THE RISKS IMPACT ANALYSIS ON THE PRODUCTION AND INSTALLATION PROCESS OF ALL-GLASS STRUCTURES

Nazar Kurylyak, PhD Student, Vasyl Yatsuk, Dr.Sc., Prof.,
Lviv Polytechnic National University, Ukraine;
e-mail: vasyl.o.yatsuk@lpnu.ua

https://doi.org/10.23939/istcmtm2025.03.

Abstract. The The FMEA method application to assess and reduce metrological risks during the production and installation of all-glass structures are considers in the article. A structural and functional analysis of the main stages of project implementation has been carried out: from the development of technical documentation to warranty service. For each the sub-stage process risk factors have been identified. According to the severity consequences criteria and occurrence and detection probability their quantitative assessment has been carried out also. The risk priority index (RPN) has been calculated, those allowed the critical zones ranking of the installation process. Based on the analysis results, to reduce risks and improve the quality of structures installation a set of technical and organizational measures has been developed. Based into the European standards EN 12150, EN 12600 and EN 16612A measurement control system has been proposed. The practical implementation of the proposed approaches has been tested in production conditions.

Key words: **Keywords:** risk, European standards, all-glass structures, quality control, technical and economic effect

1. Introduction

Aesthetic appeal and modern appearance have contributed to the widespread introduction of all-glass structures in modern architecture. However, the use of construction glass in can lead to certain technical risks that can reduce their structures safety and durability. The requirements of European standards should be followed, primarily EN 16612, EN 12150 and EN 12600, to reduce risks during the manufacture and installation of glass structures if the analysis has shown [1-3]. These regulatory documents propose effective methods for controlling and assessing of the glass structures quality. Their implementation is a prerequisite for ensuring the reliability, durability and safety of such structures. Modern digital transformation is radically changing established approaches to quality assurance and requires rapid adaptation to these changes in quality management [4-6]. The Quality 4.0 modern concept development is believed to be based on the Industrial Revolution Industry 4.0 results and uses digital technologies, automation and data analysis to optimize quality management. To ensure customer satisfaction in real time, it is important to adapt to the constant changes that occur and to establish a vital link between perfect quality and the ability of organizations to thrive in these conditions [6].

However, in practice, mechanical damage to glass structures or their loss of aesthetic value sometimes occurs. It is believed that this is the made errors result at the design stage or during construction work. Based on practical "on-site" research and literature analysis, certain risks, causes and possible consequences associated with the use of glass elements have been identified. Recommendations for the safe use of glass have also been analyzed and provided [7].

The theoretical approach to determining the strength of glass panels is usually probabilistic based on the Weibull distribution, but it requires a large sample of laboratory studies. An alternative approach to predicting the risk of failure is stochastic Griffiths defect modeling. To simplify the implementation, a modeling methodology has been proposed that eliminates the need for repeated physical experiments on glass panels of different sizes and at different loading rates [8]. It has also been proposed to use a semi-probabilistic method in the limit design of glass structures, introducing properly calibrated values of the partial safety factors of the material strength to obtain a probability of failure compatible with the target values specified for each consequence class by the Eurocode [9]. However, the results of these studies serve only as a basis for the design of glass structures in accordance with the general requirements for performance characteristics established by the standards.

General recommendations for the European standards implementation in the glass components design are provided by the European Structural Design Guide for Glass Components [10]. The authors considered the economic and safety impact of using standards on structures, which allows for increased durability and cost optimization, reduction of defects and elimination of problems during installation.

2. Drawbacks

The main problem during the production and installation of all-glass structures is the lack of a unified approach to analyzing the impact of risks throughout the entire technological cycle from glass production to its installation and transfer to the customer.

3. Goal

The purpose of this article is to analyze risks and develop proposals to reduce their impact on the production process and installation of all-glass structures. The main task of this study is to identify risks at each stage of the production process, assess material and economic losses from their occurrence, and assess the potential benefits of implementing standards.

