Safety Science 177 (2024) 106593

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Occupational risk prevention in the European Union construction sector: 30 Years since the publication of the Directive

María D. Martínez-Aires [a,*], Mónica López-Alonso [b], María Luisa de la Hoz-Torres [a], Antonio Aguilar-Aguilera [a], Pedro Arezes [c]

[a] Department Building Construction, University of Granada, E.T.S. de Ingeniería de Edificación, C/ Severo Ochoa s/n, 18171 Granada, Spain
[b] Department of Construction and Engineering Projects, University of Granad, E.T.S. Ingeniería de Caminos, Canales y Puertos s/n, 18071 Granada, Spain
[c] Full Professor on Ergonomics and Human Factors Engineering at the School of Engineering, University of Minho (UMinho), Portugal

ARTICLE INFO

Keywords:
Directive 92/57/EEC
Coordinator for safety and health
Safety and health plan
Prevention through design

ABSTRACT

The construction sector is a key industry in the economy of the European Union (EU), with a significant impact on the Gross Domestic Product and employs approximately 30 % of the industrial workforce. Despite this positive economic impact, the construction sector suffers from high accident rates which result in significant economic costs. In 1992, the EU introduced the Directive 92/57/EEC, which aimed to establish minimum Safety and Health (S&H) requirements for construction sites. The Directive lists a number of premises that justify the need to incorporate risk prevention from the design stage of a project and to strengthen coordination throughout the project's life. For these reasons, the Directive created the role of the Coordinators for S&H matters during the project preparation stage and execution stage, as well as the definition of a S&H Plan. The current paper analyses the state of the accident rate in the construction sector 30 years after publication of the Directive, the changes that have been made to the original text, as well as the identification of the difficulties that have been detected, both in terms of lack of definition and problems in implementation. It is possible to conclude that the management of prevention in the early stages of a project remains a persistent challenge for the industry. Additionally, it is essential to address the sector's adaptation to the new working methods required for its transition to Construction 4.0. This discussion can serve as a valuable tool for future decision-making aimed at improving the regulatory framework.

1. Introduction

A long and healthy life is one of the key human development indicators, both during working years and after retirement. Logically, occupational safety and health (OSH) have a direct impact on the lives of workers, with determining factors being the work sector involved and the tasks performed. According to the most recent data released by Eurostat (European Commission, 2024a), there were 2.88 million non-fatal accidents in 2021 that led to a minimum of four days of absence from work in the EU.

Furthermore, during the same period, 3347 fatal accidents were reported in the EU (European Commission, 2024a). In addition to the impact on quality of life, work-related accidents and illnesses cost the EU economy over 3.3 % of the gross domestic product (GDP) annually (ca. EUR 460 billion in 2019) (European Commission, 2021). The International Labour Organization (ILO) (ILO, 2006) emphasises that enhancing OSH has a dual impact; it diminishes human suffering by preventing workplace injuries and illnesses while also fostering the growth of better and more plentiful job opportunities. Furthermore, the provision of safe and healthy working conditions is not only ethically sound but also a strategic move that leads to more favourable business outcomes, benefiting workers and businesses alike (ILO, 2006).

Abbreviations: EU, European Union; EU-OSHA, European Agency for Safety and Health at Work; ESAW, European Statistics on Accidents at Work; GDP, Gross Domestic Product; GPP, General Principles of Prevention; ILO, International Labour Organization; MiSE, Micro-sized enterprises; NACE, Nomenclature statistique des activités économiques; OSH, Occupational Safety and Health; PtD, Prevention through Design; PPE, Personal Protective Equipment; SME, Small and medium-sized enterprises; S&H, Safety and Health.

* Corresponding author.
E-mail addresses: aires@ugr.es (M.D. Martínez-Aires), mlopeza@ugr.es (M. López-Alonso), mlhoz@ugr.es (M.L. de la Hoz-Torres), antojes@ugr.es (A. Aguilar-Aguilera), parezes@dps.uminho.pt (P. Arezes).

https://doi.org/10.1016/j.ssci.2024.106593
Received 15 October 2023; Received in revised form 31 May 2024; Accepted 14 June 2024
Available online 24 June 2024

One of the strategic sectors in the EU is construction; with a positive impact on industry, gross fixed capital formation, production in construction, and the cost construction index on GDP (Žarković et al., 2022). According to the latest data from the European Construction Industry Federation (FIEC, 2023), 13 million workers belong to the construction sector in EU-27, which means 6.6 % of total employment and 29.8 % of industrial employment. Therefore, construction represents a strategic sector amounting to 47.7 % of total gross fixed capital formation. However, data published by Eurostat (European Commission, 2024a) show that the construction sector has the highest number of non-fatal accidents at work compared with all other productive sectors, as reported by Nomenclature Statistique des Activités Économiques (NACE) (Fig. 1).

Based on the most recent Eurostat report (European Commission, 2024a), the sectors of construction; transportation and storage; manufacturing and agriculture, forestry and fishing collectively comprised approximately 45.7 % of all non-fatal accidents at work in 2021. In the same year, 2 types of injuries were notably prevalent, namely, wounds and superficial injuries, comprising 28.0 % of the total, and dislocations, sprains and strains, accounting for 26.0 % of reported cases.

Related to fatal accidents, construction is in second place, after mining and quarrying (Fig. 2). The same Eurostat report shows that more than one-fifth (22.5 %) of all fatal accidents took place within the construction sector (European Commission, 2024a).

The EU, aware of the high number of workplace accidents in all sectors and the related high economic and human costs, published an important directive in 1998 that establishes the OSH legal framework, Directive 89/391/ECC for the introduction of measures to encourage improvements in the OSH (Council of the European Union, 1989). According to several researchers (Băbut and Moraru, 2009; Morillas et al., 2013; Raynal and Hermanns, 2018), despite several differences, the European Framework Directive on Safety and Health at Work is the basis for common principles and minimum standards across the EU and includes 24 specific directives developed over time according to Article 16 (1) of Directive 89/391/EEC). It proposes several areas where individual directives should be adopted.[1]

In 1992, the European Union (EU) issued the eighth individual Directive, known as Directive 92/57/CEE, with the objective of implementing minimum Safety and Health (S&H) requirements for temporary or mobile construction sites (Council of the European Union, 1992). In its introduction, the different premises that justify the adoption of the Directive are established: the need for coordinators for S&H, the consideration of S&H from the design phase as key tools for prevention, and management for SMEs.

2022 was the 30th anniversary of the publication of the specific directive for the implementation of minimum S&H requirements at temporary or mobile construction sites, found in Directive 92/57/EEC (Council of the European Union, 1992). While some EU member countries simply translated this Directive into their regulations, others developed more comprehensive standards tailored to the specific conditions of the construction sector and the parties involved (Martínez Aires et al., 2010; Martínez-Aires, M. D. et al., 2016). The Directive has yielded positive results in enhancing safety within the construction sector from the date of adoption into national legislation (Martínez Aires et al., 2010; European Commission, 2024a). However, as can be seen in Figs. 1 and 2, the sector continues to be one of those with the highest accident rates. The data are far from the main priorities of the European Commission's Strategic Framework on S&H at Work 2021–2027, that is, improving the prevention of work-related accidents and diseases and striving towards a Vision Zero approach to work-related deaths (European Commission, 2021). The strategic framework indicates that this objective will only be possible by, among other actions, strengthening the implementation of existing standards and guidelines.

In the last 30 years, numerous studies have been published that have identified various inefficiencies in the work of the Coordinators for S&H during the project phase (Lozano-Díez et al., 2019; Oh et al., 2021; Ndekugri et al., 2022, 2023). Additionally, the lack of clarity in the training and requirements for the Coordinators for S&H has been highlighted (Martínez Aires et al., 2010; Rubio-Romero et al., 2014; Lozano-Díez et al., 2019; Ajslev et al., 2022). Problems with S&H plans have also been documented, as mentioned in the study by González García et al. (2021). This reflects the need for a comprehensive analysis of the original text.

The main objective of this research is to examine the evolution of Directive 92/57/EEC over the three decades since its publication. In addition, an examination of the identified limitations in the original text is carried out, focusing on three aspects addressed by the Directive in its premises. This paper shows an analysis of the weaknesses in the tools that were defined in the Directive as a strategy to address the premises that justified its necessity, as well as the problems that have arisen during its implementation. In addition, there is an analysis of various research publications during this period, with corresponding improvement proposals that should be incorporated into the regulatory framework for construction S&H.

This article is structured in 4 sections. Section 1 describes the context of the research, section 2 describes the objective and methodology used in this study, and section 3 shows the obtained results and the discussion of the impact of the directive 92/57/CEE of the construction accident rate in the EU Members, the changes to the directive during the 30 years, the identification of the difficulty in the procedures and the main challenges for the European Union. Finally, section 4 summaries the conclusions drawn from this study. This document is intended to be a useful tool for the various stakeholders involved in the construction process; to have an updated regulatory framework and to help them in future decision making for the improvement of the regulatory framework in the construction sector.

2. Objective and methods

To achieve the indicated main objective, an analysis of the progression of accident rates within the construction sector across EU member countries is carried out. Furthermore, it documents the modifications undergone by the text since its initial publication in 1992. Finally, given the advancements in technology within the construction sector that have led to new construction methods, the imperative need for adapting the Directive becomes evident. Therefore, the main challenges related to the Directive considering the new era of Construction 4.0 are also described, without neglecting the original premises.

To achieve these objectives, five methodological steps have been followed (See Fig. 3):

1st Step – Identification of essential tools associated with the premises under which the European Council promulgates Council Directive 92/57/EEC of 24 June 1992 on the implementation of minimum S&H requirements at temporary or mobile construction sites (eighth individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC).

2nd Step – Analysis of the impact of the Directive 92/57/EEC in accident data in EU country members.

3rd Step – Identification of changes, corrections and amendments, to the Directive since its publication.

4th Step – After that, identification of the me main difficulty in the procedures and tools associated with the Directive's premises. Improvements suggested by various organizations and researchers were explored to effectively address the identified challenges.

5th Step – Description of the main challenges related to the Directive considering the new era of Construction 4.0.

[1] Workplaces, work equipment, personal protective equipment, work with visual display units, the handling of heavy loads involving risk of back injury, temporary or mobile work sites and fisheries and agriculture.

