JRC Scientific and Technical Reports

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Support to the implementation, harmonization and further development of the Eurocodes

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- for CEN/TC250: H. Bossenmayer and G. Sedlacek
- for CEN/TC129: J. B. Waldron and J. B. Colvin
- for the European Organisation for Technical Approvals (EOTA): P. Caluwaerts
- for the European Construction Technology Platform (ECTP): J. Rodriguez Santiago, J. M. Mieres and R. Zarnic
- for the European Association of Flat Glass Manufacturers (GEPVP): J. B. Waldron
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Summary

This document describes the rationale and justification for a new European code for the design of glass structures, its parts or kits for use in civil engineering works and outlines the specific reasons for standardisation in this area as well as the main interested parties who will benefit from the new standard. The timeliness of the proposed Eurocode is made evident both by the perceived demand for a design standard pertinent to the use of glass products in construction works and by the available knowledge and technology. Finally, a tentative proposal for the consultation, feasibility analysis and initiation strategies are presented.

This proposal develops along the lines of the Construction Products Directive (Council Directive 89/106/EEC) with the aim to promote the free circulation of glass construction products and to achieve the benefits arising from the application and use of the Eurocodes, as summarised in Guidance Paper L. The proposal is based also on the Commission Recommendation 003/887/EC that urges Member States to *"undertake research to facilitate the integration into the Eurocodes of the latest developments in scientific and technological knowledge […] thus ensuring an ongoing increased level of protection of buildings and civil works, specifically as regards the resistance of structures to earthquakes and fire"*.

This document results from extensive consultation with all stakeholders, i.e. manufacturers of glass products, the construction industry, design and consulting companies and experts, standardisation and certification bodies and academia. Stakeholders expressed their concerns and interest in the development of a standard for the design of glass structures.

Owing to its properties, e.g. high compression strength and modifiable transparency, glass has great potential among building materials. This has made it popular with engineers and architects alike and has contributed to its expanding use for primary and secondary structural elements used in energy-efficient buildings and in applications related to the preservation and enhancement of built cultural heritage. In the absence of common design rules, though, the safety of citizens in the built environment is at risk because of possible sub-standard applications. In addition, the new Eurocode will provide a common understanding between owners (who ask for structural solutions supported by widely-accepted common rules), manufacturers of construction products and kits (who will specify the product properties in compliance with harmonised design procedures) and designers. On one hand this will facilitate the exchange of construction products and services between Member States and on the other will enhance the competitiveness of the European construction industry in the global market, thus will create new jobs.

European (EN), ISO and National standards for glass products exist along with guidelines produced by International Technical and Scientific Organisations, but none covers explicitly the design of glass products for structural applications. The Eurocodes suite does not contain design rules for glass structures, nevertheless the design principles and application rules of EN 1990 "Eurocode: Basis of structural design" may apply to them. It follows that the development of the proposed Eurocode may initiate on the basis of the available state-of-the-art, taking account of the actual size of the market and the current production capacity.

The proposed work programme for the development of the new Eurocode for glass structures foresees the participation of all stakeholders and is tuned with the strategic plans of CEN and EOTA. The initial works will proceed in the framework of the proposed contents of the new Eurocode. The results will be disseminated to all interested parties, hopefully also as training material for practicing and future engineers, and will serve as the basis for a techno-economic analysis to be presented to DG Enterprise.

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1 Rationale and Policy Context

This proposal is motivated by the expanding use of glass products in the construction sector, commonly referred to as architectural glass, as primary and secondary components and the lack of a proper set of European-wide design rules. Within the context of trade in the EU internal market and also the global market, the ever-increasing marketing of said glass products sets the background for the need of a concerted EU effort.

The safe implementation of glass products and the need to increase the competitiveness of this already established industrial sector are the main drivers quoted by representatives from the European construction associations and flat glass[1] producers. No less important, however, is the need for Europe to maintain a high level of technical proficiency, if it is to match the efforts of its potential competitors outside the EU. Based on their experience of using glass products in their own markets, leading EU industries are strengthening the existing and finding new markets outside of Europe. Nevertheless, their potential customers stipulate the need to back up their designs with internationally recognised standards. This cannot be left to market forces alone, but requires a coordinated effort by Industry, Standards Organisations, Certification Bodies and academia under the aegis of a European-wide regulatory authority.

The policy context of this proposal is set within the framework of the Construction Products Directive-89/106/EEC and, more specifically, the Guidance Paper L.

In regard to the Commission Recommendation 2003/887/EC on the implementation and use of Eurocodes for construction works and structural construction products, the current proposal addresses Recommendation No 6 wherein it is stated *"Member States should undertake research to facilitate the integration into Eurocodes of the latest developments in scientific and technological knowledge. Member states should pool the national funding available for such research so that it can be used at Community level to contribute to the existing technical and scientific resources for research within the Commission, in cooperation with the Joint Research Centre, thus ensuring an ongoing increased level of protection of buildings and civil works, specifically as regards the resistance of structures to earthquakes and fire".*

Having regard for said Recommendation, the Joint Research Centre (JRC), in cooperation with representatives from Industry, Standards Organisations, Certification Bodies and Research Centres from EU and EFTA Member States proposes that the Commission or CEN should endeavour to expand the current series of Eurocodes with the addition of a new Eurocode to provide harmonised methods for calculating the mechanical strength of structural elements consisting entirely, or in part, of glass.

[1] Glass manufactured in flat sheets (float, sheet and rolled), which may be further processed. It excludes bottles, containers, fibreglass, rods and tubes.

2 Benefits with Respect to Guidance Paper L

With regard to Guidance Paper L concerning the Construction Products Directive – 89/106/EEC, the new Eurocode should comply with the aims of the Eurocode programme. Thus, it will pursue the benefits listed in Section 1.1.3:

- *Provide common design criteria and methods to fulfil the specified requirements for mechanical resistance, stability and resistance to fire, including aspects of durability and economy*.

  The new Eurocode will address this point explicitly. Currently in Europe there are no common criteria for the design of primary or secondary load-bearing glass elements. The current status in Europe is that structural engineers, architects and consultant engineers depend on manufacturers' specifications and guidelines and some national standards. Furthermore, glass material properties are currently defined in a manner that is not consistent with the Eurocodes family. The new Eurocode will bridge this gap by providing prescriptive design and performance criteria and methods for the definition of key mechanical, fire and environmental-related durability properties of glass products used in construction.

