Science and Technology POLITEHNICA Bucharest, Bucharest, Romania

Abstract: *This paper compares the accident risks associated with temporary structures and stable industrial spaces, from the perspective of occupational safety and health. Although both categories of spaces can serve similar industrial, logistical or exhibition activities, differences in design, operation and maintenance determine distinct risk profiles. Temporary structures are characterized by a high degree of mobility, quick assembly, dependence on the quality of anchoring and direct exposure to meteorological factors. On the other hand, stable industrial premises benefit from permanent foundations, fixed protection systems and standardised operating procedures. The paper proposes a comparative risk matrix, a simplified HSE assessment model based on probability and severity, as well as a case study on the assembly and operation of a clear-span industrial exhibition pavilion. The results highlight that temporary structures can only achieve acceptable levels of safety through active risk management, frequent inspections and rapid interventions depending on environmental conditions.*

Keywords: temporary structures, stable industrial spaces, accident risk, occupational safety and health, anchoring, risk management.

1. INTRODUCTION

Occupational safety and health is a fundamental field of industrial engineering, with the main objective of preventing accidents and occupational diseases through the identification, assessment and control of risks [1],[2]. In the current context of accelerated economic development and the flexibility of industrial processes, there is a significant diversification of working environments, from stable, well-regulated industrial spaces to temporary structures, characterized by mobility and high adaptability [3],[4]. This diversity generates major differences in the occupational risk profile and in the way prevention measures are implemented [5].

Stable industrial spaces, such as production halls, logistics warehouses or processing units, are designed for long-term operation, with strict standards for structural strength, fire protection, ventilation and equipment safety [6]. These environments benefit from permanent infrastructures and relatively stable technological processes, which allows the implementation of effective risk management systems, based on continuous monitoring and standardised procedures [7].

In contrast, temporary structures, including exhibition halls, industrial tents, modular halls or temporary platforms, are designed for short- or medium-term use, being characterized by rapid assembly, reuse and frequent relocation [8]. Although these structures comply with specific technical regulations, their transitory nature introduces a number of additional vulnerabilities. Risks are not concentrated exclusively in the exploitation phase, but occur strongly in the assembly and disassembly stages, where the interaction between the human factor, the incompletely stabilized structure and environmental conditions becomes critical [9],[10].

Another defining aspect of temporary structures is their high dependence on external factors, especially weather conditions. Wind actions, precipitation or temperature variations can significantly influence structural behavior, generating risk situations that are not encountered to the same extent in the case of permanent constructions [11]. In addition, the frequent use of temporary electrical and mechanical installations, as well as the presence of heterogeneous work teams, contribute to increasing the complexity of risk management [12].

In this context, a rigorous comparative analysis between the two types of work environments is required in order to highlight the key differences in the nature of accidents, their frequency and the severity of the consequences. The paper aims to investigate these differences through an integrated approach, combining theoretical analysis with engineering risk assessment and an applied case study. The main objective is to identify effective risk prevention and control models in temporary structures, so that the level of safety approaches that of stable industrial spaces.

2. METHODOLOGY

The research has a theoretical-applicative character, being based on an interdisciplinary approach specific to industrial engineering and the field of occupational safety and health. In the first stage, a systematic comparative analysis of the risks specific to temporary structures and stable industrial spaces was carried out, with the objective of identifying the essential differences in terms of the nature, frequency and severity of accidents at work. This analysis made it possible to highlight the particularities of each working environment, especially in relation to structural stability and predictability of operational conditions.

Next, a qualitative assessment of the main risk factors was carried out, including structural, mechanical, electrical, meteorological and ergonomic components. The evaluation was carried out by correlating the data from the literature with the experts' observations on the behavior of the structures and their interaction with the human factor. Particular emphasis has been placed on identifying risks in critical phases of the life cycle, especially in the case of temporary structures, where the variability of working conditions is high.

To quantify the identified risks, a simplified HSE model was used, based on the determination of the probability of occurrence and the severity of the consequences. This model allowed the hierarchy of accident scenarios and the establishment of priorities in the implementation of prevention measures. Finally, the research was completed by developing an applied case study on the assembly and operation of an industrial exhibition pavilion with an area of 600 m², which provided a practical validation of the theoretical hypotheses and highlighted the importance of active risk management in temporary structures.