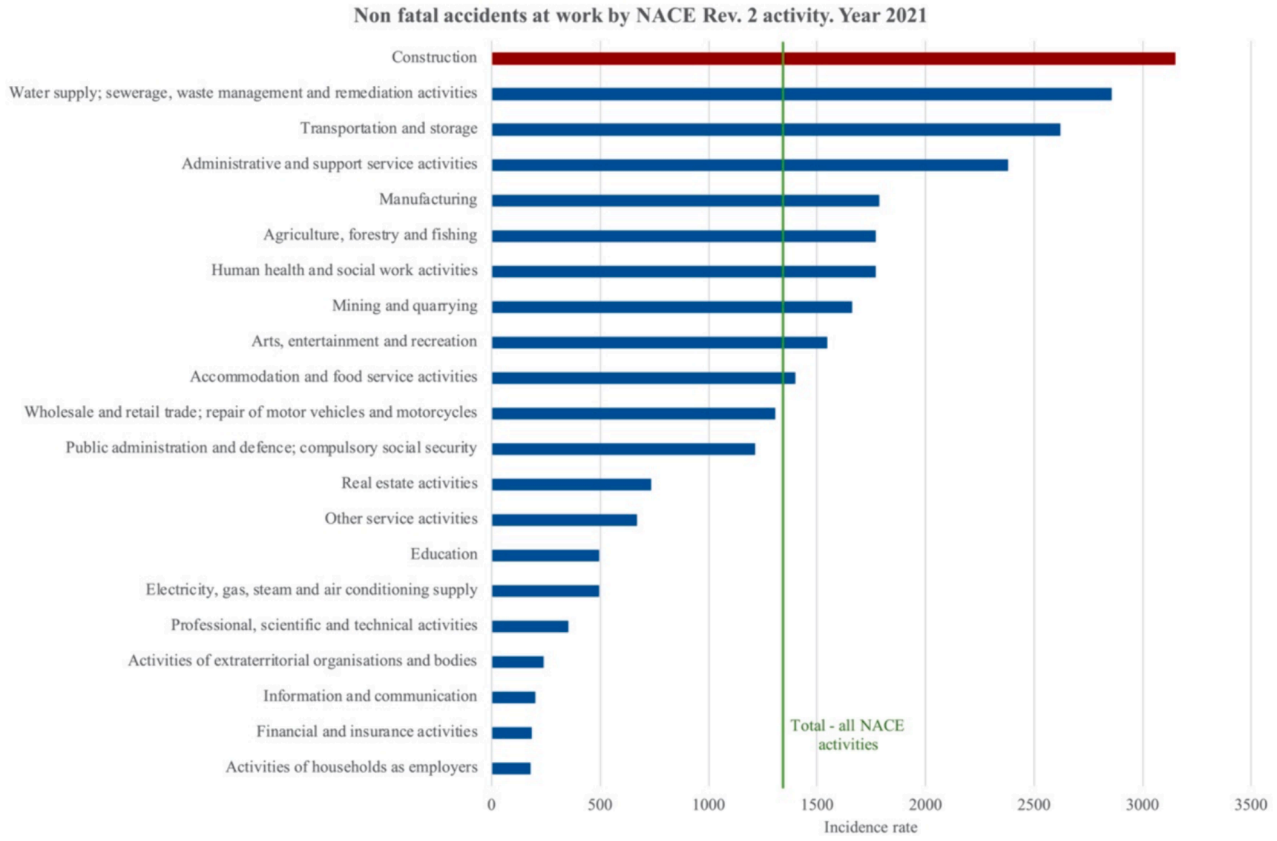

Fig. 1. Non-fatal accidents at work by NACE (comparative by sectors). Source: Own elaboration based on Eurostat data (European Commission, 2024b).

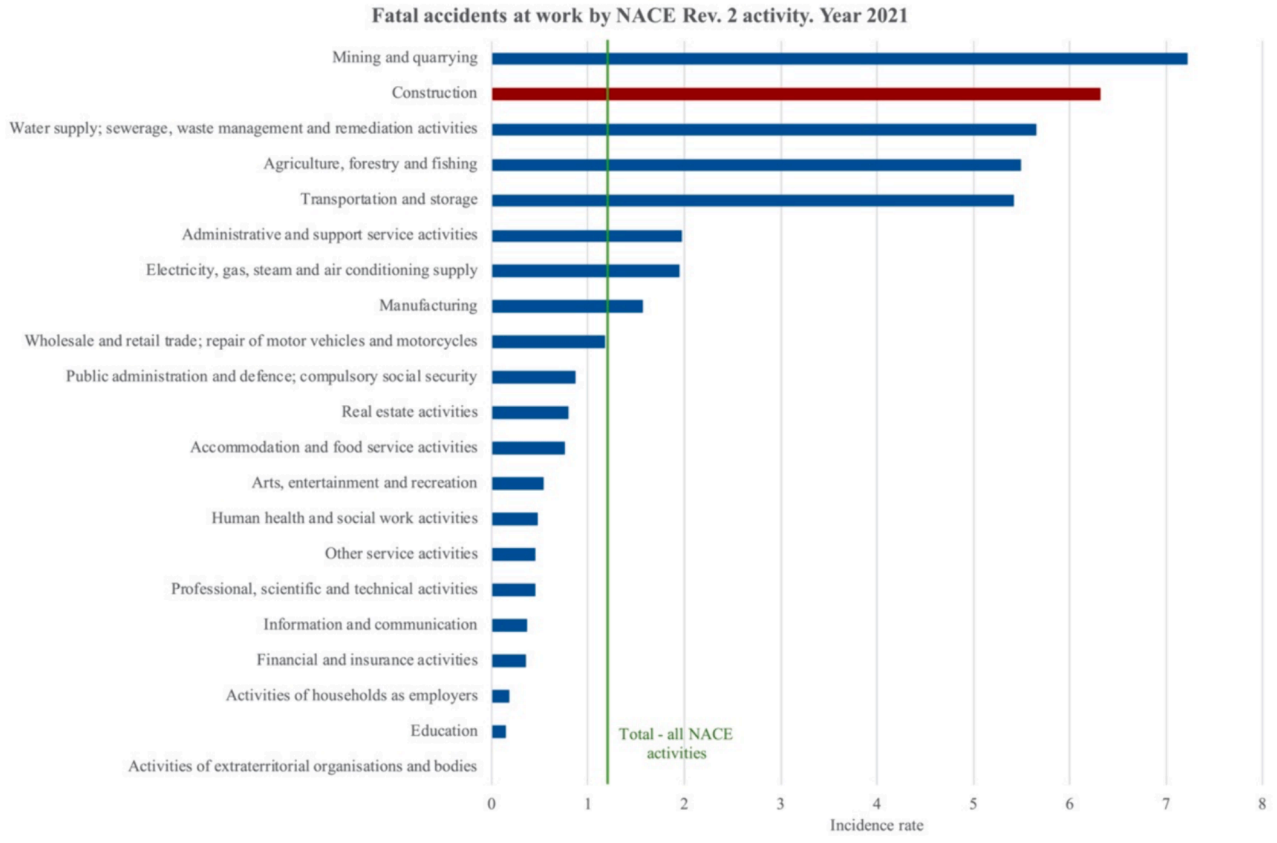

Fig. 2. Fatal accidents at work by NACE (comparative by sectors). Source: Own elaboration based on Eurostat data (European Commission, 2024b).

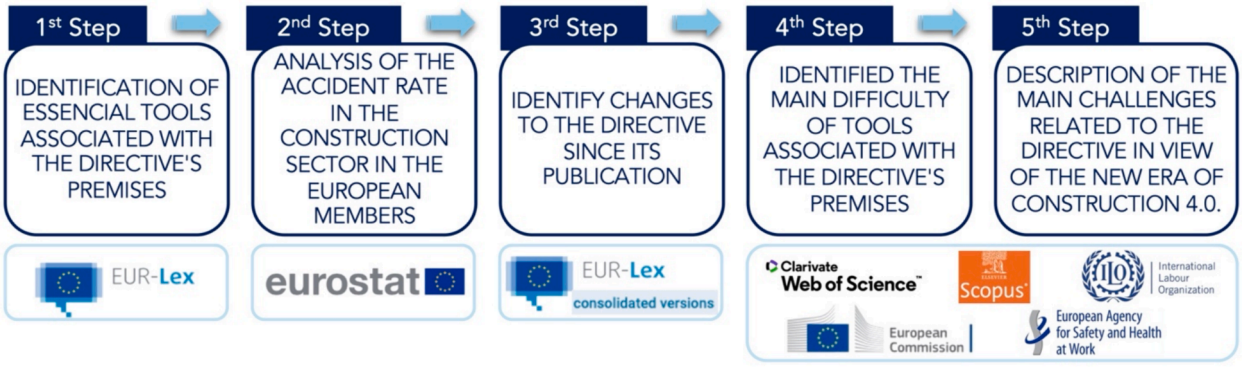

Fig. 3. Flowchart showing the steps taken in the research. Source: Own elaboration

To conduct this research, the methodology followed to achieve these five steps has been as follows:

Initially (1st Step), the Directive 92/57/EEC published in Eur-Lex has been analysed (Council of the European Union, 1992), identifying the premises that justified its necessity. For the analysis of accident rates in the construction sector in EU member countries (2nd Step), Eurostat databases Eurostat (European Commission, 2024b) have been utilized. The trends in accident rates over the past few years in each member country of the European Union have been analysed. Both non-fatal and fatal accident rates between 2011 and 2021, the most recent year for which data is available from Eurostat (European Commission, 2024a), are compared.

Subsequently, for the 3rd Step, the consolidated text of the Directive, along with corrections and modifications from the 1992 publication, has been examined. For this purpose, the information published in Eur-Lex has been analysed, identifying the scope of the amendments made to Directive 92/57/EEC (Council of the European Union, 1992).

Lastly, to address the 4th and 5th steps, the information published by various EU bodies, such as EU-OSHA, the European Commission, or Eurostat, has been analysed for difficulties in implementing the premises identified in the 1st Step. Additionally, information published by other international organizations, such as the ILO (ILO, 2024) and OSHA (OSHA, 2024), was also considered. Furthermore, a bibliographic search of scientific publications was conducted using the WoS by Clarivate 4 and Scopus. Both databases, with WoS holding a monopoly until 2004 when Elsevier introduced Scopus, are comprehensive and reliable sources of bibliographic information, covering a wide range of scientific contributions (Aghaei Chadegani et al., 2013; Zhu and Liu, 2020; Rangasamy and Yang, 2024). Articles written in English were identified using the following search criteria: “Article, title, Abstract or Keywords,” or if “92/57″ and ”Directive“ appeared in the ”References“. After eliminating matches between databases, a total of 46 papers met the specified criteria. The research findings have been analysed, specifically focusing on studies that have identified problems or challenges in implementing the premises outlined in Step 1. Additionally, studies proposing solutions or identifying alternative issues in the Directive’s implementation have also been considered, along with descriptions of the main challenges related to the construction sector in the present era of technological change.