- *Provide a common understanding regarding the design of structures between owners, operators and users, designers, contractors and manufacturers of construction products.*

  It is often the case that the production of glass products is partly based on patented technologies that do not allow flexibility within the open and competitive market of the construction sector. This inhibits the structural design process and is aggravated by the inability to interchange products of different manufacturers. The new Eurocode will provide a common basis for contractors to compare pricing for construction products that conform to a specific structural capacity and function, and thus promote a more competitive market for glass products. As regards structural reliability, it will provide a common approach, similar to that of traditional materials, and will facilitate the selection process for designers when choosing between widely-differing construction materials.

- *Facilitate the exchange of construction services between Members States.*

  Currently although many products conform to ISO, EN and other standards, the glass products industry and supplier community is highly diversified. The use of glass products in the construction sector can be significantly increased because of its high popularity among architects and interior designers. The new Eurocode will facilitate the exchange in construction services by providing a common basis for production and design, specifically geared towards construction products.

- *Facilitate the marketing and use of structural components and kits in Members States.*

  The construction sector is quite often not familiar with the range of available manufacturing methods for structural glass components or kits. A common basis for comparison of glass components and materials is therefore required. The new Eurocode will provide common methods to assess the declared values in CE marking for structural products and kits.

- *Facilitate the marketing and use of materials and constituent products, the properties of which enter into design calculations, in Members States.*

  The new Eurocode will provide a common basis for liaison with CEN Technical Committees and EOTA Working Groups for harmonisation, especially with the ones producing harmonised specifications (hEN and ETA guidelines/ETAs). This will provide designers with guidelines on the use of construction kits and so motivate the marketing of glass products and kits.

- *Be a common basis for research and development, in the construction sector.*

Research and innovation is a major driver of competitiveness in industry, particularly so when it deals with novel and versatile materials, such as glass in structural applications. While research on the use of glass products in construction is currently oriented towards the product range and market interests of each single manufacturer, the development of a new Eurocode will be a common basis for research. The development of harmonised design rules and principles will also facilitate the cross-border scientific and technical cooperation.

- *Allow the preparation of common design aids and software.*

  The subject of common software for glass design is brought to the forefront by the need of civil engineers to be able to design structural solutions using glass, a material for which most practising engineers have yet to develop a feeling for. A number of glass-systems producers have sought to take advantage of this opportunity by providing simplified design software as part of their product package. Such software has not been extensively calibrated and might be biased towards a given company's products and kits. This area is therefore in drastic need of harmonisation and extensive verification by European certification and R&D groups. A new standard would provide the common platform for design aids and software.

- *Increase the competitiveness of the European civil engineering firms, contractors, designers and product manufacturers in their world-wide activities.*

  The European construction sector not only relies on its internal market, but must compete in many prestigious projects in the global market. The application of glass in construction grows in the global market and in particular Europe, USA, China, India and Japan. The growth in glass demand in emerging countries, such as India and China, is twice that in western countries. Europe cannot lag behind in this part of the market. However, even within the internal EU market, the number of applications of glass both in new structures and as refurbishing systems for the envelopes of existing reinforced concrete and steel structures is growing steadily. The European construction industry should not be technically handicapped by the lack of standards when wishing to use this material: non-EU competitors may take its place.

3 Interested Parties

The context of this proposal within the framework of the Commission policy, namely the Construction Products Directive and Guidance Paper L, has been presented above. Here we identify the industrial parties and standardisation organisations involved in the development of the proposed standard.

3.1 Regulatory Organisations

CEN/TC250: The Evolution Group of CEN/TC250 (CEN/TC250 Chairman and other delegates) is aware of the JRC initiative to prepare a document addressing the Purpose and justification for new standards for glass in civil engineering works. In fact, the Evolution Group was briefed on the ad-hoc European group setup by the JRC to prepare the justification document. Furthermore, the Evolution Group has included in its position paper (covering the Maintenance, Promotion, Further Harmonisation and Further Development of the Eurocodes) a part on further development, where glass structures are proposed as a work item.

CEN/TC129: The mechanical strength Working Group of CEN/TC129 is aware of the JRC initiative. During the CEN/TC129 plenary meeting, in May 2006, presentations were made by CEN/TC250 and CEN/TC129 WG8 on the topic of glass strength design. The national delegations supported the joint CEN/TC250 – CEN/TC129 methodology for dealing with this topic. Whilst approximately 95% of the applications for glass in buildings can be designed by reference to simple tables/calculation methods, it was accepted that “true structural” use of glass was growing. CEN/TC129 believes that the work of JRC will enable the designer/engineer to better understand glass and therefore be able to design “true structural” glass applications. Members of CEN/TC129 and representatives of liaison body, European Association of Flat Glass Manufacturers (GEPVP), are actively engaged with the work of JRC.

European Organisation for Technical Approvals (EOTA): The dialogue between the JRC and EOTA, on the works for new standards regarding the use of glass in civil engineering works, was initiated recently. It presupposes that the proposed standards produced by CEN/TC250 for the design of glass products will be developed with reference to existing harmonised ENs for such materials and components and possibly ETAs for new types of glass.

EOTA has shown interest in the subject and is prepared to assist in the following way:

- By cross-checking where demands for ETAs and related ETAGs exist already.
- EOTA will initiate the drafting of ETAs and preferably ETAGs for prefabricated half-finished products if sufficient industrial interest is expressed.

The works on design rules for glass products in civil engineering works will also include work on rules for testing of prefabricated half-finished products that comply with the requirements for design. Such rules for testing will be given to EOTA for further consideration (incorporation in possible ETAGs), and could then result in methods for the calculation of product properties which would fit the design standard.

Moreover, it might even be feasible to use the ETAG as an “experimental” codification basis, as long as the relevant Eurocode part is not yet drafted or finalised. For example, the ETAG which serves as basis for delivering ETAs in the area of metal anchors contains an exemplary design annex, since at the time there was no other European harmonised material standard available.

3.2 Industrial Organisations

The industrial sectors that will most benefit from this proposal are the European construction and glass materials industries. For this purpose, the proposal has been developed in close cooperation with the European Construction Technology Platform (ECTP) and the European Association of Flat Glass

Manufacturers (GEPVP). Both organisations have been formally contacted by the JRC with a view to ensuring that their main concerns and needs are addressed by the proposed standard.

In the first instance it seems apparent that there is a need for the European glass industry to be more aware of the impact that a new Eurocode for the design of structural glass products would have on their core business. The following questions are to be answered: why the new standard is needed, why Eurocodes are important to the construction industry at large and why civil engineers want it. The industry should define in which manner it wishes to be represented in the drafting stages of the proposed standard.