For the risk assessment, the following relationship was used:

$$R=P\times S \tag{1}$$

where:
R=risk score
P=probability of occurrence of the event
S=severity of consequences
The values for probability and severity were rated on a scale of 1 to 5.

3. BENCHMARKING OF RISKS

In order to carry out a comparative risk analysis, data obtained from several sources were correlated: the requirements of the technical standards applicable to temporary structures and permanent constructions (EN 13782, Eurocodes), the specialized literature in the field of occupational safety and structural engineering. The analysis highlights differences between the two types of environments, determined by the level of structural stability, the degree of control of the operating conditions and the type of installations used (Table 1).

Table 1. Comparative analysis of risks between stable industrial spaces and temporary structures

Risk category	Stable industrial spaces	Temporary structures	OSH Impact
Structural risk	Low, controlled by periodic revisions	Raised in the assembly and anchoring phases	Instability, local or general collapse
Working at height	Fixed platforms, railings, controlled access	Ladders, boom lifts, harnesses, narrow profiles	Falls from height
Fire risk	Sprinklers, hydrants, partitioning	Flame retardant treated textiles/PVC	Rapid smoke propagation
Electrical installations	Buried or protected	Temporary cables, movable switchboards	Electrocution, tripping
Working environment	Controlled, air-conditioned, constantly illuminated	Exposed to wind, rain, extreme temperatures	Increasing the likelihood of accidents
The Human Factor	Stable staff, familiar with the space	Temporary teams, subcontractors	Communication and coordination errors

The comparative analysis presented in the table highlights significant differences between the risk profiles of permanent industrial premises and temporary structures, both in terms of the nature of the risks and the control mechanisms. In the case of stable premises, risks are generally well controlled through permanent infrastructures, standardised procedures and integrated technical systems, leading to a high predictability of the working environment. Temporary structures, on the other hand, are characterised by an increased degree of uncertainty, determined by the variability of installation conditions, the influence of meteorological factors and the use of temporary equipment.

It is noted that structural and working at height risks are considerably more pronounced in temporary structures, especially in the initial assembly phases, when the system is not fully stabilized. Also, temporary electrical installations and direct exposure to the outside environment contribute to increasing the likelihood of accidents. In addition, the human factor has a more pronounced influence in these environments, due to the fluctuation of the workforce and the need for rapid coordination between teams.