3. Results and discussion

3.1. Impact of the Directive 92/57/EEC of the construction accident rate in the EU members

This Directive was created due to a recognition that temporary or mobile construction sites expose workers to particularly elevated levels of risk. All the EU members carried out the transposal, maintaining the minimum content or implementing improvements (Martínez-Aires, M. D. et al., 2016). Most recently, Eurostat published a report on the development of the EU accident rate (European Commission, 2024a). Nevertheless, as shown in Figs. 1 and 2, the construction sector is far from Vision Zero. Figs. 3 and 4 show the difference in the construction accident rate between 2011[2] and 2021 according to Eurostat (European Commission, 2024b) as well as the average accident rate for EU27. Nonetheless, it has been observed that countries have similar data to those presented below, those being some prominent major risks in the sector such as: falls from height, accidents with machinery or vehicles, slips, trips and falls, ergonomic issues, noise, chemicals, dust and UV exposure (EU-OSHA, 2023). In Fig. 4, the non-fatal accident rate is depicted. Most countries have improved their data over the studied period. Only Czechia, Denmark, Latvia, Lithuania, Portugal and Sweden have poor rates (highlighted in red). Notably, Portugal stands out as the country with the worst data in 2021, along with experiencing the largest increase in the accident rate (+420.09 non-fatal accidents per 100,000 persons employed). In addition, alongside Portugal, only France and Spain have incidence rates above 5000. On a positive note, Malta (highlighted in green) has experienced the most significant decrease in its accident rate (−2487.04 non-fatal accidents per 100,000 persons employed), placing it below the EU27 average.

In the case of fatal accidents (Fig. 5), Austria is the country with the highest increase in fatal accidents (4.0), along with other countries that have not improved their data (Hungary, Croatia, Cyprus, Ireland, Italy and Slovakia). In contrast, Latvia has experienced the most significant decrease (−8.66 fatal accidents per 100,000 persons employed), following a similar trend. However, there are many countries above the EU27 average: Austria, Croatia, Czechia, France, Hungary, Ireland, Italy, Latvia, Lithuania, Portugal, Romania and Spain. There is no available data for Malta.

It is important to emphasise that the criteria for notification and/or registration vary significantly between member states (Jacinto and Aspinwall, 2004; Martínez Aires et al., 2010). For instance, a fatal accident at work is defined as an accident that leads to the death of a victim within one year of the incident. However, the criteria for associating a death with a workplace accident greatly vary; some countries consider it to be when the victim dies on the same day (Netherlands), within 30 days after the accident (Germany) or even 1.5 years after the date of the accident (Spain), among other variations (Martínez Aires et al., 2010; Eurostat, 2013).

However, considering the mentioned limitations and undergoing processes of post-harmonization for data from all productive sectors, it is evident that the construction industry continues to exhibit the worst results in terms of workplace accidents compared to other economic sectors (Figs. 1 and 2). Thus, the implementation of the Directive has led to a consistent reduction in the incidence rates of accidents in

[2] Year since ESAW has been using the Classification system (ISCO-08).

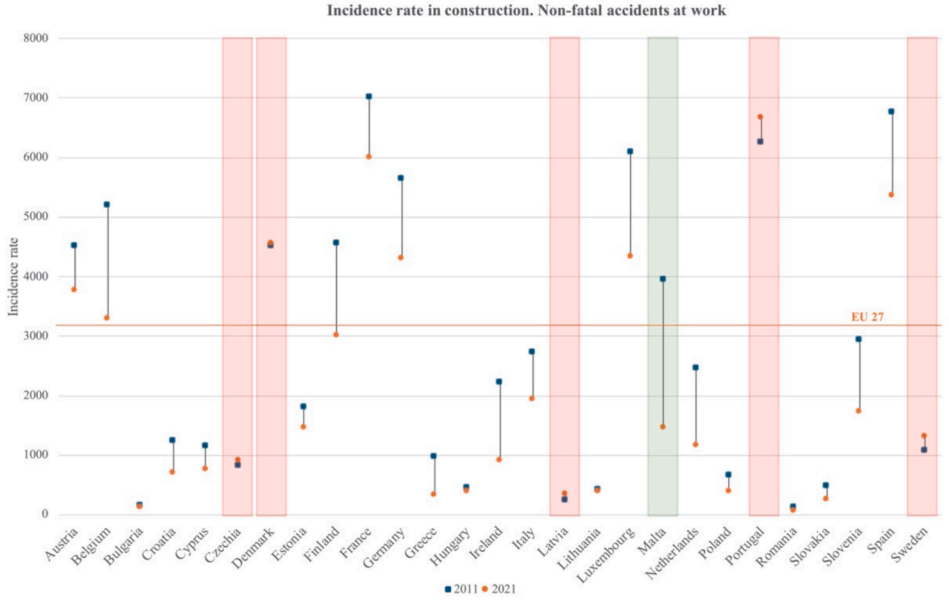

Fig. 4. Incidence rate (number of accidents per 100,000 workers) Non-fatal accidents at work in construction Year 2011 and 2021. Source: Own elaboration based on data from Eurostat (European Commission, 2024b) (last update of data: 05/10/2023).

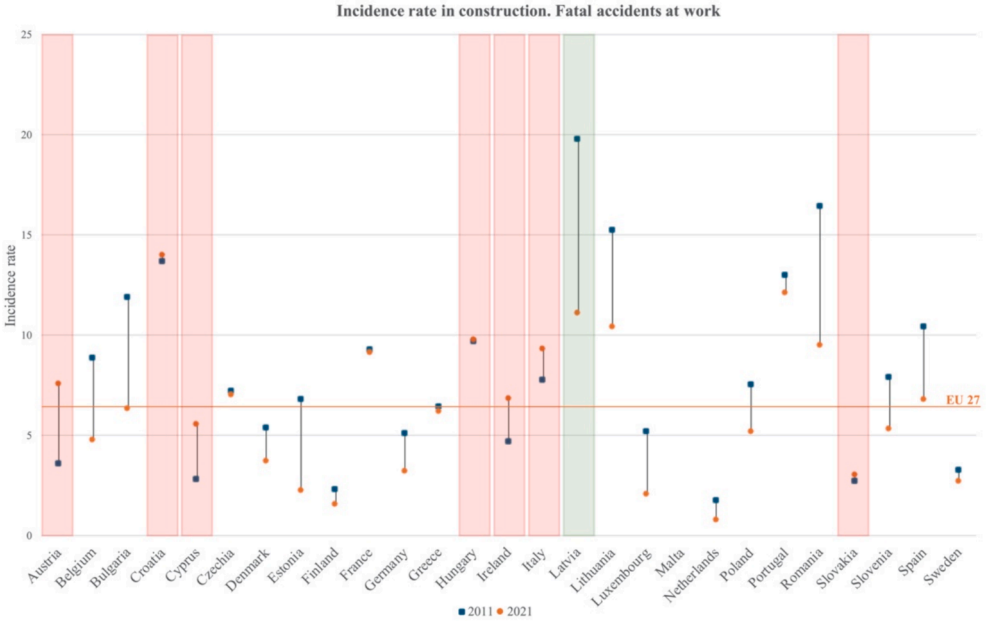

Fig. 5. Fatal Accidents at work in construction. Year 2011 and 2021. Source: Own elaboration based on data from Eurostat (European Commission, 2024b) (last update of data: 05/10/2023).

construction over time, but the decrease is still not as significant as was expected (European Commission, 2008).

3.2. *Changes to the directiva during the 30 years*

In the 30 years, the Directive has undergone some changes: two corrections from the original text and two modifications (see Table 2). Fig. 6 shows when the texts were published by the Council of the EU and when they came into force, highlighting the key years. The original text and its amendments are shown in blue. As can be seen, they were made before the Directive came into force. It also displays the two partial amendments it has undergone in these 30 years, indicating the date they came into force. Directive 2007/30/EC is highlighted in red, and Regulation (EU) 2019/1243 in green.

Before the Directive came into force on 17 July 1992, two initial modifications were implemented: the first correction aimed to rectify those errors found throughout the Directive (Council of the European Union, 1992). Subsequently, the second modification restricted the exceptions concerning the appointment of Coordinator for S&H by the client or project supervisor. Initially, the member states had the authority to grant exceptions; however, this was subject to consultation with both management and the workforce. Moreover, certain types of work involving particular risks, as listed in Annex II (a non-exhaustive list of such risks. e. g. work near high voltage power lines, work exposing workers to the risk of drowning or work on wells, underground earthworks and tunnels), remained excluded from these exceptions. The

Table 2
Corrections and modifications to the Directive 92/57/EEC.

Action		Comment	Subdivision concerned	From
Corrected by	31992L0057R(01)			23/01/1993
Corrected by	31992L0057R(02)		article 3	09/02/1993
Modified by	Directive 2007/30/EC	Repeal	article 14.4	27/06/2007
Modified by	Directive 2007/30/EC	Repeal	article 14.5	27/06/2007
Modified by	Regulation (EU) 2019/1243	Replacement	article 13	26/07/2019
Modified by	Regulation (EU) 2019/1243	Addition	article 13a	26/07/2019
Modified by	Regulation (EU) 2019/1243	Addition	article 13b	26/07/2019

modification limits the exception, indicating that the obligation to appoint coordinators cannot be exempted in cases where prior notice is required (Article 3).

Fig. 7 provides a summary of the conditions for providing documents required for the prevention and appointment of coordinators, adapted from the *Guide to Good Practice for Understanding and Implementing Directive 92/57/EEC* published in 2011 by the Commission, Directorate-General for Employment and Inclusion (Commission and Directorate-General for Employment, 2011) as a reference document.

Directive 2007/30/CE (Council of the European Union, 2007) did not imply changes in the content of the Directive itself. Instead, it simplified the reporting requirements to the European Commission on the implementation of Directive 89/391/EEC and its various individual directives. Now, EU countries must prepare a single report every five years covering the implementation of all these directives, involving modifications to Articles 14.4 and 14.5.

Furthermore, Regulation (EU) 2019/1243 (Council of the European Union, 2019) modified Article 13 and introduced Additions 13a and 13b. This adaptation affected several legal acts that mandated the use of the regulatory procedure with scrutiny of Articles 290 and 291 of the Treaty on the Functioning of the EU. These changes are duly justified in the regulation.