European Construction Technology Platform (ECTP): As regards the ECTP, it is expected that the proposal will receive strong support in view of the fact that one of the Focus Areas directly concerns the implementation of new materials and construction methods. Specifically the Materials Focus Area (FA) foresees that "*construction materials have an important role to play in sustainable development through their energy performance and durability, as this determines the energy demand of buildings through the lifetime*. *By developing the use of materials and their combinations, significant improvements of the environment and quality of life can be achieved. Together with the energy and the raw materials used during their manufacturing it becomes obvious that the production of building materials has a significant environmental impact due to the sheer quantities involved. Finally, these developments are needed to maintain and strengthen the competitiveness of European building materials producers and the entire construction sector*". In this sense, the role of glass in addressing key aspects of durability, as well as its potential to reduce the net weight of structures, cut project development times in urban and transport renewal schemes, and the simplification of the logistics of design-to-site construction, fits well with the aims of the ECTP.

However, there are also several other Focus Areas related to structural glass, e.g. FA Buildings and Cities, FA Quality of Life and FA Cultural Heritage. The glass products offer efficient ways of improving existing and creating new energy-efficient building envelopes and introducing the new technologies for the upgrading of the quality of existing buildings. Introduction of glass products into the existing buildings and their wide use in the new buildings offers the opportunity for the creation of high-quality working areas in office and industrial buildings as well in prestigious residential buildings. But the aspects of safety should be carefully addressed, especially in earthquake-prone areas and in buildings potentially exposed to terrorist threat and/or vandalism.

The new technologies for the protection of cultural sites and heritage buildings rely also on the use of large load-bearing glass panels. Therefore, the world-wide market related to the protection of cultural heritage is becoming very promising for wider use of glass products.

Having in mind the importance of the glass products for the construction sector, ECTP is the professional environment where the glass pre-normative research can be widely supported and generated. The recent discussions within the ECTP Support Group express the importance of the pre-normative research to support the development of best practice guidelines and standards (www.ectp.org).

European Association of Flat Glass Manufacturers (GEPVP): The current members of the European Association of Flat Glass Manufacturers belong to the following four groups: Glaverbel, Guardian, Pilkington and Saint-Gobain Glass. GEPVP was represented in the Structural Glass ad-hoc Working Group and contributed to the preparation of this paper.

The development of a design standard for structural glass is in line with the GEPVP objective to encourage worldwide standardisation. In particular, standardisation is required for product characteristics, measurement methods and minimum required quality levels in order to achieve global quality, better spreading of knowledge and better understanding between manufacturers and users. In this context, GEPVP actively participates in international standardisation efforts with the EU (i.e. CEN), other European associations and on a worldwide level with ISO.

The involvement of GEPVP in the development of the design standard for glass in construction works supports several aspects of the Association's mission which is to: i) represent the EU flat glass

manufacturers as a Trade Association; ii) encourage promotion and use of flat glass in EU countries and worldwide; iii) encourage R&D on flat glass by members, universities and research centres; iv) encourage worldwide standardisation and v) provide information on flat glass characteristics, performances and uses.

4 Timeliness

4.1 Market Situation and Further Trends[2]

The concept of tomorrow's towns and cities will be based on new social, economic and technological ideals focused on improving the quality of life. To attain this objective, architects and engineers of today must improve the quality of buildings and establish new principles of conceptual design of buildings. The quality of interior space and the impact of a building on its surroundings depend strongly on the physical interface that separates the outer environment from the inner building space. The conception and realisation of this interface (the envelope) are therefore of prime importance. New types of glass have improved the possibilities of designing well-functioning buildings with glass envelopes. High-quality glass products also give the opportunity to design load-bearing structural elements or systems constructed primarily of glass. The structural applications of glass in buildings and civil engineering structures are of high importance also because of the safety issues.

Global demand for glass outstrips the economic growth around the world (see section 4.2). Today's architects are using larger glass surfaces in their designs, with increasing added functionality and complexity.

The global market for flat glass in 2004 was approximately 38 million tons (~5 billion m^2)[3]. At current price levels, this represents a value at the level of primary manufacture of around € 15 billion. Over the long term, this market is growing in volume terms at nearly 4% a year. Of this demand, around 23 million tons is high-quality float glass (a process where molten glass is drawn over an enclosed molten tin bath). Around 3 million tons are covered by sheet glass (a process where molten glass is drawn out of the furnace vertically and subjected to an annealing process) and 2 million tons is rolled glass (a process where molten glass is squeezed between rollers to form sheets, usually with a pattern embossed on the surface). The remaining 10 million tons is lower-quality float produced mainly in China. A proportion of the high-quality float glass and rolled glass is further processed by laminating, toughening, coating and silvering, for use typically in insulating glass units or automotive glazing. At this level the market has a value of approximately € 44 billion.

Most of the world's float glass (90%) goes into buildings (Figure 1). Automotive applications account for around 10%. In Building Products, basic glass can undergo two or more stages of secondary processing before being installed as original or replacement windows and glazing systems, or used as a component in furniture or white goods, such as cookers and refrigerators.

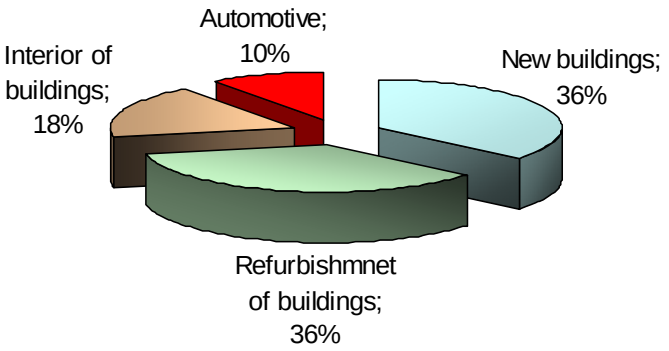


Figure 1: Float-glass consumption for various applications.

[2] The main sources of this chapter are the publications *"Pilkington Operating and Financial Review 2005: Making Glass for World's Buildings and Vehicles"* and *"Pilkington and the flat glass industry 2005"* (www.pilkington.com), GEPVP statistics.
[3] On average 1 ton is approximately 100m^2 of 4mm thick glass.

Within the Automotive sector, glass is used in original equipment for new cars, buses and trucks, for specialised transport applications including trains and ships, and also in the manufacture of replacement parts for the aftermarket. Figure 2 illustrates the main routes to market in the glass industry.