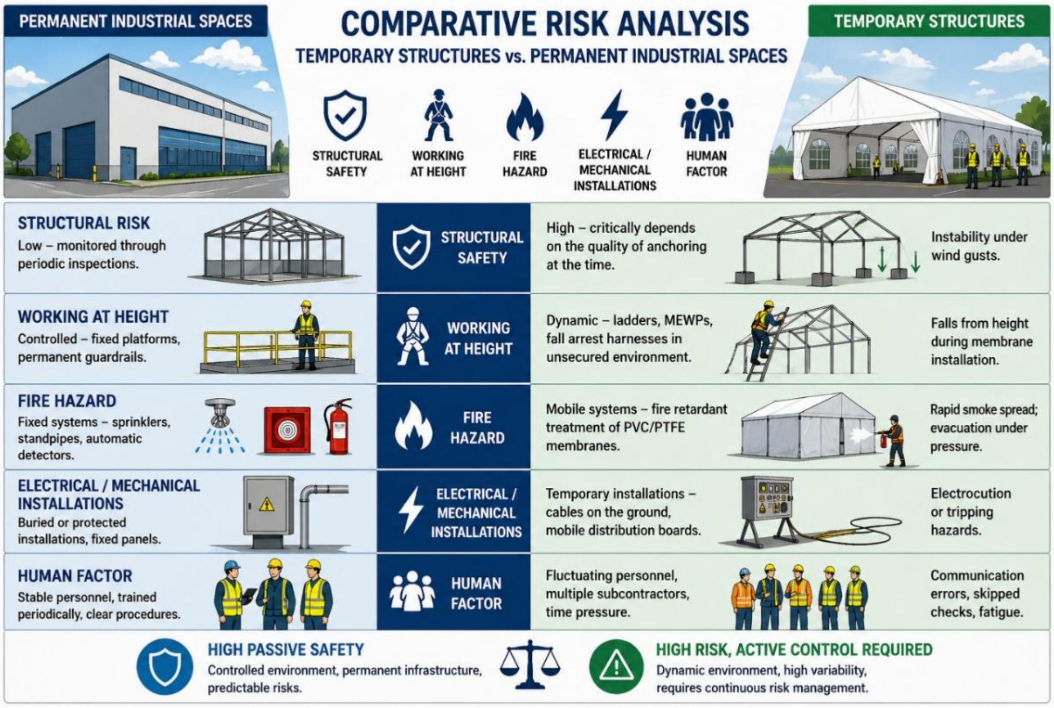

Figure 1. Comparative analysis between permanent industrial spaces and temporary structures

4. RISKS SPECIFIC TO TEMPORARY STRUCTURES

Meteorological risk and the sailing effect

Temporary structures with tensioned membranes are sensitive to the action of the wind. If the membrane is not properly tensioned or if the sidewalls are left partially open, the "sail" effect can occur, which generates lifting and pulling forces on the anchoring system. Possible consequences include:

- detachment of the membrane;
- deformation of the aluminum frame;
- pulling out anchors;
- partial collapse of the structure over workers or participants.

Risks in the installation phase

The assembly phase is one of the most vulnerable stages of the life cycle of a temporary structure. The risks arise from the handling of components, working at height, lifting gantry and the use of mobile equipment. The main dangers are:

- falling of aluminum profiles from height;
- crushing hands in the joint areas;
- finger grip when mounting bolts;
- unbalancing of portals before final anchoring;
- accidents caused by poor communication between operators.

Electrical Hazards

In temporary structures, electrical installations are often carried out by means of exposed cables, movable panels and temporary routes. They can generate risks of electric shock, short circuit, fire or tripping. Recommended measures include the use of cable ramps, differential protections, daily checking of connections and delimitation of restricted access areas.

Ergonomic risks and the human factor

In temporary structures, the human factor plays an essential role. The pressure of short deadlines, cumulative fatigue and staff turnover can favor the occurrence of accidents. Common errors include:

- failure to check the safety bolts;
- insufficient tension of the membrane;
- incomplete anchorage;
- ignoring weather changes;
- poor communication between the assembly teams.

In stable industrial spaces, the human factor manifests itself differently. Excessive familiarity with the work environment can lead to routine, decreased alertness, and underestimation of hazards.

5. HSE RISK ASSESSMENT MODEL

The HSE model used in this paper is based on the classic principles of occupational risk assessment, according to which risk is defined as a function of the probability of occurrence of an undesirable event and the severity of its consequences. Relationship: $R=P\times S$ is widely used in practice for rapid assessments and operational decisions in the field of occupational safety and health. The choice of this model is justified by the

- the need for a method applicable in the field, under dynamic conditions;
- the fast and intuitive nature of the assessment;
- compatibility with HSE standards used in industry;
- the possibility of immediate prioritization of risks.

In the context of temporary structures, where working conditions change frequently, the use of a complex model would reduce practical applicability.

The development of the model went through the following stages:

1. Identification of accident scenarios. Relevant scenarios were selected based on the analysis of the literature, observations from construction sites and assembly, technical characteristics of temporary structures, practical experience in the field of OSH. The scenarios have been chosen to cover: structural risks; operational risks; electrical hazards; risks associated with the human factor.

2. Establishing the rating scale. The values for probability and severity were rated on a scale of 1 to 5 (Table 2, Table 3).