4. Regulatory and technical support for the installation process of all-glass structures

While the production and installation of modern all-glass structures, certain basic standards and principles must be followed. During the design, the methodology for calculating the load-bearing capacity of glass panels under the action of various types of loads, such as wind force, self-weight, temperature, etc., which are given in the standard for determining the mechanical strength of glass structures [1]. For risk assessment during the manufacture of glass structures, this standard helps to identify potential weaknesses and defects that can lead to loss of structural strength.

The EN 1288-1 - EN 1288-5 standards series covers methods for testing the bending strength of glass specimens [11-15]. These methods allows to determine the risk of cracks and defects during the production process. Compliance with this standard requirements helps to minimize the risk of damage during transportation and installation. The EN 1288 series of standards covers methods for testing the bending strength of glass specimens. The use of these methods allows to determine the risk of cracks and defects during the production process. Compliance with the requirements of these standards helps to minimize the risk of damage during transportation and installation [11-15].

A separate standard, EN 12150-1, specifies the requirements for heat-strengthened glass, which is often used in structures with high safety requirements. Heat-strengthened glass undergoes an additional heat treatment that increases its strength. The standard describes test methods to reduce the risk of spontaneous fracture caused by nickel sulfide inclusions [2].

The climatic requirements are set out in the standard for the calculation of wind loads for building structures. In the case of glass facades and all-glass structures, this standard is critical for determining the permissible load level and ensuring the reliability of the structure under wind loads. This reduces the risk of glass breakage under the influence of wind gusts [16].

The EN 12600 standard describes the method for testing glass for impact resistance, which is particularly important for all-glass structures. The test allows to assess the behavior of glass upon impact, in particular the risk of sharp fragments. The use of this standard helps to minimize injuries in the event of glass breakage [3].

The EN 356 standard provides a classification of glass according to its ability to resist penetration under impact [17]. This is important for all-glass structures used in public places or buildings with increased security requirements. This assessment allows predicting possible risks in the event of vandalism or other mechanical impacts [17].

In the process of risk assessment for the manufacture and installation of all-glass structures, European standards help to systematize the requirements for materials and processes. At the glass manufacturing stage, the EN 1288 and EN 12150 standards ensure material quality control and minimize the risk of defects in production. During the installation of glass structures, the EN 16612 and EN 1991-1-4 standards provide conditions to ensure that the structure withstands the necessary mechanical loads and is safe in operating conditions. The impact resistance assessment according to EN 12600 reduces the risks in the event of accidental glass breakage, ensuring safe conditions for people in the vicinity of the structure.

The application of European standards ensures a high level of quality and reliability of all-glass structures, reducing risks for the end user and increasing the durability of the structure. It also contributes to compliance with regional safety standards and building requirements, which is especially important for certification and compliance of projects.

5. Researching methodology for the identifying risks process during the manufacture and installation of all-glass structures

Several classical approaches were used to identify sources of possible risks, collect and pre-process data. In particular, a systematic review of scientific articles made it possible to identify the main types of risks in the production of glass structures and assess their economic impact. An audit of real production and installation processes was conducted at one of the enterprises to identify non-compliance with standards and identify key risk areas. A number of risk management and quality control specialists were involved to clarify the probability of risks and their impact on production..

The methods used provide a full cycle of risk assessment, economic analysis and control over the implementation of standards. This approach allows you to optimize costs, reduce risks and ensure effective integration of European standards into the production process, increasing its reliability and competitiveness.

The analysis showed that the process of manufacturing all-glass structures is a complex and risky process that requires a high level of quality control at all stages. Assessment of the main risks at all stages from the supplier and the customer will be able to minimize the impact of these risks (Fig. 1). This entire process can be divided into the following main stages: execution of design work, manufacturing of glass, purchase of fittings, installation of all-glass structures, delivery of finished products to the customer.