Finally, it should be noted that no new modifications to the Directive are expected. The European Commission in its report on the

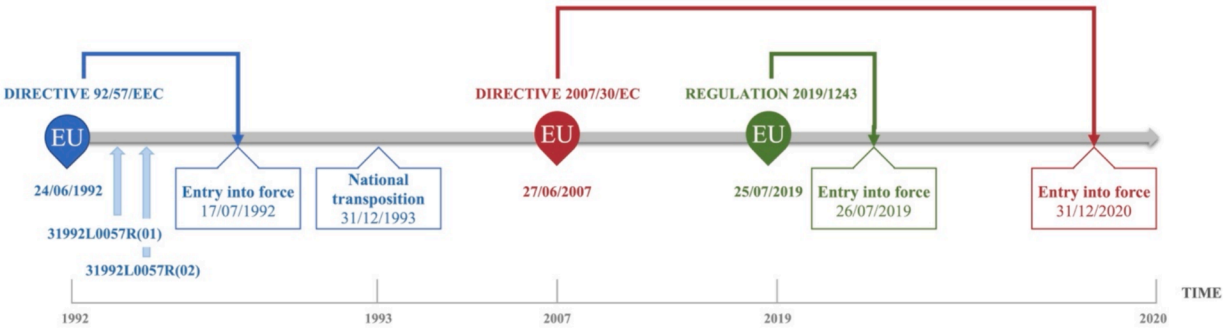

Fig. 6. Timeline of corrections and modifications to the Directive 92/57/EEC.

Number of contractors (including subcontractors)	Prior notice		S&H Plan	S&H File	Appointment of coordinators	
	Less than 31 working days and 21 workers, and less than 501 person days	More than 30 working days and 20 workers, or more than 500 person days				
One contractor			Note that national derogations are permissible if there is no particular risk		Less than 31 working days and 21 workers, and less than 501 person days	More than 30 working days and 20 workers, or more than 500 person days*
More than one contractor (including subcontractors)			Note that national derogations are permissible if there is no particular risk			

There is no need to prepare the document or to appoint coordinators.

There is need to prepare the document or to appoint coordinators.

* Added by Regulation (EU) 2019/1243

Fig. 7. Conditions for the provision of documents required for prevention and appointment of Coordinator for S&H. Source: Adapted from (Commission and Directorate-General for Employment, 2011).

modernization of the EU OSH legislation and policy (European Commission, 2017), identified the scope for removing or updating some outdated provisions (e.g. workplaces (89/654/EEC), Display screen equipment (90/270/EEC) or OSH signs (92/58/EEC)). The Directive 92/57/EEC is not included in that list.

3.3. Identification of the difficulty in the procedures and tools associated with the Directive's premises

The EU enacted the eighth individual Directive, referred to as Directive 92/57/EEC, to set forth minimum Safety and Health (S&H) standards for temporary or mobile construction sites (Council of the European Union, 1992). Its introduction articulates the various premises that justify the need for adopting this Directive.

One of the premises given by the Council of the European Communities for establishing Directive 92/57/EEC concerns the need to incorporate risk prevention from the design stage of a project. The Directive indicates over half of the workplace accidents in construction within the Community are related to decisions made during the creative phase of architectural planning. In other words, it calls for the application of the basic principles of the Prevention through Design (PtD). Therefore, it was necessary to strengthen coordination between the different parties involved in a construction project from the initial phase of project drafting. Recently, several systematic examinations of the development and trends associated with PtD research have been conducted in the discipline. One of these studies is authored by the prominent PtD researcher, Professor Jonh Gambatese (Jin, Z. et al., 2023). Samsudin et al. (2022) have explored the perspectives of the construction industry in developing countries regarding the application of the PtD concept, and recently conducted a thematic review aimed at synthesizing the literature from 2011 to 2022 on the PtD concept from an architectural perspective (Samsudin et al., 2023). Moreover, it is worth noting two systematic reviews on tools and digital information technologies for PtD (Farghaly et al., 2022; Oliveira et al., 2023).

The positive impact of applying PtD in the early stages of a construction project on reducing accidents in the construction sector is well-documented, showing that considering prevention during the initial phases of projects significantly decreases accident rates (Gambatese et al., 1997; Manuele, 2003; Gibb, 2004; Gibb et al., 2004; Weinstein et al., 2005; Behm, 2005; Gibb et al., 2006; Toole, T. Michael and Gambatese, 2008). Outside Europe, several countries have PtD focused regulatory frameworks adapted from the EU, i.e, Australia (Zou et al., 2008), Malaysia (Ministry of human resources Malaysia, 2007; Che Ibrahim et al., 2022a; Che Ibrahim et al., 2022b; Hossain et al., 2023) or Singapore (Ministry of Manpower. Singapore, 2006; Toh et al., 2017). Even studies on the importance of the PtD implementation by designers in Palestine (Abueisheh et al., 2020) or comparative legal analysis of labour protection legislation in construction in Azerbaijan and Ukraine using the example of the EU (Bozhko et al., 2018).

For this purpose, the Directive requires the appointment of the Coordinator for S&H matters during project preparation, as well as the creation of the S&H Plan. This document must be drafted before the commencement of construction activities.

Another premise that the Council of The European Community established as essential is related to the simultaneous participation of the companies involved in the execution phase as well as self-employed workers. It highlights the importance of good coordination between them, in order to reduce the number of accidents. In this sense the Directive mandates the coordinator for execution stages (Council of the European Union, 1992). The complexity of the coordination in this phase is even worse due to the size of the construction companies, where the small and medium companies (SME) represent 90 % of the total (Forteza et al., 2022).

As demonstrated in Section 3.1, the implementation of the Directive has led to a decrease in the incidence rates of construction accidents over time across some EU member countries (see Fig. 4). However, it is crucial to note that the European construction sector is still a considerable distance away from attaining Vision Zero within its territory. (European Commission, 2021).

This section explores the problems linked to the efficient implementation of the tools outlined by the Directive, specifically designed to address the underlying issues contributing to the heightened accident rates in the sector.

3.3.1. Coordinator for S&H

Related to the Coordinator for S&H matters, during the design as well as the execution phase, some problems have been identified. Some of them due to the timing of when the coordinator is designated. If the coordinator is designated late in the process, it can lead to inefficiencies or oversights in both the design and execution phases of S&H protocols. Some others problems are related to a lack of definition or training, as a problem of the definition of this individual person in the Directive.

Inefficiencies of the Coordinator for S&H during the project phase

The Framework Directive defines the General Principles of Prevention (GPP) (Art. 6) as the structural and hierarchical way to achieve an increase in worker safety (Council of the European Union, 1989). The first is avoiding risks, coinciding with the first step of hierarchy of controls of risk (Peterson, 1973). However, the GPP of the Framework Directive goes further than a simple hierarchy; they introduce the concept of risk assessment into European OSH. Therefore, after the principle of elimination, the second is risk evaluation, which cannot be avoided. This involves identifying potential hazards and assessing the associated risks from the design phase.

A study conducted by Aires et al. (Martínez Aires et al., 2010) suggested that although member states adopted Directive 92/57/EEC in different ways, there is a common underlying theme that designs should consider these GPP by identifying and eliminating hazards (Commission and Directorate-General for Employment, 2011). In 2008, the European Commission published the communication COM (2008) on the practical implementation of the Directives 92/57/EEC and 92/58/EEC (safety signs at work) (European Commission, 2008), mainly based on the national reports provided by the member states and an independent expert's report. Concerning Directive 92/57/EEC, the message underscores that while the Directive does not mention architects, engineers or consulting firms specifically, it emphasises the essential role of the designer during the project preparation phase in preventing occupational risks at construction sites. Professionals such as architects and engineers involved in project design have acknowledged familiarity with the requirements but they object to the concept of the client appointing an Coordinator for S&H for the design phase as they perceive this as a potential impediment to their creative freedom. In addition, representatives of the workers emphasised a notable absence of coordination during the design stage.

However, the 'Guide to Good Practices' published by the Commission (Commission and Directorate-General for Employment, 2011) emphasises when a designer is hired by a client to perform design work for a construction project, they must take into account the GPP during the various stages of designing the project. In other words, designers have a responsibility to consider S&H aspects in their designs to prevent occupational risks during the project's development.

In this context, a crucial aspect is the requirement for coordination throughout all stages of a project, which is imperative and yields a favourable influence on occupational safety (Lozano-Díez et al., 2019). This is corroborated by studies, even beyond the European context (Oh et al., 2021). As noted, the Directive 92/57/EEC establishes two specific roles for safety management: the Coordinator for S&H matters during both the project preparation and execution stages. Moreover, an individual or entity can be designated to fulfil both roles. The Directive outlines explicitly that the client or project supervisor must appoint one or more Coordinators for S&H matters when multiple contractors are present on a construction site. In many projects, during the project

development phase, it is often uncertain whether multiple companies will be involved, although this is the usual scenario. Following the Best Practices Guide (Commission and Directorate-General for Employment, 2011), it is necessary when it is foreseeable that more than one contractor will be present or when it is confirmed that multiple contractors will be involved. However, the functions of the Coordinator for S&H during the project phase are defined for cases in which multiple designers are present and where the coordination of the application of GPP becomes necessary.

This lack of definition was noted in the report of 2015 about the evaluation of the practical implementation of OSH directives (COWI, 2015); for example, the case of Estonia relates to the fact that the Coordinator for S&H is appointed only for the project execution stage and not for the project preparation. Another example is Sweden, urged by the European Commission regarding clarification of which roles and responsibilities were to come into force during the planning (Berglund et al., 2022).

Other countries have provided specific criteria for determining when the presence of Coordinator for S&H during the project phase is required. In Spain, during the project planning stage, such a presence becomes essential when multiple planners are engaged. Their responsibility lies in harmonising the implementation of accurate technical choices and arranging the scheduling of various tasks and work phases, whether they occur concurrently or sequentially (Royal Decree, 1997). In the amendments introduced during the transposition procedure of the Construction Design and Management Regulations (CDM) in the 2007 process (CDM, 2007), the UK established the concept of the principal designer. This newly defined role encompasses a range of responsibilities previously held by the coordinator. Specifically, the principal designer is tasked with the planning, management, monitoring and Coordination of S&H activities during the pre-construction phase of a project.

Additionally, the report published by the European Commission evaluating the practical execution of the Directive (European Commission, 2008) indicated that across the construction sector, there was a consensus that the appointment of the Coordinator for S&H occurred extremely late in the process, leading to compromised quality of their work during the implementation phase. The evaluation also indicates that during the project preparation phase, there is an absence of coordination (and oversight); effective coordination only becomes prominent during the execution stage. The Coordinator for S&H in the project phase can be an important link in the chain of prevention, as indicated by the Non-binding Guide to Good Practice (Commission and Directorate-General for Employment, 2011), and helps to realise a risk-based approach to a specific project, which avoids unnecessary bureaucratic burdens, thus reducing workload. A recent study examining fatal accidents on Norwegian construction sites underscores the ongoing importance of identifying and assessing hazards during the design and planning phases (Kjellén, 2023).