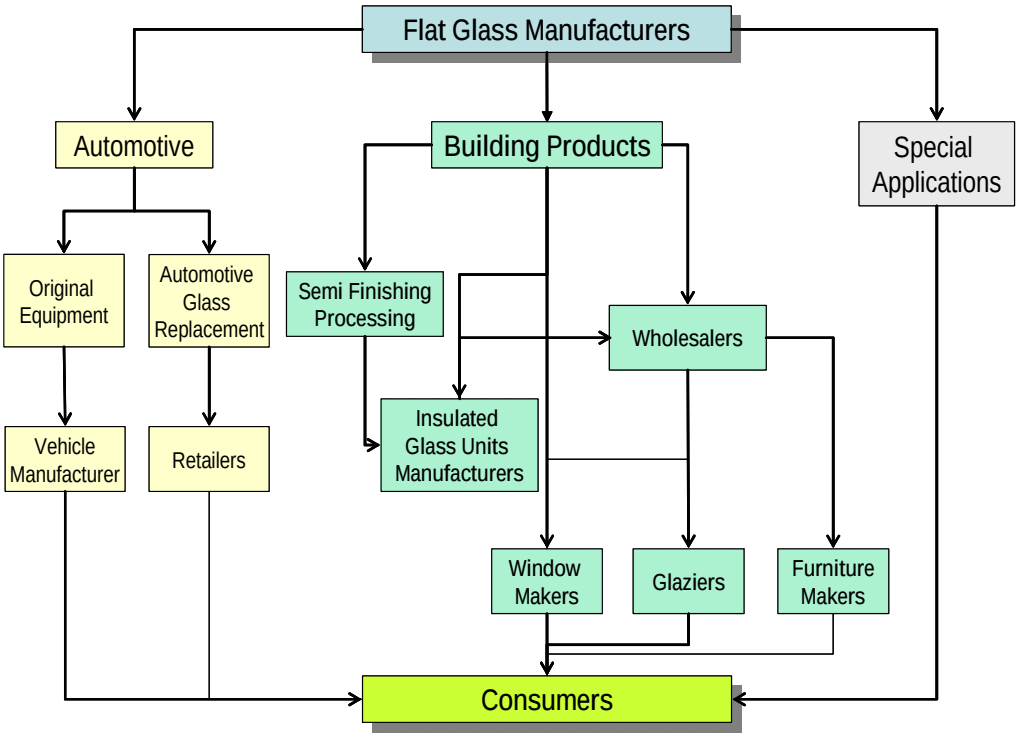


Figure 2: The main routes to market in the glass industry.

Europe, China and North America account for 75% of demand for glass (Figures 3 and 4). The four leading glass companies in the world together produce 62% of the world's high-quality float glass (Figure 5).

U.S. flat glass manufacturers have experienced sluggish growth during this decade due to the decline in the U.S. motor vehicle production and weak commercial construction activity. To offset sluggish growth, manufacturers have introduced new products and new technologies for the growing residential market. In addition, U.S. producers have increased reliance on foreign market sales. Meanwhile, competition from foreign products is increasing.

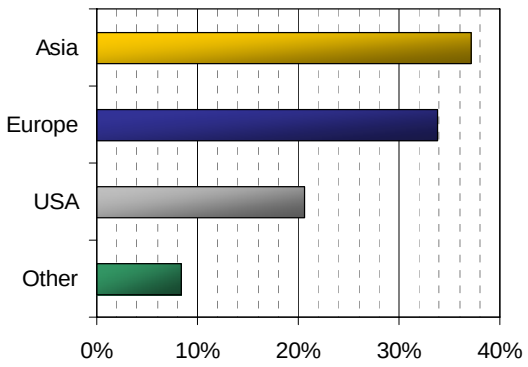


Figure 3: Share of companies in the world high-quality float glass production in 2004.

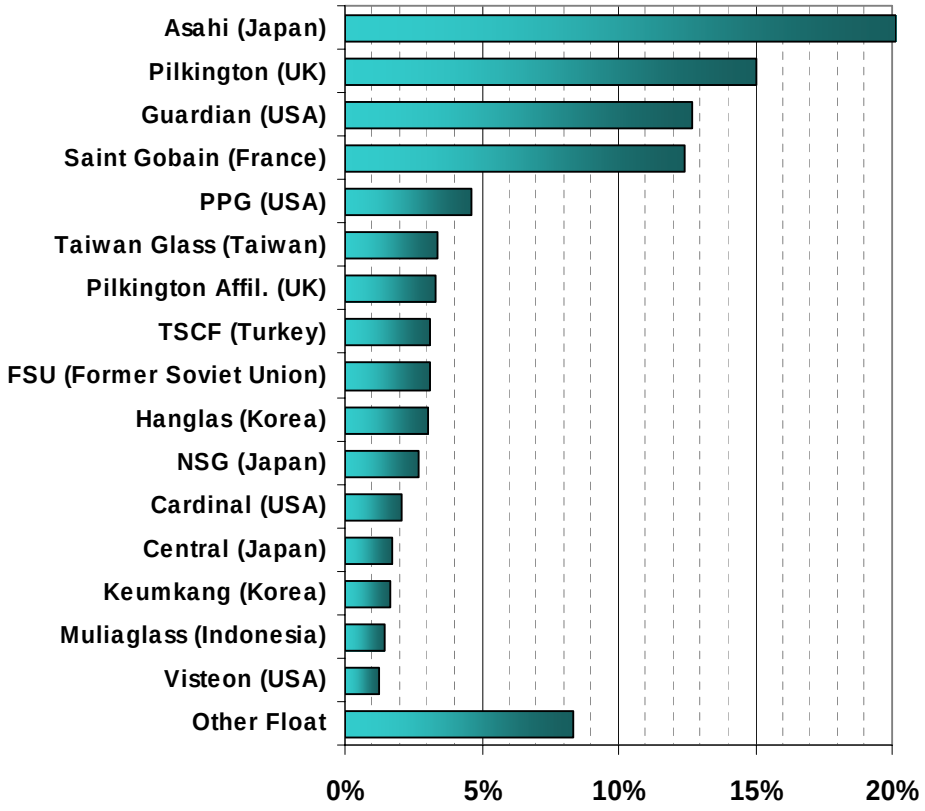


Figure 4: Share of world high-quality float glass production in 2004: major companies.

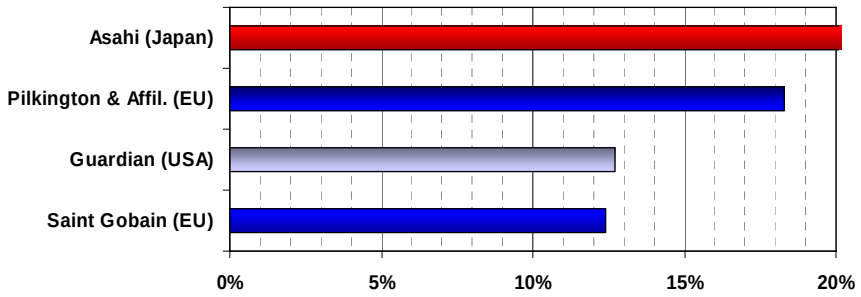


Figure 5: Share of world high-quality float glass production in 2004: top four companies.