In the process of performing design work, risks may arise during the formation of a commercial offer, establishing the correct geometric dimensions of all-glass structures, and developing and approving the technical specifications. The analysis shows that the main risks here may be incorrectly selected fittings or glass thickness, which may lead to an incorrect commercial offer. Such risks cause the supplier to need to adjust the offer, and the customer may experience delays in receiving the finished product. To minimize such risks, careful selection of fittings and correct calculation of glass thickness are required. In the process of developing the technical specifications (TS), risks arise due to incorrectly formulated requirements for openings, the parameters of compensators and gaps can also affect the accuracy of structures, insufficient or inaccurate measurements, and instrument error. This can have a negative impact: on the supplier due to the potential need to revise the TS, and on the customer due to delays in project approval. To minimize them, experts should be involved and calculations should be checked, more accurate measuring equipment should be used. During the approval of the technical specifications, risks may include inconsistency of the technical specifications with the customer's requirements, which may cause the risk of repeated approval for the supplier and incorrect requirements for the customer. In order to minimize them, consultations with the customer and additional approvals are necessary.

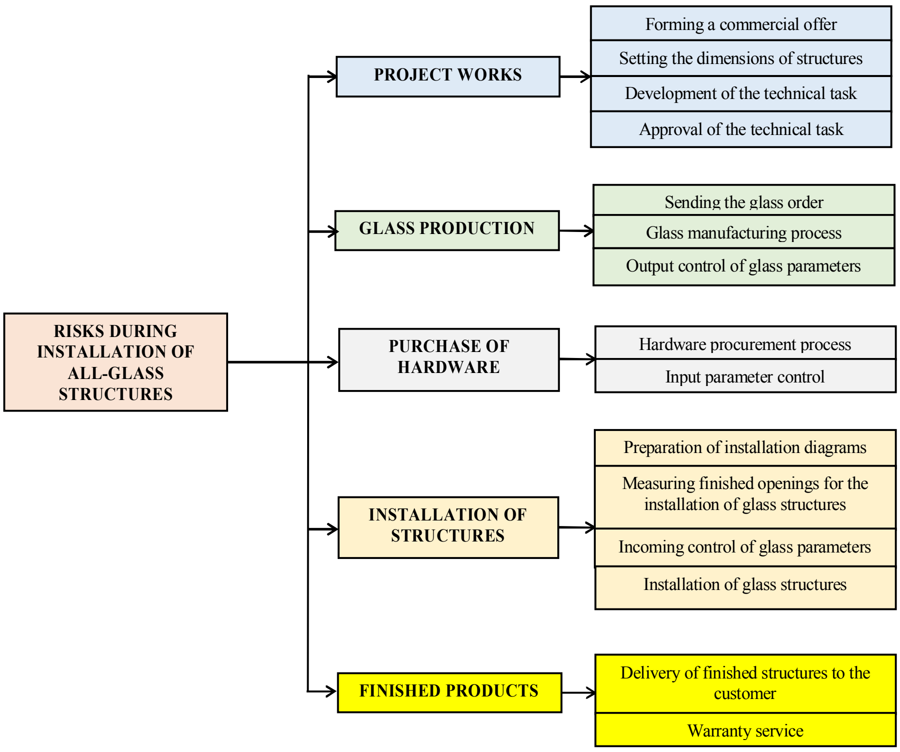

Fig.1. Assessment of the main risks at all stages of manufacturing and installation of all-glass structures

At the glass manufacturing stage, risks may arise in the processes of sending an order and manufacturing glass and initial control of its parameters. Sources of risks may be errors in the dimensions, thickness and type of glass, non-compliance of its dimensions and thickness with the drawings, the presence of defects, non-compliance of the parameters and quantity of products with the established requirements. They may affect delays and additional costs for corrections for the supplier, delays in the timing of receiving products for the customer, additional checks and possible replacement of products for the supplier, late delivery for the customer. In order to correct these risks, careful inspection before sending an order, modern equipment and control of the production process, visual and automated quality control are necessary.

