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Structural Glass Application in The Modern Era of Construction: A Review

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Abstract: Addressing the growing utilization of glass as a structural material, this paper undertakes a systematic literature review to explore key aspects such as long-term behavior, structural connections, and adherence to design regulations in Glass Structures. Despite the increasing construction of ambitious buildings incorporating glass, there remains a noticeable gap in comprehensive research. The review systematically analyses major studies, highlighting developments in the field and compiling an overview of challenges faced by previous researchers. By synthesizing this information, the paper not only provides insights into the current state of Structural Glass but also identifies gaps and opportunities for future research. The ultimate objective is to contribute to the advancement of knowledge, fostering the safe and effective utilization of glass in diverse structural applications.

Keywords: structural; glass; application

1. Introduction

A solid inorganic material known as “glass” is often transparent or translucent, hard, brittle, and resistant to the natural elements [1]. It is a magical material with so many unique qualities and applications that have given architects numerous great possibilities and designs [2]. In this paper, we delve into the multifaceted aspects of structural glass, exploring its characteristics, applications, challenges, and advancements. An emerging trend in architecture is to make structures more transparent [3] and glass, as we all know, is a classic building element that allows light to enter structures easily [4]. The main applications of glass in construction relate to a wide range of factors, including aesthetics, lighting, transparency, and insulating objectives [5]. Glass is appealing for a variety of reasons, including its transparency, chemical inertness, environmental friendliness, sustainability, strength, ease of availability, and relative affordability. There is no other frequently used material that has these properties [6]. Despite being widely used in facades, roofs, envelopes, and frame components, glass still represents a very new and little-known material that calls for distinct design concepts and additional in-depth research in order to meet safety design requirements [7].

One of the most widely used materials, glass has a wide range of applications. It may be used to create structures, to make containers and vessels, to make windows for cars, to make optical fibers for nanotechnology, etc. [6]. The usage of glass in buildings has significantly expanded during the last few decades. As a result, some transparent buildings have been built in which materials are almost invisible [8]. A variety of products have been produced as a consequence of research into improving glass as a building material, its qualities, and processing techniques which has greatly encouraged the use of glass in architecture and other fields[4]. "Structural glass" refers to buildings that use glass as a load-bearing component, such as in a column or beam or as a support for other glass parts [9]. The tendency to "make the most of glass" has driven designers to work to strengthen the support system, which is frequently a weak aspect of glass in construction. They are characterized as a significant development that enables high-performance glass structures [10].

This paper critically analyzes existing literature on the use of structural glass, aiming to synthesize the latest technological advances and enumerate challenges encountered in previous research. The subsequent sections are organized as follows to provide a comprehensive understanding of the subject matter. Section 2 outlines the comprehensive procedure for the literature search, summarizing the collected articles. Section 3 delves into the intricacies of glass manufacture, mechanical properties, types, applications, and standardization. In Section 4, we identify research gaps and propose prospective future research directions. Finally, Section 5 concludes the paper, summarizing key findings and insights.

2. Materials and Methods

2.1. Literature Review

The majority of research title on the list are retrieved using Elicit.org search results as its basis (Elicit: The AI Research Assistant). Elicit is a research assistant that helps researchers with language models like GPT-3 by automating some of their tasks. Presently, Elicit's main workflow is literature review. When you ask a question, Elicit will present relevant documents together with brief summaries of crucial information about those papers in a comprehensible table [11]. Keyword/phrase combinations utilized to look for published articles were "structural glass application". The primary literature databases, such as Science Direct, Scopus, and Google Scholar, were used to find further material. After then, the sample was collected by several rounds of scanning and clustering of research articles.

2.2. Literature Selection Process

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), which is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses that primarily focuses on the reporting of reviews evaluating the effects of interventions, but can also be used as a basis for reporting systematic reviews with objectives other than evaluating interventions (e.g. evaluating a etiology, prevalence, diagnosis or prognosis) [12]. Following a keyword or phrase search, a portfolio of 60 original research articles, reviews, conference proceedings, book chapters, and published theses was discovered. Then, 45 research papers that were pulled from various sources, polished, and categorized as a result of the content analysis. In order to ensure that the research articles were relevant to the study's intended topic of inquiry, they were carefully read and analyzed. Finally, 36 publications total were eventually used to conduct this research. The Systematic Related Literature selection process is shown in Figure 1 in order to identify the use of glass in structural application, the categorization of themes is done in accordance with the criteria and parameters that have been established as the major objective(s). These features could be referred to as sub-themes.