However, recent research continues to identify barriers to effective coordination in the project phase. Ndekugri et al. (Ndekugri et al., 2022; Ndekugri et al., 2023) identify the following: *(1) client-related challenges consequent on the statutory compliance behaviour of the CDM client; (2) supply chain fragmentation and insurance challenges to effective cooperation, coordination and communication and (3) shortcomings in how the PtD role is performed on a particular project.*

Undefinition of training and requirements for the Coordinator for S&H

Another barrier is the training and requirements for the Coordinator for S&H, what it entails a lack of definition into the Directive. In the transposition initially carried out by the EU, not all countries have set training requirements to act as Coordinator for S&H (Martínez Aires et al., 2010; Rubio-Romero et al., 2014). Already in 2008, the European Commission itself issued recommendations for member countries (European Commission, 2008), advocating for measures such as the establishment of national competency standards for Coordinators for S&H (European Commission, 2008).

Regarding the initial and specialised training of coordinators, various countries have established their own specifications, resulting in significant variations from one country to another (Bruch, 2019). Countries to formalise the transposition, namely, France, Belgium and the Netherlands, have subsequently developed more recent regulations about the Coordinator for S&H (Lozano-Díez et al., 2019). Similarly, countries such as Croatia and Romania, which took longer to incorporate these regulations, have either included them or have formulated specific competencies. The study in Denmark explores the professional identities of S&H Coordinators. It suggests that these professional identities influence their orientations toward professional practice and may direct attention toward legitimizing and sociable practices rather than focusing on preventing risks (Ajslev et al., 2022).

An examination of various reference standards allows for the verification that, for the professional role of Coordinator for S&H, more than half of the member states (71.43 % to be precise) mandate the possession of at least one qualification, while 57.41 % and 53.57 % require documented professional experience and further technical training, respectively (EU-28 includes the UK).

In 2003, the International S&H Construction Coordinators Organisation (ISHCCO) (ISHCCO, 2019a) was founded. It has been dedicated to crafting a comprehensive set of criteria for the endorsement and adoption of the qualification framework of Coordinators for S&H suggests the need to set up a European certification (ISHCCO, 2019b). However, apart from the necessity to enhance the essential prerequisites required for fulfilling the responsibilities of the S&H Coordinator' role, (Lozano-Díez et al., 2019), Ros et al. (Ros Serrano et al., 2013) outline the following skills as essential for enhancing their role, namely, communication, negotiation and project dedication. This is not forgetting other issues, such as the need to ensure the Coordinators for S&H is equipped with an appropriate system for collecting, recording, and extracting data to improve work efficiency and rigor (Borchiellini et al., 2017), as well as emphasizing their responsibility for the calculation of the coordinator's remuneration in accordance with their responsibilities (Seeling, 2001).

Despite the mentioned issues, there is no doubt about the crucial role of coordination throughout all stages of a project (Bayer et al., 2000; Lozano-Díez et al., 2019). This is further corroborated by the fact that the International Labour Organization (ILO) has recently updated its *Code of Practice of S&H in Construction* (ILO, 2022). Following the same principles as European regulations, it emphasises the importance of establishing coordination mechanisms. Correspondingly, it states that clients are required to either coordinate or appoint a qualified individual to oversee all S&H activities associated with their construction projects.

3.3.2. S&H PLAN

The essential document for all companies, regardless of size, to ensure safety in this sector should be the S&H Plan. In fact, the Directive establishes as a premise the following article 3.2 The client or the project supervisor shall ensure that prior to the setting up of a construction site a S&H Plan is drawn up in accordance with Article 5 (b). draw up, or cause to be draw up, a S&H Plan setting out the rules applicable to the construction site concerned, taking into account where necessary the industrial activities taking place on the site; this plan must also include specific measures concerning work which falls within one or more of the categories of Annex II (Council of the European Union, 1992).

Diverse approaches have been adopted by each member state to ensure the effectiveness of the S&H Plan. Nevertheless, in all countries, this document holds paramount significance, hence being legally mandated for its creation and provision in construction projects (González García et al., 2021). However, present-day documents often suffer from unnecessary details, thereby lacking essential information that is challenging to locate (Martínez-Rojas et al., 2020). It is concerning to realise that these documents gain approval without proper scrutiny of their adequacy and are distributed to construction sites with

the assumption that their mere presence suffices (Romero et al., 2019). Analysing 3600 S&H plans, González et al. projects (González García et al., 2021) found that only 13.81 % of the plans included specific risk assessments for on-site construction activities.

In several instances, the S&H Plan is drafted after the project design phase is completed; thus, ISHCCO suggests that it is drawn up during the project preparation stage and has to be included in the tender documents (Bruch, 2019). Furthermore, it should be an effective preventive tool and not just a document drafted as a legal requirement to avoid potential penalties (González García et al., 2021).

In the absence of a definition in the original text of the Directive, in 2011, the European Commission itself determined the content that a S&H Plan should contain (Commission and Directorate-General for Employment, 2011) (see Table 3). It aligns with the general information presented in Part 1 of Table 3, while also emphasising the necessity of setting up an organization chart outlining functions and responsibilities. Regarding specific risks, it goes beyond identification (Part 2) and definition of provisions (Part 3). It highlights the need to establish specific work procedures to be endorsed by contractors and subcontractors and defines monitoring and control measures.

In a more recent work, the necessary points are summarised to ensure that the S&H Plan becomes the foundation of the preventive activities of a project (González García et al., 2021): 1.- Identification of all the agents involved in the project, definition of an organisational chart detailing the roles and responsibilities in safety matters during the execution phase. 2.- Identification of the specific risks associated with the work activities, establishing adapted work procedures in collaboration with contractors and subcontractors. 3.- Definition of the exhaustive planning of preventive measures, their identification and specific monitoring and control procedures.

Finally, the client will receive the S&H file, defined in the Directive, as a tool to ensure that maintenance and repair work is carried out with complete safety (the content of which is broadly defined in Part 4 of Table 3). The Directive does not include the content that should be included in the S&H file. Berger has recently described in detail the content that the document should contain, which is set out in Table 4.

However, over the three decades since Directive 92/57/EEC was introduced, various gaps have emerged and each country has addressed them without having overarching guidelines. One notable gap relates to the management of private projects that do not fall under planning permission regulations, including exceptions from the obligation to appoint a Coordinator for S&H during project preparation or execution. According to Italy's transposition, the designation of coordinators and the establishment of S&H Plans were not mandated for private projects exempt from building permits. In 2010, the Court of Justice of the EU provided clarification through a preliminary ruling from the Tribunale di Bolzano (Italy) on the interpretation of Article 3 of Council Directive 92/57/EEC (Official Journal of the European Union, 2010).

The ruling stipulates that during the project preparation phase or, in any case, before the commencement of work, a Coordinator for S&H must be designated for any construction project involving multiple companies, irrespective of whether the work requires a building permit or involves specific risks. Concerning the S&H Plan, the Directive permits member states to establish exceptions to the obligation of preparing it, except in cases involving specific risks (Annex II) or for works that require prior notification.

Different countries have made adaptations in their regulations or issued specific documents for the implementation of the Directive in jobs not subject to planning permission. For instance, in Spain, as indicated by the ruling, projects without formal plans will require a coordinator if more than one company is involved. The S&H Plan is replaced by a document referred to as the 'Preventive Works Management Document' (INSST, 2014). The Directive has not been modified in this regard. The primary issues reported by the member states stem from the requirement to develop a S&H Plan and designate a Coordinator for S&H as early as the project preparation phase. Some countries have requested that the Commission include coordination during the preparation phase as non-binding instruments. Others wish for their national legislation to clarify the interaction between the Coordinator for S&H, designers and property owners, as well as between the project coordinator, site managers, self-employed workers and property owners (European Commission, 2008). This topic has also not been addressed.

3.3.3. *SMEs and subcontracting*

One of the characteristics of the construction sector in Europe (European Commission, 2020; Bellocchi and Travaglini, 2023) is its

Table 3
Suggested contents of S&H Plan (Commission and Directorate-General for Employment, 2011).

Part 1. General information about the project	• Description of the project • Names of the stakeholders • Client expectations on how the project will be carried out and the S&H success criteria that will be applied
Part 2. Project-specific information and information sources	• Identifying project hazards • Identifying off-site hazards that will need to be taken into account • Identifying risks from the design that are not likely to be obvious to others (including the unusual) • Identifying work involving particular risks according to Annex II (see Square 4) • Identifying other sources of information relevant to S&H
Part 3. Information on how the project should be managed	• Management arrangements • Arrangements for welfare • Site rules (taking account as necessary of other industrial activities at the site) • Arrangements made to deal with common issues • Arrangements made to deal with project risks that are not likely to be obvious to others (including the unusual) • Arrangements made to take account of work involving particular risks • Arrangements made to take account of other activities at the site including industrial ones • Arrangements for safety and health during any joint occupation with the client and eventual handover to them • Arrangements in the event of injuries and emergencies
Part 4. Arrangements for contributing information to the S&H File	Include information on: • how and when project stakeholders are expected to contribute to the S&H • how the coordinators for the project preparation stage and the project execution stage will cooperate in preparing the SH& File

Table 4
Historic site data of S&H file. Source: (Berger, 2020).

- *Site survey information;*
- *Site investigation reports and records;*
- *Photographic record of essential site elements;*
- *Statement of design philosophy, calculations and applicable design standards;*
- *Drawings and plans used throughout the construction process, including drawings prepared for tender purposes;*
- *Record drawings and plans of the completed structure;*
- *Maintenance instructions;*
- *Instructions on the handling and/or operation of equipment together with the relevant maintenance manuals;*
- *Results of proofing or load tests;*
- *Commissioning test results;*
- *Materials used in the structure identifying, in particular, hazardous materials including data sheets prepared and supplied by suppliers;*
- *Identification and specification of in-built safety features, for example, emergency and firefighting systems and fail safe devices; and*
- *Method statements produced by the principal contractor and/or contractors.*

business structure; the small and medium-sized enterprises (SMEs) represent 90 % of all firms in the sector (Forteza et al., 2022). Furthermore, the high level of subcontracting in the sector results in a significant number of micro-sized enterprises (MiSEs) with fewer than 10 employees. Both SMEs and MiSEs are often poorly managed (Anyfantis et al., 2021); moreover, they do not view risk assessment as a useful tool. One of the main criticisms directed at Directive 92/57/EEC is the increase in administrative burden and disproportionate costs it imposes on companies, especially SMEs (European Commission, 2008). The evaluation of the European strategy on S&H at work 2007–2012 (COWI, 2013) suggested that employers had difficulties in understanding the Directive and recommended the creation of non-binding guidance at the EU level to help all players understand their obligations and rights (Commission and Directorate-General for Employment, 2011). In 2015, a new report stressed the advice to put more emphasis on the S&H within SMEs and MiSEs in a future revised Construction Directive (COWI, 2015).