Table 2. Probability scale, Probability, P

Probability (P)	Description
1	Very rare
2	Rare
3	Occasional
4	Common
5	Very common

Table 3. Severity scale, Severity, S

Severity (S)	Description
1	No consequences
2	Minor injuries
3	Medium lesions
4	Serious injuries
5	Death

In order to quantify the risks specific to temporary structures, the following model is proposed, summarized in Table 4:

Table 4 Practical application of the HSE risk assessment model for scenarios specific to temporary structures

Accident Scenario	Probability P	Severity S	Score R = P × S	Prevention measure
Pulling out the anchor	2	5	10	Daily plucking and checking tests
Sliding on the membrane	4	3	12	Non-slip footwear and lifelines
Electric shock through exposed cables	3	4	12	Cable channels and differential guards
Collapse under snow load	1	5	5	Weather monitoring and quick clearance
Drop from height during installation	3	5	15	Harnesses, boom lifts, training and supervision

Interpretation of results. Based on the scores obtained:

- **R = 15** → critical risk → immediate intervention
- **R = 10–12** → high risk → urgent measures
- **R ≤ 5** → controllable risk

The model highlights a key feature in temporary structures: the probability (P) is higher and the severity (S) remains high, leading to higher risk scores compared to stable spaces.

6. CASE STUDY: 20M × 30M INDUSTRIAL EXHIBITION PAVILION

The case study analyzes the structural and operational behavior of a modular "clear-span" exhibition pavilion, with a clear opening of 20 m and a length of 30 m, resulting in a total area of 600 m². The structural system is designed for temporary use, without internal support elements, which implies a significant load on the main load-bearing elements.

The structure is made of EN AW-6061-T6 aluminum alloy, characterized by:

- high mechanical strength ($\sigma_y \approx 240$ MPa);
- light weight;
- favorable behavior to corrosion.

The main elements are extruded profiles with rectangular section (203 × 110 × 4 mm), sized to take over combined bending and compression stresses. The roof is made of PVC composite textile membrane (≈ 850 g/m²), with a secondary structural role, but with a major influence on aerodynamic behavior. The Keder clamping system ensures the continuity of the membrane and the uniform transfer of forces to the frame.

The anchoring system is mixed:

- mechanical anchors (metal stakes);
- gravitational ballasts (concrete blocks).

This configuration introduces a direct dependence on local geotechnical features, as opposed to permanent structures.

Anchoring stage

Before the installation, a tensile test was carried out to check the pull-out resistance of the stakes. Results:

- asphalt area: approximately 800 kg/stake;
- soft soil: about 450 kg/stake.

The difference necessitated the use of 1000 kg ballast blocks in areas with low strength. This measure highlights the dependence of temporary structures on the local characteristics of the land.

Lifting stage

The lifting of the portals was carried out with the help of hydraulic columns. During the operation, a risk generated by lateral wind gusts of approximately 35 km/h was identified. The measure applied consisted of the rapid installation of the X-shaped bracing system, immediately after the positioning of the first portals.

Exploitation under dynamic actions

During the event, wind gusts of about 65 km/h were recorded. The membrane showed visible oscillations, accompanied by high acoustic noise. In areas where membrane tension has decreased, the tendency of water accumulation has been observed, a phenomenon known as "water ponding". Compared to a stable industrial hall, where the rigid roof significantly reduces this risk, the temporary pavilion requires active maintenance and periodic checks.

Performance and safety indicators

In order to carry out a relevant comparative analysis between stable industrial spaces and temporary structures, a number of performance and safety indicators have been defined. These indicators allow the characterization of systems not only from the perspective of static risk, but also of operational behavior under variable conditions. The indicators used were selected to reflect: structural stability; control of environmental conditions; influence of the human factor; maintenance and monitoring needs.

For the comparative analysis, indicative indicators were used:

- *Predictability of the working environment.* Environmental predictability is the ability of the system to maintain constant operational conditions over time.
- *Control of external factors*. This indicator reflects the system's ability to limit external influences (wind, precipitation, temperature).
- *The need for operational inspections*. The frequency of inspections is directly related to risk variability.
- *Potential severity of accidents*. Severity is determined by the energy involved in the event.
- *Dependence on the human factor*. This indicator reflects the contribution of human error to risk

Table 5 Performance and safety indicators

Indicator	Stable industrial space	Temporary structure
Environmental predictability	High	Reduced
Control of external factors	High	Limited
The need for daily inspections	Moderate	High
Potential severity of accidents	Medium-high	High
Dependence on the human factor	Average	Very high
Vulnerability to wind	Low	High

The case study indicates that the 600 m² pavilion can be installed logistically efficiently, but the level of safety depends on inspections, correct anchoring and permanent adaptation to weather conditions.