At the glass manufacturing stage, risks may arise in the processes of sending an order and manufacturing glass and initial control of its parameters. Sources of risks may be errors in the dimensions, thickness and type of glass, non-compliance of its dimensions and thickness with the drawings, the presence of defects, non-compliance of the parameters and quantity of products with the established requirements. They may affect delays and additional costs for corrections for the supplier, delays in the timing of

receiving products for the customer, additional checks and possible replacement of products for the supplier, late delivery for the customer. In order to correct these risks, careful inspection before sending an order, modern equipment and control of the production process, visual and automated quality control are necessary.

During the installation of all-glass structures, risks may arise due to incorrect installation diagrams, which may lead to errors in the installation of structures. The main risks that may cause delays in the entire process are non-compliance of the openings for the installation of structures, non-compliance of the dimensions and thickness of the glass and fittings with the project requirements during the incoming inspection of glass and fittings, errors during installation or damage to the structures. This may negatively affect the costs for the supplier due to project adjustments, delays in installation, costs for replacing unsuitable components and correcting defects. The negative impact for the customer will be the postponement of the completion of the project, possible installation errors and the costs for correcting them. In order to correct the impact of such risks, it is necessary to carefully check the installation diagrams and finished openings, conduct incoming inspection of all elements before installation, involve qualified installers and carry out operational control of the work performed.

During the installation of all-glass structures, risks may arise due to incorrect installation diagrams, which may lead to errors in the installation of structures. The main risks that may cause delays in the entire process are non-compliance of the openings for the installation of structures, non-compliance of the dimensions and thickness of the glass and fittings with the project requirements during the incoming inspection of glass and fittings, errors during installation or damage to the structures. This may negatively affect the costs for the supplier due to project adjustments, delays in installation, costs for replacing unsuitable components and correcting defects. The negative impact for the customer will be the postponement of the completion of the project, possible installation errors and the costs for correcting them. In order to correct the impact of such risks, it is necessary to carefully check the installation diagrams and finished openings, conduct incoming inspection of all elements before installation, involve qualified installers and carry out operational control of the work performed.

6. The results of the study of the process of identifying risks during the manufacture and installation of all-glass structures

In the manufacturing process, an effective way to prevent accidents and protect workers from serious accidents during glass production is to use a risk matrix and a methodology for determining the advantages of orders by similarity to the ideal solution.

The study [18] focuses on assessing the health hazards of workers associated with glass production, including exposure to dust, heavy metals, noise, and high temperatures. This approach allows for a broader understanding of the risks that arise not only in the context of structural reliability, but also in the context of the safety of the working environment.

Attempts have also been made to theoretically and experimentally substantiate the risks when using glass as a commercial multilayer product. The influence of these safety sheets on the mechanical response of glass to bending has also been investigated. In particular, the results of simulation analyses carried out using a three-dimensional model in finite element software (e.g. Abaqus/CAE) have been considered. However, they mainly concern the analysis of risks regarding the mechanical stability of all-glass structures [8]. The safety verification of glass structures is usually carried out on the basis of a deterministic approach without an assessment of the probability of failure. Therefore, the use of a semi-probabilistic method in the limit design of glass structures makes it possible to obtain a probability of failure compatible with the target values specified for each consequence class by Eurocode 1 (EN 1990) [19]. However, other sources of risk are not taken into account.

Based on known risk factors, historical failure data, incident statistics, and expert assessments, a list of possible risk factors is formed [20]. For this purpose, various risk identification methods are used, such as brainstorming methods, expert interviews, analysis of primary documentation, and historical data are also used [20]. Based on the identified factors, specific events that can lead to quality losses are determined (Fig. 1).

The results of the study of the impact of risks at each stage on the overall process of manufacturing and installing all-glass structures using historical data and applying corrective actions are presented in Table. The study was conducted on a sample of 150 orders (projects) completed in the period 2022–2025.