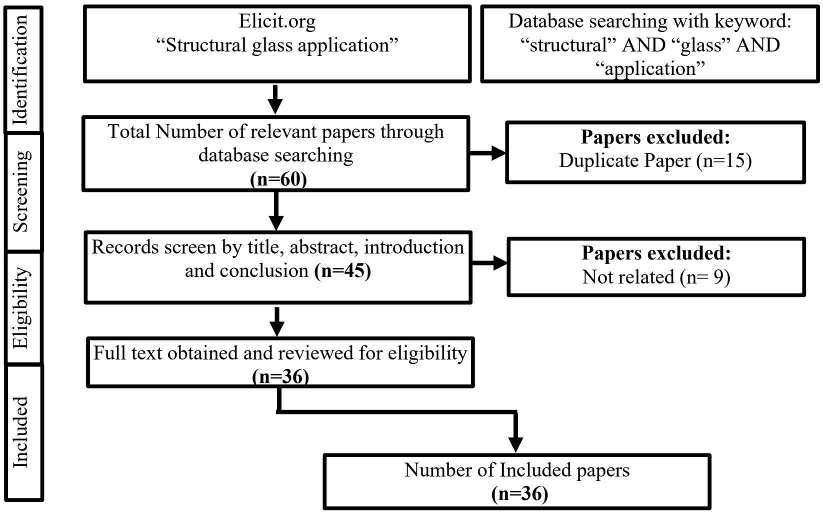

Figure 1. Systematic Related Literature selection process

Software called NVivo is used for mixed-methods and qualitative research. In particular, it is used to analyze unstructured text, audio, video, and image data from sources such (but not restricted to) interviews, focus groups, surveys, social media, and journal articles [13]. One of the advantages of this software is the use of Word Frequency queries, which are valuable for identifying potential themes, especially in the early stages of a project, and for examining the most commonly used terms in a specific demography [14]. The software can also generate visuals after the query that could be useful for writing, such as a Word Cloud (also known as a tag cloud or text cloud), which is a graphic representation of a text in which the words are sized up according to how frequently they are used in the collection of articles[15]. The Word Cloud shown in Figure 2 can be used as a guide in selecting the possible themes to be emphasize in the study.