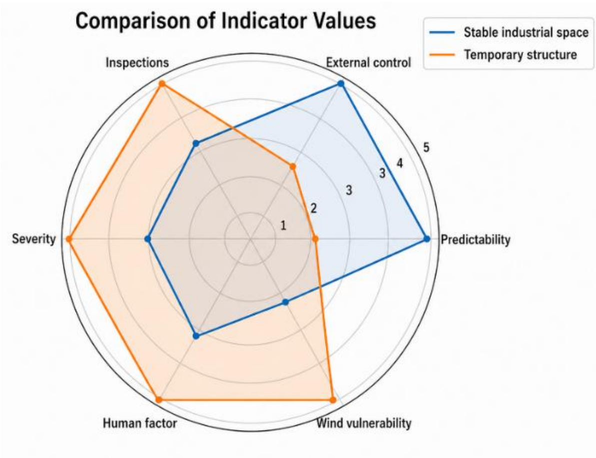

Figure 2. Comparison of performance and safety indicators between stable industrial spaces and temporary structures.

The radar graph highlights the significant differences between the two types of systems analysed (fig.2). Stable industrial spaces show high values for predictability and control of external factors, which reflects a stable and well-regulated operating environment. In contrast, temporary structures record maximum values for indicators associated with operational risk, such as the need for inspections, the potential severity of accidents, dependence on the human factor and vulnerability to wind action.

The extended polygonal shape in the case of temporary structures indicates a risk distribution oriented towards dynamic and variable factors, while the more compact profile of stable spaces suggests a more efficient control of operating conditions.

Prevention and protection measures

In order to reduce the risks in the temporary structures, the following recommendations have been identified:

- carrying out pulling tests for anchors;
- daily checking of membrane tension;
- wind speed monitoring by anemometers;
- use of lifelines and anti-fall equipment;
- training of teams before each stage of assembly;
- establishing a procedure for stopping work in adverse weather conditions;
- checking temporary electrical installations;
- designation of an HSE manager during assembly, operation and dismantling.

7. CONCLUSIONS

The comparative analysis carried out highlights the fact that the differences between temporary structures and stable industrial spaces are not only of a constructive nature, but are deeply reflected in the occupational risk profile and in the way they are managed. While stable industrial spaces offer a predictable, controlled environment supported by permanent infrastructures, temporary structures are characterized by a high degree of variability, uncertainty and dependence on external factors.

The results of the research confirm the initial hypothesis that temporary structures have a higher level of probability of accidents, even if the severity of the consequences remains comparable to that of stable spaces. This combination frequently leads to higher risk scores, especially in the critical assembly and disassembly phases, where structural stability is incomplete and the influence of the human factor is maximum.

The simplified HSE model used has proven to be effective for rapid risk assessment and prioritisation under dynamic conditions specific to temporary structures. Its application in the case study highlighted the existence of critical risks, such as falling from a height or structural instability, which require immediate interventions and rigorous control measures.

The case study on the clear-span exhibition pavilion demonstrated that, although these structures can be logistically and economically efficient, their safety depends crucially on the quality and adaptation of the anchoring system to local conditions, continuous monitoring of meteorological factors, frequent and rigorous inspections, and the level of training and coordination of the teams involved.

An essential aspect highlighted is the decisive role of active risk management in temporary structures. Unlike stable spaces, where safety is integrated into infrastructure and processes, in the case of temporary structures it must be maintained through continuous, adaptive and proactive actions. The research also highlights the importance of the human factor, which has a much more pronounced influence in temporary structures. Execution errors, poor communication or lack of experience can significantly amplify existing risks, which requires the implementation of specific training programs and permanent supervision.

In conclusion, temporary structures can achieve an acceptable level of safety comparable to that of stable industrial spaces only under the conditions of applying a rigorous risk management system, based on continuous assessment, strict operational control and adaptation to environmental conditions. In the absence of these measures, the specific vulnerabilities of these structures can lead to a significant increase in the probability of injury.