The increase in the overall risk severity after the implementation of corrective actions to 112% can be explained not by a simple redistribution of risks between stages, but by the clarification and detailing of their assessment. The introduction of additional control measures, multi-level verification and the use of more accurate measurement methods made it possible to identify previously overlooked or underestimated risks. Thus, a value of more than 100% reflects an increase in the objectivity and completeness of the risk assessment, and not an increase in the actual overall danger. This provides more accurate risk management and increases the level of safety and reliability of structures.

The analysis of changes in significance after the implementation of corrective actions showed that, unlike other stages, where risks were effectively reduced, in points 4 (installation of structures) and 5 (delivery of finished products) there was an increase in significance. This is explained by the fact that the implementation of corrective actions at the previous stages, in particular, increasing the accuracy of measurements, the quality of fittings and control of the technical task, transferred responsibility and concentration of residual risks to the stages of installation and delivery. In other words, reducing risks at the early stages revealed hidden risks at the final stages - in particular, the human factor, installation errors and possible defects detected during final acceptance.

The corrective actions in points 4 and 5 included improved installation diagrams, test installations, more detailed on-site monitoring, and the introduction of a post-installation monitoring system. However, these actions paradoxically increased the detection of new or previously hidden problems, which led to an increase in their relative importance in the overall risk distribution

Table. Results of the study of the impact of risks of each stage on the overall process of manufacturing and installing all-glass structures

№	Stages	Validity, %	Weight after adjustment, %
1	***Project work***	***27***	***34***
1.1	formation of a commercial offer	6	8
1.2	setting the correct dimensions	7	9
1.3	development of the technical task	9	10
1.4	approval of the technical task	5	7
2	***Production of glass***	***26***	***27***
2.1	sending an order for glass	8	9
2.2	glass production	11	9
2.3	output control of glass parameters	7	9
3	***Закупівля фурнітури***	***14***	***13***
3.1	hardware procurement process	9	7
3.2	checking hardware parameters	5	6
4	***Installation of glass structures***	***26***	***29***
4.1	drawing up assembly diagrams	6	7
4.2	measuring openings for structures	5	6
4.3	incoming control of glass parameters	8	8
4.4	incoming control of glass parameters	7	8
5	***Handing over of finished products***	***7***	***9***
5.1	handing over of finished products	4	5
5.2	warranty service	3	4
	General indicators:	***100***	***112***