Lately, the report on the ex-post evaluation of the EU occupational S&H directives (European Commission, 2017a) examined the connection between the comprehensive Framework Directive. One of the top three OSH actions defined was assisting enterprises, especially micro-companies and SMEs, in adhering to occupational S&H regulations. In a recent study, Forteza et al. (Forteza et al., 2022) concluded that 'Site structure complexity', encompassing aspects such as structure, organization and the safety resources accessible on-site, along with resource factors contingent on companies, exert the most significant influence on risks. Consequently, implementing the necessary risk control measures poses a formidable challenge for SMEs. Other research highlights that managing multiple service providers working on sites continues to be a challenge (Jounila et al., 2020). The management of interferences certainly requires a specific analysis (Labagnara et al., 2016). It should be highlighted that numerous studies aim to develop tools for proper OSH management in these types of companies; however, gaps still exist (Fan et al., 2020). Some were identified by Cagno et al. (Cagno et al., 2011) who highlighted the problem that decisions are based on the 'limited' experience and instinct of entrepreneurs and/or managers.

Additionally, occupational disease trends thus become important to study as well, including their relation to changes to management structures and processes, imposed through supranational directives, i.e., how these have been perceived and adopted in practice with specific health issues in mind. In these cases, a focus on smaller companies may be especially important, given the need to improve the health and safety-related preventive measures that smaller companies undertake in general (Berglund et al., 2022).

Therefore, it is evident that S&H management remains a challenge for SMEs; that is to say, it continues to be a premise to consider for the definition of new strategies focused on SMEs. This provides an opportunity to analyze and discuss nation-specific structural changes related to arguably the most significant shift in S&H policy in the European construction industry, particularly for SMEs and MiSEs. However, in its report regarding the modernization of EU legislation and policy on OSH, the European Commission (2017) recognized the potential for eliminating or revising certain obsolete provisions; notably, Directive 92/57/EEC was not considered for removal or updating in this context.

3.4. Main challenges for the EU

In this section, an approach to new situations in the construction sector, that are not included in the Directive, is explored. As has been mentioned, the construction sector has a positive effect on industry, gross fixed capital formation, production in construction and cost construction index on GDP (Žarković et al., 2022). Studies on accident rates in various EU countries demonstrate the positive impact of OSH regulatory frameworks, including within the construction sector (Farina et al., 2013). Berger suggests that this improvement will continue in the upcoming years, with estimates indicating that accidents on smaller construction sites will be reduced by about 33.3 % and on larger construction sites by 20 % (Berger, 2020).

Limited knowledge in S&H

As noted, Directive 92/57/EEC placed the focus on integrating prevention into the early phases of a project. However, even 30 years later, it remains challenging to effectively implement this approach. Various studies underscore the significant challenges posed by designers' limited safety knowledge (Toole, T. M., 2005; Rubio-Romero et al., 2014; Tymvios and Gambatese, 2016). A recent study categorised identified interventions into four main groups, namely, (a) enhancing competency/knowledge; (b) leveraging technological tools; (c) implementing checks/audits; and (d) granting recognitions/certification (Asmone et al., 2022). Furthermore, a lack of familiarity with methods for integrating S&H into the design process is often cited as a common reason for non-compliance with this obligation. Notably, designers emphasise that any modifications should avoid severe disruptions to the design process and not encroach upon their creative liberty (Frijters and Swuste, 2008). The primary objective remains to be the development of designs that prioritise the safe execution of construction activities throughout the 'whole life' of the project (Commission and Directorate-General for Employment, 2011).

New technologies

Toole and Gambatese identified three strategies to facilitate the improvement and evolution of PtD in the construction sector (Toole, T. Michael and Gambatese, 2008).

- Increased prefabrication
- Enhanced use of safer materials and systems
- Greater reliance on construction engineering

Recent research suggests that a continued exploration of the effects of PtD within the context of prefabrication/modularization and sustainability is essential (Jin, Z. et al., 2023). Moreover, it is argued that the most effective means of enhancing PtD awareness involves fostering seamless communication and collaboration among academia, industry and regulatory bodies. This emphasis on sustainability is echoed by Che (Che Ibrahim et al., 2022b), who also underscores the requirement for

studies to bridge the gap in the educational landscape of PtD, an idea previously tackled in the work of López- Arquillos et al. (López-Arquillos et al., 2015). This training involves learning to recognise hazards during the design phase using available documentation and technological platforms (Hardison and Hallowell, 2019). As an example, immersive technologies could have a crucial impact on tasks such as hazard recognition and visualization, safety training, safety-oriented design, risk assessment and risk perception across diverse construction activities (Babalola et al., 2023).

Over the past 30 years, the construction sector has undergone significant changes and the integration of new work methodologies (Mihić et al., 2019; Rebelo et al., 2019; Patrucco et al., 2021; Oliveira et al., 2023). Furthermore, the use of Building Information Modelling (BIM) in conjunction with other technologies such as Virtual Reality (VR) and Geographic Information Systems (GIS) can integrate prevention measures during the design phase to target the higher levels of the hierarchy of controls (Jin, Z. et al., 2023). Even the use of social networks is being employed by researchers, for instance, Weibo for addressing construction hazards (Zeng and Li, 2022); Twitter as a tool for emergency management (Martínez-Rojas et al., 2018), or to analyze the social structure of "occupational safety" (Song et al., 2022).

Nevertheless, the BIM methodology represents a great opportunity to enhance safety management throughout the project's lifecycle (Martínez-Aires, María D. et al., 2018; Collinge et al., 2022). Several studies have proposed innovative methods of quantitative construction safety risk assessment for building projects at the design stage using the BIM methodology (Lu et al., 2021). Furthermore, the possibility of creating digital twins within the BIM framework opens up as a tool for decision-making in safety management in the building construction industry (Torrecilla-García et al., 2021). However, the process of training and education in BIM also presents a barrier, alongside other influencing factors, such as the absence of standardization and resistance to change (Taat et al., 2022).

Industrialization and prefabrication

On the other hand, as indicated by Toole and Gambatase (Toole, T. Michael and Gambatese, 2008), the industrialization of construction processes and the integration of emerging technologies constitute the strengths of the so-called Construction 4.0. Consequently, this exposes the construction industry to novel challenges in OSH, although Industry 4.0 technologies hold the potential to address these challenges (Smallwood and Allen, 2023). For instance, prefabricated construction, due to its advantages over traditional methods, has been shown to eliminate or reduce industry-related stressors effectively, thereby promoting better mental health (Fagbenro et al., 2023). Nevertheless, the construction sector's shift towards industrialised processes necessitates an adoption of management systems employed in other industrial domains for decades. A pertinent example is the application of LEAN philosophy within the construction sector (Howell and Koskela, 2000), which has demonstrated significant positive impacts on productivity and OSH (Abu Aisheh et al., 2022).

Emerging work procedures require organizations to exhibit resilience in the face of swift technological changes, necessitating the integration of novel risk assessment systems that are more dynamic (EU-OSHA, 2021). To achieve this, organizations will require support from institutions. Nevertheless, the trajectory is undeniably shifting towards heightened consciousness and encompassing a more extensive range of risks. The endorsement of preventive actions not only stems from legal provisions but also benefits from diverse forms of stakeholder backing (among them, the owner's engagement in construction safety plays a vital role (Liu et al., 2017; Kjellén, 2023). This support takes the form of interactive tools, traditional guidance resources, robust management systems and European product standards. Each of these components contributes to improving the management of intricate risk scenarios and identifying suitable preventive strategies (EU-OSHA, 2023).

Cultural aspect

To conclude, it must be emphasized that it is also necessary to address cultural aspects in safety management in construction (Kjellén, 2023) to achieve high safety performance in construction projects. Organizational culture, acceptance of safety practices, and effective management of specific factors are crucial aspects to ensure a safe working environment in the construction industry (Winge et al., 2019). Nevertheless, it cannot be overlooked that the culture of the nation in which it operates has a significant impact on the safety culture, as it is strongly influenced by the national culture (Thirugnana Sambandan et al., 2021) Bayramova et al. (Bayramova et al., 2023) claim the primary source of influence and commonly employed control mechanism in the industry relies on regulations and the adoption of technology. However, the effectiveness of adopting new technology or implementing new rules and regulations depends on the acceptance of these deployments by individuals.

4. Conclusion

After analysing the evolution of Directive 92/57/EEC over the last three decades since its publication, it can be inferred that the 27 EU countries have regulated the entities and documents as defined within it. However, when comparing the construction sector to other sectors, labour accident statistics reveal that the incidence rates, both for non-fatal and fatal accidents, remain high in the former, entailing corresponding human and social costs. Thus, it is imperative to identify opportunities and challenges for informed decision-making when reviewing and updating the regulatory framework concerning S&H in a strategic EU sector such as construction.

Directive 92/57/EEC identifies that PtD of a construction project is crucial for preventing occupational risks. Thus, it defines the role of the Coordinator for S&H in the design phase, whose role is crucial in ensuring the application of the GPP during the project ideation process. However, this phase continues to have gaps due to delays in coordinator appointment and a lack of training and expertise among designers, which hinder the application of PtD without interfering with the creative process. Furthermore, a weak point of the Directive is the lack of standardized training requirements for Coordinators for S&H across the EU.

Considering that the construction sector is characterized by a large number of SMEs and MiSEs, effective OSH management requires agile management tools. This is due to the complexity of complying with regulatory requirements imposed by the Directive, which entails a complex and challenging bureaucratic burden. Furthermore, these types of companies undertake numerous projects where an execution plan is not necessary-an aspect not covered by the Directive, leading to the non-application of GPP in the early stages of such activities.

Moreover, the S&H Plan is defined as the essential tool to ensure safety in any enterprise within the construction sector. However, it is still far from achieving this goal due to the need for improved procedures and responsibility definitions.