Future research directions may aim at developing advanced risk assessment models that integrate real-time monitoring of environmental conditions, the use of digital technologies (IoT, smart sensors) and predictive simulations to increase the level of safety in temporary structures.

8. REFERENCES

[1]. ASRO, SR EN 13782:2015 – Temporary structures. Tents. Security.
[2]. European Committee for Standardization, EN 13782: Temporary structures – Tents – Safety.
[3]. European Committee for Standardization, SR EN 1991-1-4: Eurocode 1 – Actions on structures. Wind actions.
[4]. European Committee for Standardization, SR EN 1999: Eurocode 9 – Design of aluminium structures.

[5]. European Committee for Standardization, SR EN 13501-1 – Fire classification of construction products and elements.
[6]. OSHA, 29 CFR 1926 – Safety and Health Regulations for Construction.
[7]. **Ratay, R. T.,** *Forensic Structural Engineering: Handbook of Temporary Structures*, McGraw-Hill.
[8]. **Brauer, R.** L. (2016). *Safety and health for engineers* (3rd ed.). Wiley.
[9]. **Choudhry, R. M., Fang, D., & Mohamed, S.** (2007). The nature of safety culture: A survey of the state-of-the-art. *Safety Science, 45*(10), 993–1012. https://doi.org/10.1016/j.ssci.2006.09.003
[10]. Eurostat. (2023). *Accidents at work statistics*. https://ec.europa.eu/eurostat
[11]. European Committee for Standardization. (2015). *EN 13782: Temporary structures – Tents – Safety*. CEN.
[12]. European Committee for Standardization. (2005). *EN 1991-1-4: Eurocode 1 – Actions on structures – Wind actions*. CEN.
[13]. European Committee for Standardization. (2007). *EN 1999: Eurocode 9 – Design of aluminium structures*. CEN.
[14]. **Gibb, A., Haslam, R., Hide, S., & Gyi, D.** (2006). The role of design in accident causality. *Construction Management and Economics, 24*(5), 543–556. https://doi.org/10.1080/01446190500213739
[15]. **Hinze, J.** (2006). *Construction safety* (2nd ed.). Prentice Hall.
[16]. **Hughes, P., & Ferrett, E.** (2020). *Introduction to health and safety at work* (6th ed.). Routledge.
[17]. International Labour Organization. (2021). *World employment and social outlook: Trends 2021*. ILO.
[18]. International Organization for Standardization. (2018). *ISO 45001: Occupational health and safety management systems – Requirements with guidance for use*. ISO.
[19]. **Manuele, F. A.** (2014). *Advanced safety management: Focusing on Z10 and serious injury prevention* (2nd ed.). Wiley.
[20]. Occupational Safety and Health Administration. (2023). *Safety and health regulations for construction (29 CFR 1926).* U.S. Department of Labor.
[21]. **Ratay, R. T.** (2010). *Forensic structural engineering handbook* (2nd ed.). McGraw-Hill.
[22]. **Reason, J. (**1997). *Managing the risks of organizational accidents*. Ashgate.
[23]. **Salmon, P. M., Walker, G. H., & Stanton, N. A.** (2016). Human factors methods and accident analysis. *Safety Science, 86*, 24–40 https://doi.org/10.1016/j.ssci.2016.02.008
[24]. **Swuste, P., Frijters, A., & Guldenmund, F.** (2012). Is it possible to influence safety in the building sector? *Safety Science, 50*(5), 1333–1343. https://doi.org/10.1016/j.ssci.2011.12.030
[25]. **Toole, T. M.** (2002). Construction site safety roles. *Journal of Construction Engineering and Management, 128*(3), 203–210. https://doi.org/10.1061/(ASCE)0733-9364(2002)128:3(203)
[26]. **Zhou, Z., Goh, Y. M., & Li, Q.** (2015). Overview and analysis of safety management studies in construction. *Safety Science, 72*, 337–350. https://doi.org/10.1016/j.ssci.2014.10.006
[27]. **Lingard, H., & Rowlinson, S**. (2005). *Occupational health and safety in construction project management*. Spon Press.