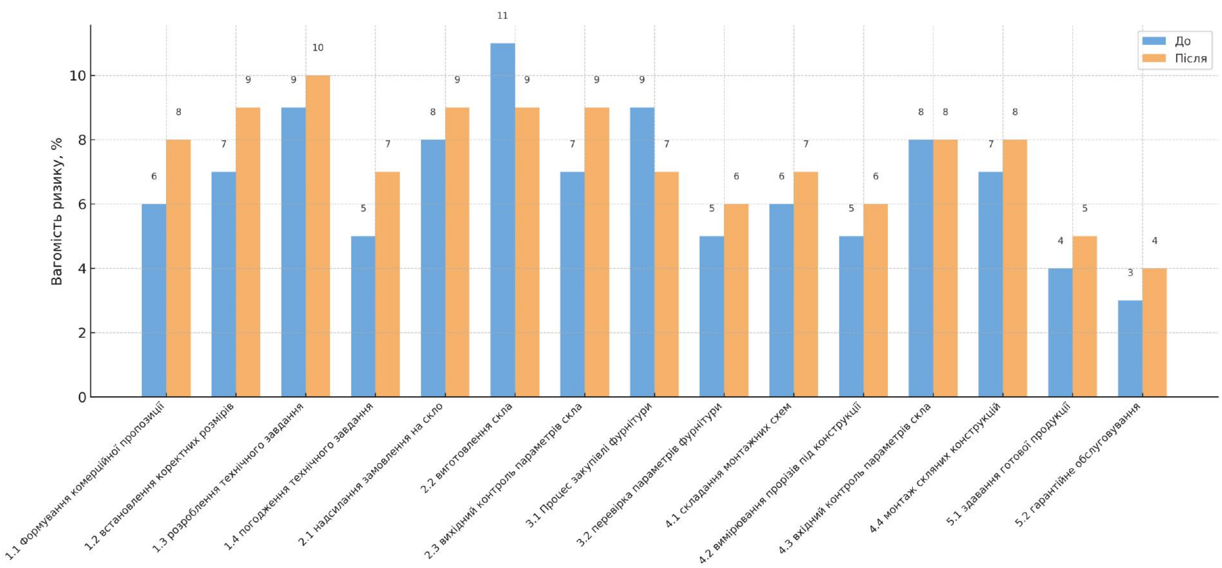

Fig. 2 . Risk distribution by components of the stages before and after adjustment (FMEA method)

The FMEA (Failure Mode and Effects Analysis) method was used to identify potential failure points and assess their impact on the quality of installation of all-glass structures. Risk assessment was carried out using three parameters: S — severity of consequences, O — frequency of occurrence, D — probability of detection. Based on these assessments, the risk priority index (RPN) was calculated using the ratio RPN=S×O×DRD, which allowed for a structured identification of the most critical process elements. This approach provides a reasonable prioritization of corrective actions, reduces the probability of defects and optimizes the quality management system when installing large-sized glass elements.

7. Possible ways to reduce the risks during the installation of all-glass structures

To reduce financial and economic risks in the process of manufacturing all-glass structures, it is possible to propose a plan of measures that covers each stage of the process from the selection of materials to installation and quality control (Table 2).

Table 2. Ways to reduce financial and economic risks during of manufacturing and installation all-glass structures

Offer name	Offer description	Possible source of economic effect
1	2	3
1. Process planning and material selection		
1.1. Supplier Verification	Enter into contracts with reliable suppliers who have quality certificates and ensure compliance with delivery deadlines.	Avoiding costs for material replacement and reducing work duration
1.2. Material quality control	Implement procedures for checking the quality of materials at the receiving stage (glass, fittings). This will help detect defects before production begins.	Avoiding costs for material replacement and reducing work duration
1.3. Creation of material reserve	Keep a certain reserve of materials to avoid delays due to possible shortages or defects in deliveries.	Avoiding costs due to shortages and reducing work duration
2. Organization of the measurement process		
2.1. Preparing tools	Ensure regular calibration of measuring instruments to improve measurement accuracy.	Avoiding costs due to shortages
2.2. Staff training	Train employees in proper measurement techniques to reduce the likelihood of errors	Avoiding costs due to shortages
2.3. Additional checks	For important projects, conduct repeated measurements or involve independent experts to control the results	Avoiding costs due to shortages
3. Glass production and quality control		
3.1. Implementation of quality standards	Applying standards such as EN 16612 and EN 12150 to ensure glass meets strength requirements	Avoiding costs due to shortages
3.2. Use of automated control systems	Automate the quality control process to detect defects that may not be visible during visual inspection	Increased productivity
3.3. Regular equip-ment maintenance	Performing maintenance on production equipment to minimize the likelihood of breakdowns during manufacturing	increasing labor productivity, avoiding costs due to shortages and reducing work duration
4. Preparation of technical specifications		
4.1. Joint agreement of the technical task	Conducting consultations with the customer to clarify the requirements and features of the project to reduce the risk of rework	Avoiding the risk of losing the contract and/or reducing the duration of the work
4.2. Detailed descrip-tion of technical requirements	Creation of an accurate and comprehensive technical specification taking into account all design parameters (glass thickness, fittings, dimensions, etc.)	Avoiding the risk of losing the contract and/or reducing the duration of work and reducing defects
5. The process of installing all-glass structures		
5.1. Test installation	Carrying out a test installation to verify compliance with the design and avoid errors during the installation phase	Avoiding the risk of defects and reducing work duration
5.2. Preparation of installation diagrams	Development of detailed installation diagrams taking into account the specifics of the project. This will reduce the likelihood of errors during installation	Avoiding the risk of defects and reducing work duration
5.3. Ensuring safety at the installation site	Provide training for installers on safety issues to avoid damage to structures	Avoiding the risk of insurance payments from injuries, reducing defects and duration of work
6. Outgoing quality control before delivery of products to the customer		
6.1. Multi-level quality control	Implementation of multi-level quality control at each stage of manufacturing and installation, including visual inspection, automated checks and final inspection before delivery	Avoiding the risk of defects and reducing work duration