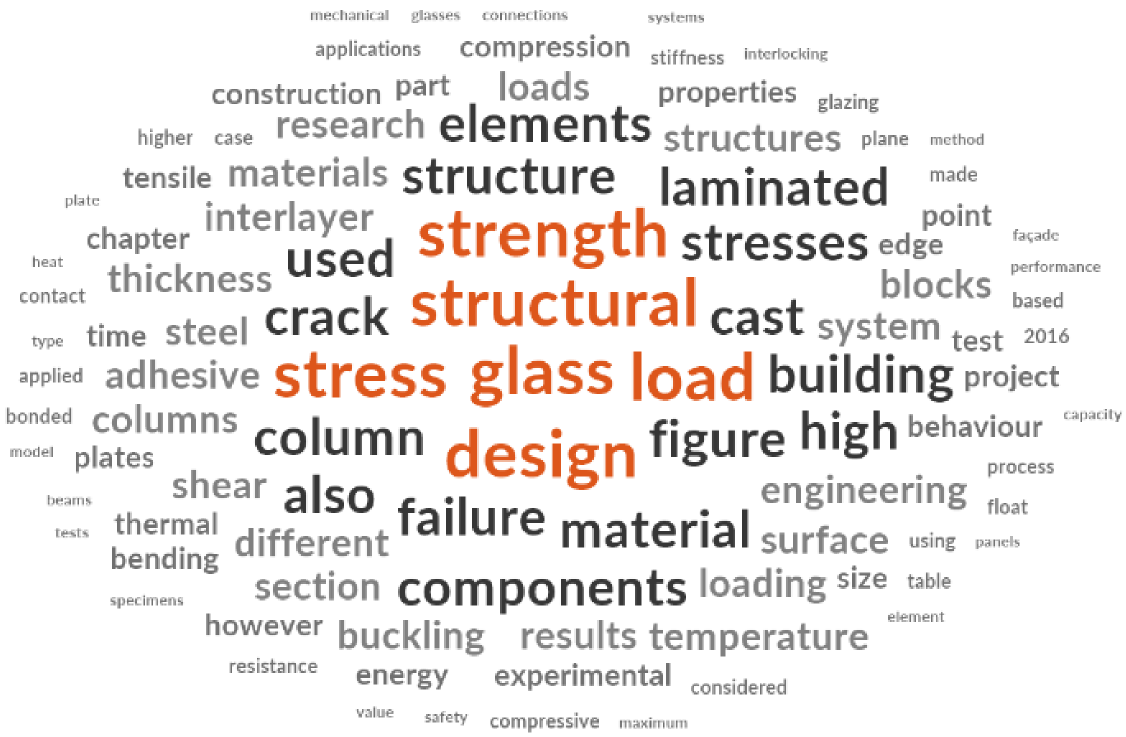

Figure 2. Word Cloud from the used literatures

3. Results and Discussion

In the subsequent sections, the researchers comprehensively explore the foundational aspects of structural glass, including its manufacturing process and mechanical properties (Sections 3.1). The exploration then delves into the various types of glass and its role as a structural element (Sections 3.2), examining applications in existing structures and the standardization of glass components (Sections 3.3). Each section provides an in-depth examination of the research methodologies employed, critically assessing their execution and emphasizing laboratory investigations and analyses. This categorization ensures a detailed exploration of each aspect, contributing to a comprehensive understanding of the subject matter.

3.1. Foundational Aspects (Glass Manufacturing Process, Mechanical Properties of Glass).

3.1.1. Glass Manufacturing Process.

Since ancient times, glass has been used for a variety of purposes in daily life [16]. It has been 4000 years ago since it was developed. In early nineteenth century, it was by pulling glass ribbon vertically out of the molten glass pool, is how sheet glass was created. The glass is distorted as a result of the molten glass's varied viscosities [17]. Over time, the science and engineering of glass as a material improved significantly. In the late 1950s, Sir Alastair Pilkington created a new, ground-breaking production technique (float glass production), which is still used to produce 90% of flat glass today [18]. The components (silica, lime, soda, etc.) used in the float glass process are first mixed with cullet (recycled shattered glass), and then the mixture is heated in a furnace to about 1600°C to create molten glass. A molten tin bath's top is then covered with the molten glass. By pouring molten glass on the tin bath while it is being carefully heated, a flat glass ribbon of uniform thickness is created. After cooling down gradually in the tin bath, the glass is put into the annealing lehr for a further controlled gradual cooling down. By altering the pace at which the glass ribbon enters the annealing lehr, the thickness of the glass ribbon can be changed. Glass is often cut onto big sheets measuring 3 m by 6 m. From this method, flat glass sheets with thicknesses ranging from 2 to 22 mm are manufactured for sale. Typically, the market offers glass with a thickness of up to 12 mm, while thicker glass may be available upon request [6].

3.1.2. Mechanical Properties of Glass. Glassy materials are intrinsically strong but fragile due to the lack of microstructure, and they frequently exhibit exceptional sensitivity to flaws [19]. It can be thought of as an "amorphous solid" when it is hard. Because of this, glass has a very brittle mechanical characteristic and no plastic deformation capacity. Under load, the strain response to the stress is linearly proportional, leading to abrupt failure [20]. The Figure 3 shows the Stress-Strain Relationship of Steel and Glass, while in Table 1 are the tabulated properties of Glass along with most widely used materials in construction such as Concrete & Steel.

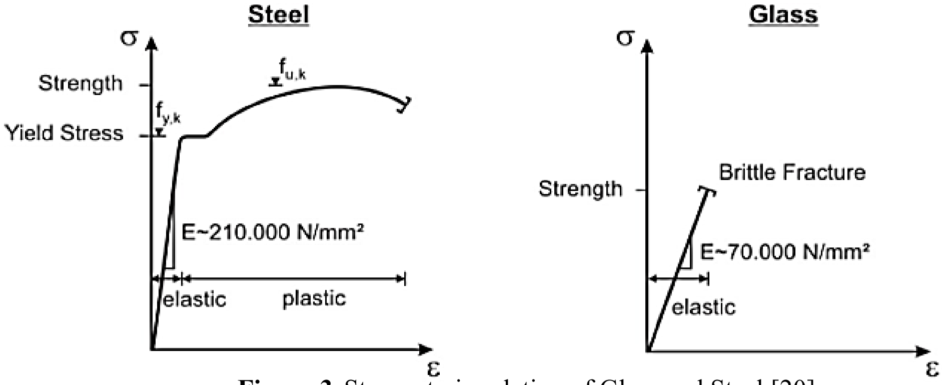

Figure 3. Stress-strain relation of Glass and Steel [20]