When combined with the growing industrialization of the construction sector, the need to adopt innovative work approaches arises, along with adapting an industry that historically maintained a certain distance from more industrialized sectors. This entails the urgent need to establish increasingly flexible and dynamic regulations and develop guidelines and tools that facilitate the management of new production procedures and their inherent risks.

CRediT authorship contribution statement

María D. Martínez-Aires: Conceptualization, Formal analysis, Funding acquisition, Investigation, Supervision, Writing – original draft, Writing – review & editing. **Mónica López-Alonso:** Conceptualization,

Formal analysis, Writing – original draft, Writing – review & editing. **María Luisa de la Hoz-Torres:** Investigation, Writing – review & editing. **Antonio Aguilar-Aguilera:** Investigation, Writing – review & editing. **Pedro Arezes:** Formal analysis, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors acknowledge financial support from the Ministerio de Universidades, grant Salvador Madariaga PRX22_00228. Funding for open access charge: Universidad de Granada / CBUA.

References

Abu Aisheh, Y.I., Tayeh, B.A., Alaloul, W.S., Almalki, A., 2022. Health and safety improvement in construction projects: A lean construction approach. Int. J. Occup. Saf. Ergon. 28 (4), 1981–1993. https://doi.org/10.1080/10803548.2021.1942648.

Abueisheh, Q., Manu, P., Mahamadu, A., Cheung, C., 2020. Design for safety implementation among design professionals in construction: The context of Palestine. Saf. Sci. 128, 104742 https://doi.org/10.1016/j.ssci.2020.104742.

Aghaei Chadegani, A., Salehi, H., Md Yunus, M.M., Farhadi, H., Fooladi, M., Farhadi, M., Ale Ebrahim, N., 2013. A comparison between two main academic literature collections: Web of science and Scopus databases. Asian Soc. Sci. 9 (5), 18–26. https://doi.org/10.5539/ass.v9n5p18.

Ajslev, J.Z.N., Møller, J.L., Andersen, M.F., Pirzadeh, P., Lingard, H., 2022. The hierarchy of controls as an approach to visualize the impact of occupational safety and health coordination. Int. J. Environ. Res. Public Health 19 (5). https://doi.org/10.3390/ijerph19052731.

Anyfantis, I.D., Leka, S., Reniers, G., Boustras, G., 2021. Employers' perceived importance and the use (or non-use) of workplace risk assessment in micro-sized and small enterprises in Europe with focus on Cyprus. Saf. Sci. 139, 105256 https://doi.org/10.1016/j.ssci.2021.105256.

Asmone, A.S., Goh, Y.M., Lim, M.S.H., 2022. Prioritization of industry level interventions to improve implementation of design for safety regulations. J. Saf. Res. 82, 352–366. https://doi.org/10.1016/j.jsr.2022.06.011.

Babalola, A., Manu, P., Cheung, C., Yunusa-Kaltungo, A., Bartolo, P., 2023. A systematic review of the application of immersive technologies for safety and health management in the construction sector. J. Saf. Res. 85, 66–85. https://doi.org/10.1016/j.jsr.2023.01.007.

Băbut, G., Moraru, R., 2009. Critical analysis concerning the transposition into national and European Union State members legislations of the obligations regarding the risk assessment issued from 89/391/EEC Directive (II). Quality - Access to Success 10 (9), 43–53.

Bayer, H., Gsell, A., Hammer, H., Sauermoser, S., Scheiber, M., 2000. Planning of mitigation measures regarding the aggravated risk imposed by rockfall. Felsbau 18 (1), 30–35.

Bayramova, A., Edwards, D.J., Roberts, C., Rillie, I., 2023. Enhanced safety in complex socio-technical systems via safety-in-cohesion. Saf. Sci. 164, 106176 https://doi.org/10.1016/j.ssci.2023.106176.

Behm, M., 2005. Linking construction fatalities to the design for construction safety concept. Saf. Sci. 43 (8), 589–611. https://doi.org/10.1016/j.ssci.2005.04.002.

Bellocchi, A., Travaglini, G., 2023. A quantitative analysis of the European construction sector: Productivity, investment, and competitiveness. In: Rugiero, S., Di Nunzio, D. (Eds.), Digital Transitions and Innovation in Construction Value Chains. Edward Elgar Publishing, pp. 18–48.

Berger, J., 2020. The health and safety protection plan and the file containing features of the byrilding according to EEC directive 92/57. In Doble, R.j., Haupt, T.C., Hinze, J. (Ed.), *The management of construction safety and health* (pp. 39-45). Rotterdam, Netherlands: CRC Press.

Berglund, L., Johansson, J., Johansson, M., Nygren, M., Samuelson, B., Stenberg, M., 2022. A post-analysis of the introduction of the EU directive 92/57/EEC in the Swedish construction industry. Buildings 12 (10). https://doi.org/10.3390/buildings12101765.

Borchiellini, R., Cirio, C., De Cillis, E., Fargione, P., Maida, L., Patrucco, M., 2017. Criticalities on highway maintenance yards: Some suggestions to improve the effectiveness of OS&H supervision/inspection activities. Chem. Eng. Trans. 57, 397–402. https://doi.org/10.3303/CET1757067.

Bozhko, V., Kulchii, I., Szydło, J., 2018. Comparative legal analysis of the legislation of labor protection in construction using the example of the EU, Azerbaijan and Ukraine. Int. J. Eng. Technol. (UAE) 7, 54–58. https://doi.org/10.14419/ijet.v7i3.2.14375.

Bruch, E. (2019). *Evaluation of the EU occupational safety and health directives construction sites – 92/57/EEC* (2019th ed.). Luxembourg: International Safety and Health Construction Coordinators Organization (ISHCCO Asbl). Retrieved from https://www.ishcco.org/wp-content/uploads/2019/09/Evaluation-of-the-EU-Occupational-Safety-and-Health-Directives_June-2016.pdf. Assessed May 2024.

Cagno, E., Micheli, G.J.L., Perotti, S., 2011. Identification of OHS-related factors and interactions among those and OHS performance in SMEs. Saf. Sci. 49 (2), 216–225. https://doi.org/10.1016/j.ssci.2010.08.002.

CDM, 2007. In Health and Safety Executive (Ed.), *The construction (design and management) regulations 2007* (No. 320 ed.). UK: Retrieved from https://www.legislation.gov.uk/uksi/2007/320/contents/made. Assessed March 2023.

Che Ibrahim, C.K.I., Belayutham, S., Awuzie, B.O., Oke, A.E., 2022a. Analysis of designers' prevention through design (PtD) competence in the construction industry: A study of Malaysia, Nigeria, and south Africa. Saf. Sci. 150 https://doi.org/10.1016/j.ssci.2022.105710.

Che Ibrahim, C.K.I., Manu, P., Belayutham, S., Mahamadu, A., Antwi-Afari, M., 2022b. Design for safety (DfS) practice in construction engineering and management research: A review of current trends and future directions. J. Build. Eng. 52 https://doi.org/10.1016/j.jobe.2022.104352.

Collinge, W.H., Farghaly, K., Mosleh, M.H., Manu, P., Cheung, C.M., Osorio-Sandoval, C. A., 2022. BIM-based construction safety risk library. Autom. Constr. 141, 104391 https://doi.org/10.1016/j.autcon.2022.104391.

Commission, E., & Directorate-General for Employment, S. A. and Inclusion., 2011. Non-binding guide to good practice for understanding and implementing directive 92/57/EEC on the implementation of minimum safety and health requirements at temporary or mobile construction sites Publications Office. https://doi.org/10.2767/31797.

Council of the European Union, 1989. Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work. Official Journal of the European Communities. Retrieved from https://eur-lex.europa.eu/. Assessed March 2023.

Council of the European Union, 1992. Directive 92/57/EEC of 24 June 1992 on the implementation of minimum safety and health requirements at temporary or mobile construction sites (eighth individual directive within the meaning of article 16 (1) of directive 89/391/EEC), Retrieved from https://eur-lex.europa.eu/. Assessed March 2023.

Council of the European Union, 2007. Directive 2007/30/EC of the European Parliament and of the Council of 20 June 2007 amending Council Directive 89/391/EEC, its individual directives and Council Directives 83/477/EEC, 91/383/EEC, 92/29/EEC and 94/33/EC with a view to simplifying and rationalising the reports on practical implementation (text with EEA relevance). Retrieved from https://eur-lex.europa.eu/. Assessed March 2023.

Council of the European Union, 2019. Regulation (EU) 2019/1243 of the European Parliament and of the Council of 20 June 2019 adapting a number of legal acts providing for the use of the regulatory procedure with scrutiny to articles 290 and 291 of the treaty on the functioning of the European Union (text with EEA relevance). Retrieved from https://eur-lex.europa.eu/. Assessed March 2023.

COWI, 2013. Evaluation of the European strategy on safety and health at work 2007-2012. DG Employment, Social Affairs and Inclusion. Final Report. Available at. https://ec.europa.eu/social/BlobServlet?docId=10965&langId=en. Assessed May 2024.

COWI, 2015. *Evaluation of the practical implementation of the EU occupational safety and health (OSH) directives in EU MSs*. Denmark. Available at. https://ec.europa.eu/social/BlobServlet?docId=16897&langId=en. Assessed March 2023.

EU-OSHA, 2021. The development of dynamic risk assessment and its implications for occupational safety and health. Available at. https://osha.europa.eu/en/publications/development-dynamic-risk-assessment-and-its-implications-occupational-safety-and-health. Assessed April 2023.

EU-OSHA, 2023. Occupational safety and health in Europe: State and trends 2023. Available at. https://osha.europa.eu/en/publications/occupational-safety-and-health-europe-state-and-trends-2023. Assessed March 2023.

European Commission, 2008. *COM/2008/0698. communication from the commission to the Council, the European parliament, the European economic and social committee and the committee of the regions on the practical implementation of health and safety at work directives 92/57/EEC (temporary and mobile sites) and 92/58/EEC (safety signs at work)* Retrieved from https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A31989L0391. Assessed May 2023.

European Commission, 2017. *Safer and healthier work for all - modernisation of the EU occupational safety and health legislation and policy. Communication from the commission to the European Parliament, the council, the European economic and social committee and the committee of the regions*. Available at. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017DC0012. Assessed March 2023.

European Commission, 2020. The European construction sector. A global partner. Available at. https://ec.europa.eu/docsroom/documents/4721/attachments/1/translations/en/renditions/native. Assessed March 2023.

European Commission, 2021. *EU strategic framework on health and safety at work 2021-2027* (COM(2021) 323 final ed. Brussels: Retrieved from https://osha.europa.eu/en/safety-and-health-legislation/eu-strategic-framework-health-and-safety-work-2021-2027. Assessed March 2023.