Continuation of **Table 2**

1	2	3
6.2. Strength and durability testing	Conducting tests, such as impact resistance (EN 12600), to ensure products meet safety standards	Avoiding the risk of defects and reducing work duration
6.3 Documenting the control process	Keeping records of all inspections and tests, which will allow you to identify systematic errors and improve the process	Avoiding the risk of defects and reducing work duration
7. Warranty service and customer feedback		
7.1. Feedback system	Implement a customer feedback process to identify potential defects or unmet expectations. This will help improve production processes	Avoiding the risk of defects and reducing work duration and increasing competitiveness
7.2. Regular inspection of the structure	Offer customers regular inspection and maintenance of glass structures to prevent potential problems	Avoiding the risk of defects and reducing work duration
7.3. Analysis of warranty cases	Studying warranty cases to identify the causes of recurring problems and prevent them in future projects	Avoiding the risk of defects and reducing work duration
Summary and expected results of the risk reduction plan		Estimating the possible economic effect

The financial consequences of delays can include direct and indirect costs of corrections, as well as lost opportunities. Direct costs include additional costs for labor, equipment, and other resources required to complete the project. Indirect costs include the costs of maintaining personnel or equipment that were hired specifically for the project and the costs of temporarily storing materials or structures. Lost opportunities can occur when resources are held up on one project, which can limit the ability to take on new projects and result in lost profits.

This plan will significantly reduce the likelihood of risks in the process of manufacturing and installing all-glass structures, ensuring reduced costs for eliminating defects and rework, improving product quality and reliability, increasing customer satisfaction and minimizing warranty claims, and reducing project execution time by eliminating delays and errors.

Practice shows that the implementation of this plan helps the company optimize processes, ensure compliance with standards and reduce financial losses associated with risks. The introduction of European standards in the production and installation of all-glass structures will have a significant economic effect, as it will reduce costs, increase process efficiency and increase project profitability.

8. Conclusions

Thus, the current tasks of regulatory and metrological ensuring a high level of quality and reliability of installation of all-glass structures are the application of European standards. This allows to reduce risks for the end user and increase the durability of structures. In addition, such an approach will contribute to compliance with regional safety standards and construction requirements, which is especially important for certification and assessment of conformity of projects.

The analysis provided an assessment of the sources of the main risks at all stages of the manufacturing of all-glass structures. used to identify potential points of failure and assess their impact on the quality of the installation of all-glass structures. The risk assessment was carried out according to the parameters of the severity of the consequences, the frequency of occurrence and the probability of detection. Based on these assessments, a risk priority index was calculated, which allowed for a structured identification of the most critical elements of the process. As a result, such an approach can provide a reasonable priority for corrective actions, reduce the probability of defects and optimize the quality management system during the installation of large-sized glass elements. To reduce financial and economic risks in the manufacturing process of all-glass structures, the entire technological process was analyzed, recommendations were made for its optimization, which will significantly reduce the likelihood of risks in the manufacturing and installation of all-glass structures. Everything will ensure a reduction in costs for defect elimination and rework, an increase in product quality and reliability, an increase in customer satisfaction and a minimization of warranty claims, and a reduction in project execution time by eliminating delays and errors.

Conflict of Interest

The authors state that there are no financial or other potential conflicts regarding this work.