Table 1. Properties of Glass, Concrete, and Steel

Property	Glass [21]	Concrete [22]	Steel [23]
Density (kg/m^3)	2500	2240 – 2400	7800 – 8000
Compressive strength (MPa)	1000 (theoretical)	20 - 40	≈172[24]
Tensile strength (MPa)	120 – 200 (laminated)	2 – 5	350 – 420
Young's modulus (GPa)	70	14 – 41	200
Poisson's ratio	0.22	0.20 – 0.21	0.25

3.2. Types and Structural Role of Glass (Types of Glass, Glass as Structural Element).

3.2.1. Type of Glass.

For typical glass panels undergoing heat treatment to increase strength, they can be divided structurally into three groups: annealed, heat-strengthened, and tempered glass [17]. The Figure 4 illustrates the characteristics of the above-mentioned materials.

	Annealed	Heat Strengthened	Fully Tempered
(max)Compressive strength	(200) 120 MPa		
(max)Tensile strength	(45) 20 MPa	(70) 40 MPa	(120) 80 MPa
Type of fracture/ Size of pieces	Large & Sharp	Smaller & Softer	Very Small
			
Water Temperature Long-term loads	Sensitive	Non-sensitive	Non-sensitive
Cost	Low	High	Higher

Figure 4. Characteristics of Annealed, Heat Strengthened & Fully Tempered glass [16]

3.2.2. Annealed (or Float) Glass.

The most prevalent type of architectural glass is this one [4]. Glass that has undergone a slow cooling process from a high temperature after manufacturing to reduce residual stress and enable scoring and snapping cutting is known as annealed or float glass. This glass is among the weakest glass varieties and has a high risk of breaking when put under stresses for which it was not intended or when it is placed improperly. It tends to shatter into sharp-edged, pointed fragments. The pointed shards may create piercing injuries while the sharp edges may produce cutting wounds. The glass's residual compressive surface stress is between 24 and 69 MPa [25].

3.2.3 Heat (or Thermally)-Strengthened Glass.

Compared to annealed glass, heat-strengthened glass is at least twice as strong and resistant to breaking from wind loads or thermal strains [4]. To increase the glass's resilience to mechanical and thermal loads, it underwent a controlled heating and cooling process. In this process, the glass experiences both a permanent compressive surface stress and a permanent tensile interior stress. The glass has a higher bending strength than annealed glass thanks to the compressive surface stresses, which also lower the risk of glass failure. Heat-strengthened glass will break with identical post-failure and breakage characteristics to annealed glass [25].

3.2.4 Fully Tempered (or Toughened) Glass.

Similar to heat-strengthened glass, toughened glass has undergone the same processing steps but has had a quicker cooling process. As a result, there is a greater magnitude of compressive surface stress than there is in heat-strengthened glass. The glass now has a greater bending strength than heat-strengthened glass. Compared to annealed or heat-strengthened glass, this high strength glass is much less likely to break when mechanical or thermal loads are applied [25]. Fully tempered glass typically has a surface compressive stress of 80 to 150 MPa [6]. Its higher resistance to glass breaking comes from its strength, which is at least four times that of annealed glass. Under some circumstances, fully tempered glass can be used as safety glazing because when it breaks, it breaks into numerous little fragments known as "dice"[4]. Although float glass is the most widely accessible glass type, due to its low tensile strength and brittle failure behavior, it is rarely employed in load-bearing structural components. Most load-bearing glass structural members use laminated and toughened glass [6].