4.2 Potential for Future Development

4.2.1 Market issues

Over the past 20 years, glass demand has grown more quickly than Gross Domestic Product (GDP). Over the long-term, glass demand is still growing at around 3.9% per annum (Figure 6). Demand growth for glass is driven not only by economic growth, but also by legislation and regulations concerning safety, noise attenuation and the response to the growing need for energy conservation. However, the lack of design standards for use of glass in civil engineering works can, in the long term, decrease the growth of glass consumption in structural applications. This is an important issue, because in the next decade there is expected to be a quick growth of flat glass consumption in developing markets. Appropriate standards for building practice are more needed in these markets than in developed ones, where the growth will be slower in the future.

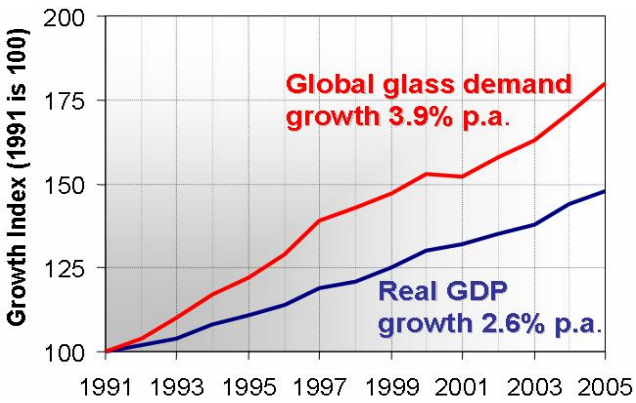


Figure 6: Comparison of the growth indices of glass demand and real GDP.

The main growth drivers that will influence the flat glass consumption in buildings and civil engineering respond to several contemporary demands, as presented in Table 1.

Table 1: Growth drivers for future flat glass consumption.

Demand	**Growth Drivers**
Energy saving (heating)	Energy saving legislation and building regulations, reduction of energy loss from buildings and energy labelling of windows.
Energy saving (cooling)	Energy saving legislation, reduction of air-conditioning load in buildings. Preventing non air-conditioned buildings from overheating.
Safety	Increasing legislative requirement for safety glass.
Security	Requirement for transparency combined with security/safety features.
Fire protection	Compliance with fire regulations combined with requirements for good light transmission.
Acoustic	Increasing noise levels caused by traffic, aircrafts etc progressively covered by legislation.
Self-cleaning	Reduce use of detergents and improve safety of cleaning works on high-rise buildings. Product range now extended to incorporate self-cleaning features.

In general, the wider use of any structural material is governed by the availability and use of relevant standards and technical specifications. However, not only standards but the relevant knowledge of designers is a leading force of progress. Therefore, the development of knowledge and its transfer

from the industrial to the academic environment and vice-versa is one of the bases for future growth of glass products consumption. The other important driver is formal educational processes.

4.2.2 Safety issues

The lack of standardisation leaves opportunities for deficient glass products and services to slip through the usual, prescriptive, quality-assurance processes established in the construction sector. It is possible that an unregulated market, currently characterised by the potential to deliver wide profit margins, could result in the implementation of sub-standard applications that one day may result in failures. Glass structural design standards are essential to limit the number of structural failures that arise from avoidable negligence resulting from bad design or construction practice due to the lack of a harmonised standard. When failures in such structures occur, it is important to distinguish when they result from the acceptable risk associated with any design standard, where safety comes before profit, rather than those resulting from an unregulated market, where profit comes before safety.

4.2.3 Technical issues

The main issues related to the use of glass in load-bearing elements are summarised in Table 2. The upgrade of the current situation, where different standards are in use in different countries, can be achieved by the development of the European standard that would also be a helpful tool for the further penetration of European glass products to developing markets.

Table 2: Main issues related to the further development of standards to help the practical application of the knowledge gained in the application of glass as structural products.

Item / Issue	**Level of solution /perception**
Availability of materials	high
Versatility of products	high
Technology level	high
Cost	moderate
Codes, standards and specifications	good, but still insufficient: lack of harmonised design standards
Supportive data banks	fair
Understanding of behaviour	weak, perceived unreliability
Knowledge of structural mechanics	relatively high
Knowledge of design methodology	insufficient
Knowledge of detailing	poor
Confidence in reliability of structure	low

A more appropriate approach for innovative products which is consistent with the Construction Products Directive is to confirm the technical validity of said products following the ETA route, which is there to allow an innovative product to be assessed by an Approval Body. This would allow for patented technology to be neutrally assessed with the necessary assurances provided by the certification of conformity. Thus a viable mechanism exists but as yet has not been fully exploited due to lack, amongst other factors, of any harmonised design standard. Another possible reason for system manufacturers to ignore the EOTA route is commercial design sensitivity, i.e. some system technologies are covered by patents.

4.3 Current Status of Glass Product Standards

4.3.1 Eurocodes[4]

The globalisation of the construction market comprising construction products, engineering and construction services requires international standards families in order to avoid inconsistencies due to the use of various national standards. So far, there are two sources of international standards families: one in the USA, the other in Europe, each consisting of a set of design standards in connection with product and testing standards (Figure 7).

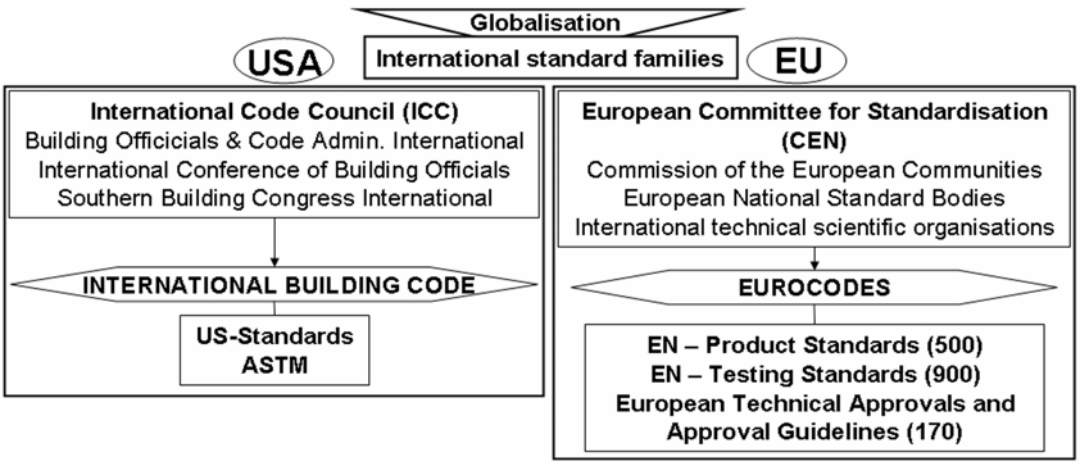


Figure 7: Globalisation – International standards families.