Reference

[1] EN 16612:2019. Glass in building – Determination of the lateral load resistance of glass panes by calculation

[2] EN 12150-1:2015+A1:2019. Glass in building. Thermally toughened soda lime silicate safety glass – Definition and description

[3] EN 12600 Safety Glazing Testing Summary

[4] Zulqarnain, A.; Wasif, M.; Iqbal, S.A. Developing a Quality 4.0 Implementation Framework and Evaluating the Maturity Levels of Industries in Developing Countries. Sustainability 2022, 14, 11298. https://doi.org/10.3390/su141811298 (Last accessed: 20.05.2025)

[5] Shockey S. Quality 4.0 and the Future of Quality Management. Electronic resource, available: https://clarkstonconsulting.com/insights/future-of-quality-management/ (Last accessed: 20.05.2025)

[6] Bassi D. Quality 4.0: Quality Management in the Digital Age. Electronic resource, available: https://www.linkedin.com/pulse/quality-40-management-digital-age-darshi-bassi/ (Last accessed: 20.05.2025)

[7] Respondek Z. Glass Building Elements - Technical Aspects of Safe Usage in the Structure. System Safety: Human - Technical Facility - Environment. VOLUME 1 (2019): ISSUE 1 (MARCH 2019). available: https://sciendo.com/article/10.2478/czoto-2019-0038/ (Last accessed: 20.05.2025)

[8] Silvana M, Numerical fragility assessment and structural performance analysis of glass facade systems including post-fracture residual capacity. (2023) Tesi di dottorato. Electronic resource, available: https://arts.units.it/handle/11368/3048138 (Last accessed: 20.05.2025)

[9] Pathirana M, Lam N., Pereira S., Lihai Z., Dong R., Gad E. Risks of failure of annealed glass panels subject to point contact actions. International Journal of Solids and Structures. Volume 129, 15 December 2017, Pages 177-194. https://www.sciencedirect.com/science/article/pii/S0020768317304067?via%3Dihub

[10] Joint Research Centre: Institute for the Protection and Security of the Citizen, Langosch, K., Dimova, S., Pinto, A. V., Siebert, G. et al., *Guidance for European structural design of glass components – Support to the implementation, harmonization and further development of the Eurocodes*, Dimova, S.(editor), Pinto, A. V.(editor) and Denton, S.(editor), Publications Office, 2013, https://data.europa.eu/doi/10.2788/5523 (Last accessed: 20.05.2025)

[11] prEN 1288-1 rev - Glass in building - Determination of the bending strength of glass - Part 1: Fundamentals of testing glass

[12] EN 1288-2:2000 - Glass in building - Determination of bending strength of glass - Part 2: Coaxial double ring test on flat specimens with large test surface areas

[13] EN 1288-3:2000 - Glass in building - Determination of the bending strength of glass - Part 3: Test with specimen supported at two points (four-point bending)

[14] EN 1288-4:2000 - Glass in building - Determination of the bending strength of glass - Part 4: Testing of channel shaped glass

[15] EN 1288-5:2000 - Glass in building - Determination of the bending strength of glass - Part 5: Coaxial double ring test on flat specimens with small test surface areas

[16] EN 1991-1-4 Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions

[17] EN 356 Intruder Resistance: Testing and Classification of Resistance Against Manual Attack

[18] National Research Council (US) Committee on Industrial Hygiene. Occupational Health Hazards in the Glass Manufacturing Industry. National Academies Press (US); 1988. https://www.ncbi.nlm.nih.gov/books/NBK499748/

[19] Badalassi M., Biolzi L., Gianni Royer-Carfagni G., Salvatore W. Safety factors for the structural design of glass. Construction and Building Materials. Volume 55, 31 March 2014, Pages 114-127. https://doi.org/10.1016/j.conbuildmat.2014.01.005

[20] Артемук О-С., Микийчук М., Метод прогнозування метрологічних ризиків якості продукції, *Measuring and computing devices in technological processes*, vol. 4, pp. 179–186, 2024, https://doi.org/10.31891/2219-9365-2024-80-22