3.2.5 Laminated Glass.

Laminated glass is frequently used in building envelopes because it has a safer failure mode than float glass and tempered glass [6]. In order for the cross section to mechanically respond with a composite effect, two or more glass layers must be joined with an interlayer to create a laminated glass [20]. The glass assembly may be the best option for various applications since it might perform better than monolithic glass. The type of glass, thicknesses of glass, and interlayer varieties and thicknesses employed in construction, all affect the laminated glass's strength, breaking properties, and post-failure behavior [25]. Additionally, an adhesive is used to sandwich a transparent sheet of polymer, like polyvinyl butyral, between two or more layers of flat glass [4]. This interlayer typically has a thickness of 0.38mm, 0.76mm, 1.52mm, etc. [17]. The capacity to protect one layer by another and stop broken glass from falling to the ground are the advantages of laminated glass over just single-layered glass [26]. The risk of cutting and piercing injuries from exposed glass edges is reduced greatly since it typically splits into glass fragments that remain glued to the interlayer. This stops glass shards from falling from high altitudes in the event of failure [25]. Figure 5 shows the typical crack pattern of laminated glass under consecutive hard body impacts [27].

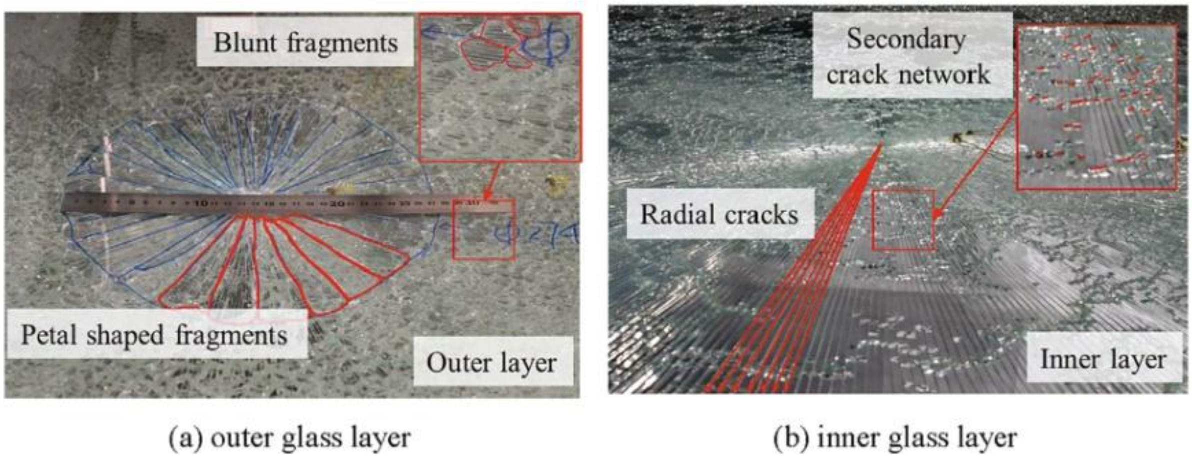

Figure 5. Typical crack pattern of laminated glass tested [27]

3.2.6 Glass as Structural Element.

"Glass structures" refer to buildings that make extensive use of glass, typically as the building envelope [9]. Glass is being used more and more in structural applications to replace or combine load-bearing components composed of conventional construction materials due to the constant need for architectural transparency in structures [7]. Transparent and translucent structures can be built by using structural glass. The benefits of doing this include creating buildings with a "lightness of appearance" and providing interior space with more natural light [25]. The structural design of glass domes and glass facades had a major influence on how it developed, and from there, nearly all types of structural glass elements were created [16].

3.2.7 Structural Glass as a Column.

The capacity to support loads is a column's most crucial feature. This is true for a structural glass column [26]. In order to obtain appropriate resilience against impact as well as to acquire redundancy, laminated column sections are required. Designing such load-bearing glass structures requires understanding the stability behavior of laminated glass panes as well as the necessary technical parameters [20]. There are a few different arrangements for glass columns that are possible: Stacked columns are composed of float glass panels that are stacked vertically (next to the other) or horizontally (one upon the other). A liquid or film-based adhesive interlayer (laminate foil or film), for example, may be used to bind the panels together. Applying a perpendicular force will also keep them joined without an interlayer (dry stack) [16]. Since glass columns are stiff elements, the design is less likely to be governed by shear. However, if the columns are short enough, shear becomes the limiting factor and buckling is no longer [10]. To be able to transfer loads (such as dead loads, snow loads, and wind loads), these types of elements subjected to compression must have appropriate strength, stiffness, and residual load carrying capacity [28].