The European standards family is being prepared by CEN and so far includes 10 Eurocodes with 58 Parts with design rules, about 500 EN standards for products and 700 EN standards for testing. It also contains so far around 170 European Technical Approvals and European Technical Approval Guidelines worked out by EOTA.

The Eurocodes consist of the governing EN 1990 – Eurocode: Basis of Structural Design which concretises the “Essential Requirements” by design principles and application rules and of EN 1991 – Eurocode 1: Actions on structures and of EN 1992: Eurocode 2 to EN 1999: Eurocode 9 with design rules for concrete structures, steel structures, composite structures, timber structures, masonry structures, geotechnical design, design in seismic regions and aluminium structures (Figure 8).

[4] The source of this chapter is the paper “Basis of Design and Standard Codes for Glass Structures” written by G. Sedlacek, F. Wellershoff, R. Kasper and M. Pilsl.

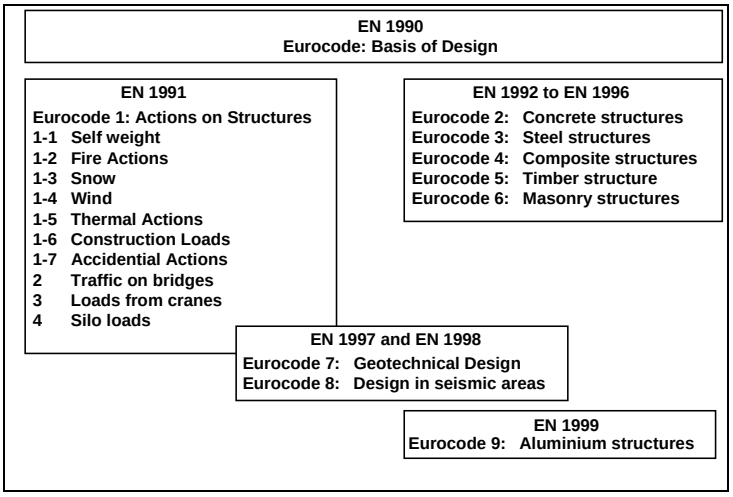


Figure 8: The Eurocodes family.

The Eurocodes give deemed-to-satisfy design rules with two targets (as explained in the Commission Guidance Paper L “Application and use of the Eurocodes”):

1. To determine the “characteristic values” of product properties (e.g. strength or stiffness) as defined in the product standard by calculations instead of determining them by testing. This requires European unified rules. The technical properties are needed as technical information for CE marking.
2. To be used for European tenders for the design of construction works. Then “design values” are needed that consist of characteristic values from the product standards and of partial factors that are “Nationally Determined Parameters” given in “National Annexes” to the Eurocodes.

The possibility to choose between determination of product properties by testing or by calculation creates a “conflict” between using the rules in the Eurocodes and the execution and evaluation of tests. EN 1990 – Eurocode: Basis of structural design gives the relevant test evaluation procedure to determine characteristic values and design values. It is this fact that requires Eurocode design rules to be based on results of tests on large-scale components, so that the user in general has an advantage when using the Eurocode rules instead of particular testing (Figure 9).

Competition between	
Product standard EN 1090	**Eurocode Eurocode 3**
Experimental determination of product properties R_k directly from	Calculative determination of product properties R_k indirectly from
Statistical evaluation of component testing	
Delivery with declared values R_k	Application of R_k for the design of structures $R_d = R_k / \gamma_M$

Figure 9: Relation between Product standards and the Eurocodes.

The Eurocodes are evolving documents. So far, they do not contain design rules for glass structures, though the design principles and application rules in EN 1990 apply to them. A survey on what Eurocodes and product standards are applicable to glass structures is given in Figure 10.

EN 1990 – Eurocode: Basis of structural design			
EN 1991	Actions on structure	EN 13474	Design of glass components
Part 1-1	Self weight and imposed loads on floors and roofs	EN 1993	Design of steel structures
Part 1-2	Fire actions	Part 1-1	Basis and buildings
Part 1-3	Snow	Part 1-4	Stainless steels
Part 1-4	Wind	Part 1-8	Joints and connections
Part 1-5	Thermal actions	Part 1-10	Tension elements
Part 1-6	Construction loads	Part 2 -A	Requirements for bearings
Part 1-7	Accidental actions	EN 1337	Structural bearings

Figure 10: Eurocodes and product standards applicable to glass structures.

EN 1990 specifies the general format of limit state verifications for the ultimate limit state including robustness, serviceability limit state and durability, where for glass structures the damage tolerance in the ultimate limit state is a main concern.

4.3.2 International and National Standards

The number of standards being in force in developed countries worldwide shows that the glass product standardisation is relatively well developed. The European countries are leading both on the level of national and common EU standards (Figure 11). All these standards are related to use of glass in buildings and most of them are related to structural use of glass with a few exceptions that covers energy efficiency issues. Standards are in general covering classifications of different types of flat glass, test methods for determination of mechanical properties of glass sheets (hardness, impact resistance and bending strength), performance and blast resistance (USA), tolerances (Spain), fixings (Spain), conformity evaluation (EN). Several national and international (EN, ISO) standards deal also with sealants and sealing of glass panels. ISO standards cover also issues of durability and appearance of glass panels.

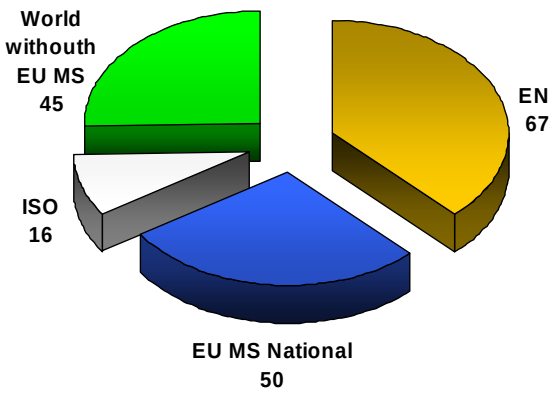
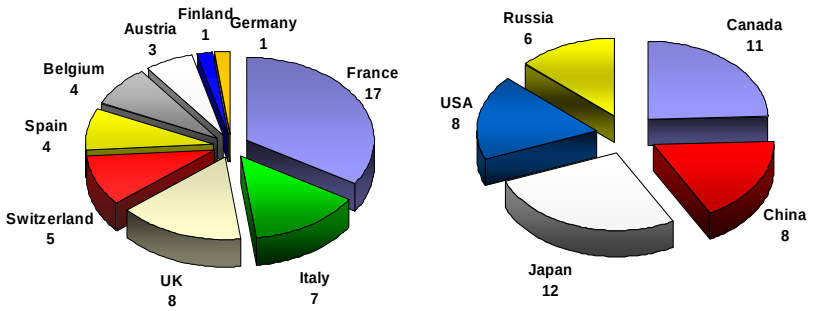


Figure 11: Number of standards related to glass and its products at global level.

Figure 12 shows the number of National standards for glass and glass products in EU Member States and countries outside EU. EN standards adopted in EU Member States are not taken into account in Figure 12. The total number of standards in European Member States is equal to 114 that highly outnumber the standards in the rest of the world (61).



(a) (b)

Figure 12: Number of national standards related to glass and its products in EU Member States (a) and other countries worldwide (b).

A good example among available standards is the codes of practice issued as British Standards that are dealing with design and installation of glass panels. In Germany there are in use two technical regulations related to structural use of flat glass. Special attention deserves being drawn to the working document entitled “Ouvrages particuliers en verre” that is under development by a group of experts led by the Belgian Building Research Institute (CSTC/WTCB).

The brief overview of standards related to use of glass in buildings clearly shows that there are no standards that would in general cover the design of structural elements and structures made of glass products. Therefore, a concerted attempt toward development of such standards is required. The effort made by CSTC/WTCB should be taken as a very positive example.

5 Potential Benefits of Having a Standard and Detriments in its Absence

In the sections above the growth of the glass products application in the construction sector was analysed. The following conclusions might be drawn:

- Potential for continuing growth;
- Lack of preparedness of the European market, and
- The possibility of the USA market to overtake the European industry.

In the absence of European standards in this area, it is possible that USA producers will attempt to use their expertise and presumed consolidated standardisation status to compete in the European market. Just as notable though, is the potential for expansion in the Asian, and, particularly, the Chinese market, which accounts for the single largest growth rate in the world. In this sense the lack of standards could prove to be a stumbling block for the successful bid by a European company in this, currently the largest and fastest-growing, construction market in the world. Clearly the R&D investment devoted to developing a European technology in this area runs the risk of failing in competitive world markets if it is not backed up by standards.

Another threat to EU industry resulting from a lack of standardisation, already referred to in the preceding sections, is the implementation/use of sub-standard products and designs that may put at risk the health and safety of citizens. Furthermore, catastrophic failures in such products could give the EU construction sector, and the glass industry in general, negative publicity which may benefit its immediate non-EU competitors. The only means to reduce this risk is the implementation of harmonised standards explicitly geared to glass products. This is at present underway with the CE marking of 13 glass product families by mid-2007.

The benefits of a standard can be resumed as follows:

- The European producers and industries will be motivated to produce and construct high-quality construction products. These will not only meet the requirements for safety in the Member States, but, by ensuring a high quality, will enable European industry to compete advantageously against imported products within the open, competitive, European market.
- Due to the market stagnation induced by the absence of clear guidelines, there is a tangible possibility of favouring the acquisition of European firms by extra-EU enterprises and multinationals, with subsequent loss of a leading position in the global market.
- Competitiveness of Europe would surely benefit, especially from the construction industry stand point.
- The development of a new standard would give an important thrust to theoretical and experimental research in this field throughout Europe.
- The development of a Eurocode would comply with pressing needs and exigencies of diverse nature, originating from industries, end users and designers.

Other salient points associated with the lack of an EU-wide design standard for structural glass can be resumed as follows:

- Member States have different views of glass as a structural material and specific requirements to have glass products tested to levels over and above those given within the harmonised European Norms.
- Currently, the number of structural glass applications is steadily increasing, so it is expected that the gap between the application and standards is bound to widen.

- Different standards are being developed Europe-wide, so it is expected that in the future there will be difficulties in producing a new standard that harmonises all of them.
- Harmonisation of the various existing approaches for design is strongly needed and elimination of the confusion generated by the documents produced by private firms to promote their products should be sought.
- Unification of testing procedures (for materials, elements, etc.) should be pursued.
- The need for a new unified standard is felt throughout Europe (trans-nationality).
- The European industries have clearly demonstrated a keen interest in supporting the activities related to the development of a new standard, as demonstrated by their involvement and contribution to the present document.
- In the initial stage, the preparation of the standard could benefit from the experience and the work carried out by CSTC/WTCB coordinated group of experts that produced a working document entitled “Ouvrages particuliers en verre”.

6 Strategic Plan (How to Move Forward)

6.1 Work Programme

The proposed work programme will require industrial associations to pool resources from their members, ensuring the participation of those that have most to gain from the new standard. This will consider the individual commercial interests that are inherent in the competitive environment of the construction sector.

The role of National Authorities and National Standards Bodies as overseers of the standard development will ensure that commercial interest is bounded by the broader interest of the public.

Considering the academic and research institutions, the prospect of developing a new standard within the context of appropriately funded programmes will motivate both young and experienced researchers and the return of a sizeable portion of the scientific Diaspora.

The strategic plan will be drafted by the aforementioned stakeholders. The main steps of the plan will be as follows:

1. Define the legal and economic basis that will motivate participation.
2. Define the stake that each of the stakeholders will have in the development of the new standard.
3. Approval by all stakeholders of the strategic plan, responsibility lines and management structure.
4. Definition of scope of standard (structures, materials and processes).
5. Framing the new standard within the strategic plans of CEN and EOTA. Define the setting of the new standard within the context of the current Eurocode set and likewise for ETAGs.
6. Techno-economic analysis (including construction and manufacturing methodologies, economic life-cycle analysis, repair and rehabilitation techniques) to be presented to DG ENTR.
7. Technical Recommendation to be submitted to CEN/TC250 in support of the development of the Eurocode for the design of glass structures.
8. Dissemination of results (including knowledge bases of glass products in building and civil engineering applications) to individual members of professional, commercial and academic organisations.
9. Training issues (specific programmes for practising and future civil engineers).

Activities listed in points 1 to 5 will be managed by DG Enterprise and Industry with support from the stakeholders, where necessary. Upon receipt of a positive answer on the commencement of the technical works, a Core Group (see section 6.2) will deal with the technical issues described in points 6 and 7. Dissemination of results and training (points 8 and 9) will be addressed after completion of the technical tasks and will see the involvement mainly of industrial and university/research partners as well as technical associations.

6.2 Organisation of Works

The works shall be carried out by a Core Group (project group with 5 - 7 persons). The members of the Structural Glass ad-hoc Working Group will propose/nominate a number of experts to participate in the Core Group. They will deal with:

- glass products and production methods;
- half-finished and finished products and their properties;
- design methods for glass structures and composite action with other structures;
- execution quality management;
- drafting of design standards.