3.2.8 Structural Glass as a Beam.

The glass roof, floors, and even a footbridge (Kraaijvanger/Urbis building in Rotterdam, Netherlands) are supported by glass beams [10]. At a specific critical load value, a beam that is bent about the axes of highest flexural rigidity may buckle laterally. If the beam's flexural rigidity in the plane of bending is less than the lateral bending rigidity, or that of the weak axis, then this lateral buckling is significant in the design of beams without lateral support. The beam will be stable as long as the load on such a beam is less than the critical value [20].

3.2.9. Structural Glass as a Wall (load bearing).

Given that they stabilize the entire glass structure, the glass walls are more complicated than the glass columns. They should be built to withstand wind-induced horizontal in-plane forces that are distributed by the ceiling's diaphragmatic function, as well as vertical in-plane compression forces from the upper structure and their own weight. Due to their fixed ends' resistance to rotation, they should also be able to withstand any ensuing bending moments. The glass walls should withstand buckling if load eccentricity and/or starting curvature are present [16].

3.2.10. Structural Glass as Pane.

Until the length to breadth ratio exceeds 1:2, glass panes carry in both directions. Kirchhoff's linear theory applies since a glass pane behaves like a plate with little deflection. Calculated stresses are found along the glass as well as at its boundaries, which are frequently crucial. However, if the anticipated deflection is more than the thickness of the glass, the glass pane cannot be taken into consideration under the linear deformation theory but rather as a membrane. As a result, the glass often adopts an effective shape of a suspended membrane [10]. Glass is a highly prized material by architects, builders, and investors due to its aesthetic advantages, superior environmental resilience, and significant stiffness of glass panes [29].

Figure 6. Glass-Bottomed Pool – USA

Figure 7. Glass bridge - China

Figure 8. Apple Store Cube – USA

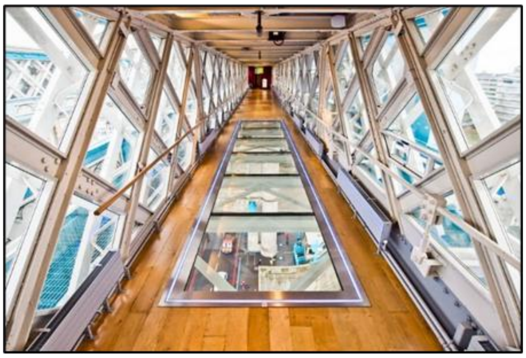

Figure 9. Tower Bridge - UK

3.3. Applications and Standardization (Existing Glass Structures, Standardization)

3.3.1. Existing Glass Structures.

Some example of structures or projects that are already utilizing Structural Glass are shown in the following figures. First, the Market Square Tower's rooftop features the highest glass-bottomed (cantilevered) pool in the world, which is located in Houston, Texas, as shown in Figure 6 [30].

Second, Figure 7 depicts a 218-meter-long glass bridge at the county-level city of Baojing Palace in Yingde in the Guangdong Province of south China [31]. Third, Figure 8 shows the 32-foot-tall Apple cube that was unveiled on May 19, 2006, the people were being transported to the basement by glass circular stairs and a glass elevator in the form of a rising cube [32]. Lastly, Figure 9 displays the Tower Bridge, which offers a unique vantage point 42 meters over the River Thames and 33.5 meters above street level where visitors can watch London life through the Glass Floors [33]. The list could be expanded to include a great number of more glass buildings. An actual illustration of how the use of structural glass is on the rise and how this could perhaps create a new market for building supplies.

3.3.2 Standardization.

Although few standards or codes exist to govern the design and construction of anything but the most basic glass structures, glass has come to be recognized as a structural material. Engineers must design in the absence of codes using their prior knowledge and testing results. In the past years, enough knowledge has become available to the general public for engineers to build glass structures that adhere to serviceability requirements [25]. Design guidelines for glass structural design are necessary to reduce the amount of structural failures brought on by avoidable negligence as a result of subpar design or construction methods caused by a lack of harmonized standards [4].

4. Future Research Recommendations

Considering the massive development in use of glass in construction from an architectural to now a structural element, there are still a number of challenges found in recent studies. Some of the topics for consideration are listed in Table 2:

Table 2. Further Studies as recommended by the literature review

Ref	*Future Research Recommendations*	*Ref*	*Future Research Recommendations*
[5]	The actual behavior of structural glass assemblies; application of specific fail-safe design rules	[34]	Design codes and standards linked to real-life applications
[25]	Structural connections; post-failure performance	[4]	Safety issues
[35]	New techniques for joining glass members without high stress concentrations; Post-breakage behavior of glass structures	[3]	Lateral and lateral-torsional instability of beams
[36]	Adhesive joining - long-time behavior of such a joint (creeping, aging)	[9]	Building codes
[26]	Structural response of glass columns bonded by an adhesive with low stiffness; long-term behavior of the glass	[16]	More load cases and combinations should be investigated including: Seismic loads, Fire loads, Blast loads, Fatigue

The research gaps need further studies as mentioned by the authors of the reviewed literature because they observed that this unconsidered variable in their study may contribute to the positive development of the Structural Glass application. From the authors' point of view, a thorough investigation of the blast or explosion effect on these materials is also deemed necessary, as events like that may cause unimaginable damages both to people and property.

5. Conclusions

In summary, the evaluation of construction materials, including Concrete, Steel, Timber, and the emerging contender, Glass, underscores the perpetual quest for innovation in the construction industry. As architects, engineers, scientists, and construction professionals engage in tireless studies, the demand for improvements aligns with the dynamic requirements of our rapidly evolving world. Despite the historical reliance on traditional materials, the newfound potential of Glass challenges preconceptions, offering a viable alternative for load-bearing applications. Reiterating the underlying rationale for our evaluation, the conclusion accentuates the ongoing pursuit of novel materials and innovative solutions. Looking ahead, this study prompts a reflection on the consequences of embracing Glass as a construction material, opening avenues for further research and exploration into the future directions of this evolving field.

References

1. Britannica, (accessed Jan. 26, **2023**), https://www.britannica.com/technology/glass
2. Constro Facilitator. Importance of Glass in Architecture Design. https://constrofacilitator.com/importance-of-glass-in-architecture-design (accessed Jan. 26, **2023**).
3. Martens, K.; Caspeele, R.; Belis, J. Development of composite glass beams – A review. *Engineering Structures* **2015**, *101*, 1–15, https://doi.org/10.1016/j.engstruct.2015.07.006
4. Savic, J.; Djuric-Mijovic, D.; Bogdanovic, V. Architectural glass: Types, performance and legislation. *Facta Universitatis - Series Architecture and Civil Engineering* **2013**, *11(1)*, 35–45, https://doi.org/10.2298/fuace1301035s
5. Bedon, C. Structural Glass Systems under Fire: Overview of Design Issues, Experimental Research, and Developments. *Advances in Civil Engineering* **2017**, 1–18, https://doi.org/10.1155/2017/2120570
6. Achintha, M. Sustainability of glass in construction. In Elsevier eBooks; **2016**; 79–104. https://doi.org/10.1016/b978-0-08-100370-1.00005-6
7. Bedon, C.; Santarsiero, M. Transparency in structural glass systems via mechanical, adhesive, and laminated connections - existing research and developments. *Advanced Engineering Materials* **2018**, *20 (5)*, https://doi.org/10.1002/adem.201700815
8. Pariafsai, F. A review of design considerations in glass buildings. *Frontiers of Architectural Research* **2016**, *5 (2)*, 171–193, https://doi.org/10.1016/j.foar.2016.01.006
9. Snijder, B.H.H. Structural Glass and Glass Structures: An Introduction. *Structural Engineering International* **2004**, *14(2)*, 72, https://doi.org/10.2749/101686604777964071
10. Bon, E. Structural Opportunities for Glass. Master of Engineering in High Performance, Massachusetts Institute of Technology, **2003**.
11. Elicit. What is Elicit? (accessed Jan. 20, **2023**) https://elicit.org/faq
12. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), (accessed Jan. 13, **2023**) https://www.prisma-statement.org/
13. STATISTICAL & QUALITATIVE DATA ANALYSIS SOFTWARE: ABOUT NVIVO, (accessed Jan. 13, **2023**) https://libguides.library.kent.edu/statconsulting/NVivo
14. Run a Word Frequency Query, (accessed Jan. 13, **2023**) https://help-nv11.qsrinternational.com/desktop/procedures/run_a_word_frequency_query.htm
15. What Is A Word Cloud? (accessed Jan. 13, **2023**) https://monkeylearn.com/word-clouds/
16. Felekou, E. Structural Glass in High-Rise Buildings. Master, Delft University of Technology, **2016**.
17. Chan, S. L. Basic Structural Design Considerations and Properties of Glass and Aluminum Structures. **2006** https://hkisc.org/proceedings/2006421/11_SLChan%20facade2006b.pdf
18. Axinte, E. Glasses as engineering materials: A review. *Materials & Design* **2011**, *32 (4)*, 1717–1732, https://doi.org/10.1016/j.matdes.2010.11.057
19. Demetriou, M. D.; Launey, M. E.; Garrett, G.; Schramm, J. P.; Hofmann, D. C.; Johnson, W. L.; Ritchie, R. O. A damage-tolerant glass. *Nature Materials* **2011**, *10 (2)*, 123–128, https://doi.org/10.1038/nmat2930
20. Feldmann, M.; Kasper, R.; Abeln, B.; Cruz, P.; Sulcova, Z.; Belis, J.; Beyer, J.; Colvin, J.; Ensslen, F.; Wellershoff, F.; Eliášová, M.; Žarnić, R.; Galuppi, L.; Geßler, A.; Grenier, C.; Haese, A.; Hoegner, H.; Kruijs, R.; Langosch, K.; Louter, C.; Schneider, J.; Manara, G.; Schula, S.; Morgan, T.; Siebert, G.; Neugebauer, J.; Rajčić, V.; Royer-Carfagni, G. Guidance for European Structural Design of glass components: Support to the Implementation, Harmonization and Further Development of the Eurocodes; **2013**.
21. Glass Physical Properties, Structural Glass Design, (accessed Jan. 27, **2023**) https://www.structuralglass.org/single-post/2016/11/26/glass-physical-properties