The Core Group should be supported by a full assembly of selected experts, including Working Groups for specific fields.

6.3 Scope of Standard

On the basis of a go-ahead for a new standard, the planning and consultation stage will be conducted by the key stakeholders under the auspices of the European Commission, namely DG Enterprise and Industry. As was highlighted in Section 3 (Interested Parties) this will concern on the one hand the key EU-wide organisations representing the industrial parties and on the other, the regulatory authorities from Member States as well as CEN, EOTA and research institutions with a proven record in pre-normative research and standard development.

In the first instance the construction sector organisations will be expected to identify the first wave of construction works for which industry sees the most pressing need and to perform an economic and life-cycle analysis. This will serve to identify the generic structural elements, their potential application rate as a percentile of the whole market and the potential demand of glass as a material. These data will then be transmitted to the glass producers in order to gauge the most appropriate manufacturing methods and to compare the present-day production capacity to the prospective demand. This will set the background for the structures and materials that the producers of standards and guidelines (i.e. CEN and EOTA) and pre-normative researchers (e.g. ECTP, ESTEP) will have to address.

Another important aspect of the consultation stage will be to consider the scope of the proposed standard balanced by the cost of its development. One suggestion received by the JRC is that a compact design standard (i.e. not as extensive as the concrete or steel Eurocodes) could be drafted to accommodate the prerequisites of the Construction Products Directive and be commensurate with the actual size of the glass market. This could then set the framework for a more extensive standard if the market use continues to increase.

6.4 Technical Recommendation

The work plan aims at the preparation of a technical report featuring a “Technical Recommendation” that will be forwarded to CEN/TC250 in support of the development of the new standard. In the process of preparing the technical content of the future glass Eurocode, use will be made of Background Documentation including:

- source of rules – justification by experimental/analytical evidence;
- parametric studies;
- bibliography.

Resulting from the consultation with the Structural Glass ad-hoc Working Group, the following documents should be considered as basis for the Technical Recommendation:

- Guidance Paper L: Use and application of Eurocodes;
- CEN/TC250 Document N 250 G – Policy Guidelines and Procedures for CEN/TC250 Structural Eurocodes;
- EN 1990 – Basis of structural design;

- Works carried out in CEN/TC129;
- Existing national and international standards.

6.5 Tentative List of Contents of the Standard

A tentative list of contents of the design standard, compatible with the Eurocodes suite, is given in the following:

1. General
2. Basis of design
3. Materials and production methods
4. Robustness, durability and maintenance
5. Structural analysis
6. Ultimate Limit States
7. Serviceability Limit States
8. Structural detailing, connections
9. Structural fire behaviour
10. Design assisted by testing
11. Annex 1: Construction and assembly procedures

A particular task will be the development of the chapter “Basis of Design” in consistency with the Eurocode rules.

Because of the brittle behaviour of glass, the accidental situation of cracking of a glass pane has to be considered so that particular robustness criteria apply (see also EN 1991-1-7):

- Glass members should be replaceable.
- The choice of the glass product and of its integration into a structure may depend on failure consequences, e.g. to avoid progressive collapse, or to provide residual resistance for a certain time after failure, or to reduce hazard immediately after cracking.

The safety assessment for the integrity of glass members will follow the general reliability requirements for structural design laid down in EN 1990 taking account of resistance models for certain glass types that include time effects of loading, size effects of members and environmental effects.

7 Conclusion

Glass has one of the greatest potentials of all the building materials used today. It provides high compression strength and perfect transparency – but also the possibility to alter its transparency through the integration of materials which have a switchable light transmissivity. Today's coating technologies, as well as the possibility of reinforcing glass with different stiffening materials, open a nearly endless range of new ways of using glass.

While glass has been used as a building material for centuries, its structural properties only became a matter of serious research at the end of the last century (1980s). Since this time, the load-bearing behaviour of glass, its failure characteristics and the possibilities of influencing its light transmissivity have been widely investigated. Some of the research outcomes led to the creation of standards, but there is still an urgent need for wide pre-normative research oriented to the development of standards for structural design that would enable the wider use of glass in primary and secondary structural elements, with a special targeting to European and non-European developing markets.

There are two main factors that drive the need for a new European standard for the design of glass products. In the first place, as for any structural product, European citizens should expect appropriate levels of safety for glass structures. It is to be expected that these must be ensured within the context of harmonised and respected standards, such as the Eurocodes. Secondly, in view of the world-wide competition in the area of construction products and the constantly increasing use of glass products in civil engineering works, European industry's capacity to compete will be hampered if its products are not backed up by effective construction standards.

Consultation with the major European construction organisations, such as the European Construction Technology Platform (ECTP) and the European Association of Flat Glass Manufacturers (GEPVP), has highlighted the need for a common design standard for glass products. The present lack of such standards at national level motivates the need to implement standards from a common basis. The current climate towards EU-wide harmonisation within the present Eurocode family precludes replication of standard development at single Member States and avoids the associated additional cost.

The analysis described in this paper has shown that it is timely to initiate the development of a European design standard for structural glass. The feasibility of the proposal is evidenced by the available material (product and test standards and results of pre-normative research) that can serve as basis for the development of the glass Eurocode.

Development of new European standards for use of glass products in civil engineering works will increase the number of structural glass applications. It will offer support to designers that will be able to realise attractive architectural ideas. On the other hand, the demand for structural applications will stimulate glass manufacturers to develop innovative high-quality and high-performance, considering aspects of sustainability, glass products to be added to the list of those already produced by the highly-developed European glass industry. Last, but not least, the new standards will influence the development of European construction sector and generate new jobs.

European Commission

EUR 22856 EN – Joint Research Centre

Title: Purpose and justification for new design standards regarding the use of glass products in civil engineering works

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Abstract

This document describes the rationale and justification for a European code for the design of glass structures, its parts or kits for use in civil engineering works, outlining the specific aims and reasons for standardisation in this area, and the main interested parties (industry, consumers, National Authorities, Standards Organisations and distributors) who will benefit from the new standard.

The timeliness of the Eurocode is made evident both by the perceived demand for a design standard pertinent to the use of glass products in construction works and by the available technology.

In view of the importance of the construction industry in the European market, this proposal examines the benefits of the new Eurocode, or conversely, the detriments were it not to be implemented. Moreover, given the number of construction works currently using glass products both as primary and secondary elements in the absence of a European design standard, this proposal considers the urgency with which it is required. The need for the standard is examined also in consideration of the position of European glass producers and construction industry in the global market.

Finally, this document provides a tentative proposal for the consultation and initiation strategies.

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