22. Concrete Properties. Engineering ToolBox, (accessed Jan. 27, **2022**) https://www.engineeringtoolbox.com/concrete-properties-d_1223.html
23. Steels, General Properties, (accessed Jan. 27, **2023**). MatWeb. https://www.matweb.com/search/datasheet.aspx?bassnum=MS0001&ckck=1
24. The Compressive Strength of Steel, (accessed Jan. 27, 2023) https://blog.redguard.com/compressive-strength-ofsteel#:~:text=Most%20structural%20steel%20has%20a,it%20is%20reinforced%20with%20steel
25. Ledbetter, S. R.; Walker, A. R.; Keiller, A. P. Structural Use of Glass. https://doi.org/10.1061/ASCE1076-0431200612:3137
26. Ouwerkerk, E. Glass Columns. June **2011**.
27. Wang, X.-E.; Yang, J.; Chong, W. T. A.; Qiao, P.; Peng, S.; Huang, X. Post-fracture performance of laminated glass panels under consecutive hard body impacts. *Composite Structures* **2020**, *254*, 112777, https://doi.org/10.1016/j.compstruct.2020.112777
28. Kalamar, R.; Eliášová, M. Load Bearing Innovative Construction from Glass. *IOP Conference Series Materials Science and Engineering* **2015**, *96*, 012066, https://doi.org/10.1088/1757-899x/96/1/012066
29. Respondek, Z. Glass building elements - Technical aspects of safe usage in the structure. *System Safety Human - Technical Facility - Environment* **2019**, *1 (1)*, 291–298, https://doi.org/10.2478/czoto-2019-0038
30. Shenoy, S. The World's Highest Glass-Bottomed Pool Is Situated In The Market Square Tower USA. Curly Tales, (accessed Jan. 27, **2023**) https://curlytales.com/the-worlds-highest-glass-bottomed-pool-is-situated-in-the-market-square-tower-usa/
31. Glass Bridge Opens to Visitors in South China's Guangdong, (accessed Aug. 26, **2024**) CGTN. https://news.cgtn.com/news/3d3d514e7763444d32457a6333566d54/share_p.html
32. Ward, V.; Hicks, J. The Untold Story of How the Apple Store Cube Landed in Midtown. Intelligencer, (accessed Jan. 27, **2023**) https://nymag.com/intelligencer/2014/09/story-behind-the-apple-store-cube.html
33. City of London. Top Things to See at Tower Bridge, (accessed Jan. 27, **2023**) Tower Bridge. https://www.towerbridge.org.uk/whats-inside
34. Honfi, M. O. D. Glass Structures – Learning from Experts; CRC Press/Balkema: **2013**.
35. Hans Schober, J. S. S. B. Developments in Structural Glass and Glass Structures. February **2004**.
36. Blandini, L. Lucio. Prototype of a Frameless Structural Glass Shell. Structural Engineering International, January **2008**.