European Commission, 2024a. Eurostat. accidents at work statistics report. Available at. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Accidents_at_work_statistics. Accessed May 2024. Assessed April 2024.

European Commission, 2024b. DataBase Eurostat. Available at. https://ec.europa.eu/eurostat/web/main/data/database. Accessed May 2024.

Eurostat. 2013. European statistics on accidents at work (ESAW) - methodology. (No. 2002497109). Luxembourg: Office for Official Publications of the European Communities. Available at. https://ec.europa.eu/eurostat/documents/3859598/5926181/KS-RA-12-102-EN.PDF. Accessed March 2023.

Fagbenro, R.K., Sunindijo, R.Y., Illankoon, C., Frimpong, S., 2023. Influence of prefabricated construction on the mental health of workers: Systematic review. Eur. J. Invest. Health, Psychology and Education 13 (2), 345–363. https://doi.org/10.3390/ejihpe13020026.

Fan, D., Zhu, C.J., Timming, A.R., Su, Y., Huang, X., Lu, Y., 2020. Using the past to map out the future of occupational health and safety research: Where do we go from here? Int. J. Hum. Resour. Manag. 31 (1), 90–127. https://doi.org/10.1080/09585192.2019.1657167.

Farghaly, K., Collinge, W., Mosleh, M.H., Manu, P., Cheung, C.M., 2022. Digital information technologies for prevention through design (PtD): A literature review and directions for future research. Constr. Innov. 22 (4), 1036–1058. https://doi.org/10.1108/CI-02-2021-0027.

Farina, E., Bena, A., Pasqualini, O., Costa, G., 2013. Are regulations effective in reducing construction injuries? an analysis of the Italian context. Occup. Environ. Med. 70 (9), 611–616. https://doi.org/10.1136/oemed-2012-101087.

FIEC, 2023. Construction in Europe: Key figures 2023. Available at. https://fiec-statistical-report.eu. Accessed March 2023.

Forteza, F.J., Carretero-Gómez, J.M., Sesé, A., 2022. Organizational factors and specific risks on construction sites. J. Saf. Res. 81, 270–282. https://doi.org/10.1016/j.jsr.2022.03.004.

Frijters, A.C.P., Swuste, P.H.J.J., 2008. Safety assessment in design and preparation phase. Saf. Sci. 46 (2), 272–281. https://doi.org/10.1016/j.ssci.2007.06.032.

Gambatese, J.A., Hinze, J.W., Haas, C.T., 1997. Tool to design for construction worker safety. J. Archit. Eng. 3 (1), 32–41.

Gibb, A. Designing for safety and health in construction-a European/UK. *Designing for Safety and Health in Construction: Proceedings from a Research,* Portland, OR, USA. 44-57.

Gibb, A., Haslam, R., Hise, S., Gyi, D., 2004. The role of design in accident causality. *Designing for safety and health in construction* (Hecker, S.; Gambatese, J.; Weinstein, M. ed., pp. 11-21). Eugene. Oregon: University of Oregon Press.

Gibb, A., Haslam, R., Gyi, D., Hide, S., Duff, R., 2006. What causes accidents? Proc.- Inst. Civil Eng. Civil Eng. 159 (2), 46–50.

González García, M.N., Segarra Cañamares, M., Villena Escribano, B.M., Romero Barriuso, A., 2021. Constructioń s health and safety plan: The leading role of the main preventive management document on construction sites. Saf. Sci. 143, 105437 https://doi.org/10.1016/j.ssci.2021.105437.

Hossain, M.A., Hafizh, M.R., Nadeem, A., 2023. Investigating prevention through design (PtD) concept for safety in Malaysian construction industry. AIP Conf. Proc. 2643 (1), 030024 https://doi.org/10.1063/5.0112687.

Howell, G. A., Koskela, L., 2000. Reforming project management: The role of Lean Construction. Available at. http://eprints.hud.ac.uk/id/eprint/26025/. Assessed March 2023.

ILO, 2006. Occupational safety and health: Synergies between security and productivity. Retrieved from https://www.ilo.org/wcmsp5/groups/public/—ed_protect/—protrav/—safework/documents/meetingdocument/wcms_110380.pdf. Accessed January 2024.

ILO, 2022. Safety and health in construction. Geneva: International Labour Office.978-92-2-036885-5.

ILO, 2024. International Labour Organization. Retrieved from https://www.ilo.org/. Accessed January 2024.

INSST, 2014. Directrices básicas para la integración de la prevención de los riesgos laborales en las obras de construcción. Available at. https://www.insst.es/documentacion/catalogo-de-publicaciones/directrices-basicas-para-la-integracion-de-la-prevencion-de-los-riesgos-laborales-en-las-obras-de-construccion. Accessed March 2023.

ISHCCO, 2019a. European construction industry safety and health coordination. A paper by the international safety and health construction coordinators organisation. Available at. https://www.ishcco.org/wp-content/uploads/2019/11/Description-of-co-ordinator-rev-191027.pdf. Accessed March 2023.

ISHCCO, 2019b. Qualification framework of safety and health construction coordinators. Available at. https://www.ishcco.org/ishcco-qualification-framework/. Accessed March 2023.

Jacinto, C., Aspinwall, E., 2004. A Survey on Occupational Accidents' Reporting and Registration Systems in the European Union. Saf. Sci. 42, 933–960. https://doi.org/10.1016/j.ssci.2004.07.002.

Jin, Z., Gambatese, J., Karakhan, A., Nnaji, C., 2023. Analysis of prevention through design studies in construction: A subject review. J. Saf. Res. 84, 138–154. https://doi.org/10.1016/j.jsr.2022.10.015.

Jounila, H., Reiman, A., Laine, J., Kauppila, O., 2020. HSEQ at shared industrial workplaces: Experiences from collaboration on supplier audits. Int. J. Quality Res. 14 (1), 65–78. https://doi.org/10.24874/IJQR14.01-05.

Kjellén, U., 2023. Preventing fatal accidents in construction through the management of barriers. Heliyon 9 (11). https://doi.org/10.1016/j.heliyon.2023.e21715.

Labagnara, D., Maida, L., Patrucco, M., Sorlini, A., 2016. Analysis and management of spatial interferences: A valuable tool for operations efficiency and safety. Geoingegneria Ambientale e Mineraria 149 (3), 35–44.

Liu, H., Jazayeri, E., Dadi, G.B., 2017. Establishing the influence of owner practices on construction safety in an operational excellence model. J. Constr. Eng. Manag. 143 (6) https://doi.org/10.1061/(ASCE)CO.1943-7862.0001292.

López-Arquillos, A., Rubio-Romero, J., Martinez-Aires, M., 2015. Prevention through design (PtD). the importance of the concept in engineering and architecture university courses. Saf. Sci. 73, 8–14. https://doi.org/10.1016/j.ssci.2014.11.006.

Lozano-Díez, R.V., López-Zaldívar, O., Herrero del Cura, S., Verdú-Vázquez, A., 2019. Analysis of the impact of health and safety coordinator on construction site accidents: The case of Spain. J. Saf. Res. 68, 149–156. https://doi.org/10.1016/j.jsr.2018.12.012.

Lu, Y., Gong, P., Tang, Y., Sun, S., Li, Q., 2021. BIM-integrated construction safety risk assessment at the design stage of building projects. Autom. Constr. 124 https://doi.org/10.1016/j.autcon.2021.103553.

Manuele, F.A., 2003. On the practice of safety, third edition. New Jersey (Canada): John Wiley & Sons Inc.0-471-27275-2.

Martínez Aires, M.D., Rubio Gámez, M.C., Gibb, A., 2010. Prevention through design: The effect of European directives on construction workplace accidents. Saf. Sci. 48 (2), 248–258. https://doi.org/10.1016/j.ssci.2009.09.004.

Martínez-Aires, M.D., Rubio Gámez, M.C., Gibb, A., 2016. The impact of occupational health and safety regulations on prevention through design in construction projects: Perspectives from Spain and the United Kingdom. Work 53 (1), 181–191. https://doi.org/10.3233/WOR-152148.

Martínez-Aires, M.D., López-Alonso, M., Martínez-Rojas, M., 2018. Building Information Modeling and Safety Management: A Systematic Review. Saf. Sci. 101, 11–18. https://doi.org/10.1016/j.ssci.2017.08.015.

Martínez-Rojas, M., Pardo-Ferreira, M., Rubio-Romero, J., 2018. Twitter as a tool for the management and analysis of emergency situations: A systematic literature review. Int. J. Inf. Manag. 43, 196–208. https://doi.org/10.1016/j.ijinfomgt.2018.07.008.

Martínez-Rojas, M., Martín Antolín, R., Salguero-Caparrós, F., Rubio-Romero, J.C., 2020. Management of construction safety and health plans based on automated content analysis. Autom. Constr. 120 https://doi.org/10.1016/j.autcon.2020.103362.

Mihić, M., Vukomanović, M., Završki, I., 2019. Review of previous applications of innovative information technologies in construction health and safety. Organization, Technology and Management in Construction 11 (1), 1952–1967. https://doi.org/10.2478/otmcj-2019-0004.

Ministry of human resources Malaysia. 2007. Retrieved from https://www.dosh.gov.my/index.php/legislation/guidelines/building-construction-engineering-work/669-01-guidelines-for-public-safety-and-health-at-construction-sites-2007/file. Accessed January 2024.

Ministry of Manpower. Singapore. (2006). Workplace safety and health act 2006, Retrieved from https://sso.agc.gov.sg/Act/WSHA2006. Accessed January 2024.

Morillas, R.M., Rubio-Romero, J., Fuertes, A., 2013. A comparative analysis of occupational health and safety risk prevention practices in Sweden and Spain. J. Saf. Res. 47, 57–65. https://doi.org/10.1016/j.jsr.2013.08.005.

Ndekugri, I., Ankrah, N.A., Adaku, E., 2022. The design coordination role at the pre-construction stage of construction projects. Build. Res. Inf. 50 (4), 452–466. https://doi.org/10.1080/09613218.2021.1971061.

Ndekugri, I., Ankrah, N.A., Adaku, E., 2023. Performance barriers for coordination of health and safety during the preconstruction phase of construction projects. J. Constr. Eng. Manag. 149 (7) https://doi.org/10.1061/JCEMD4.COENG-12073.

Official Journal of the European Union, 2010. Case C-224/09. Reference for a preliminary ruling. directive 92/57/EEC. implementation of minimum safety and health requirements on temporary and mobile construction sites; article 3 requirement to appoint a coordinator for safety and health matters and draw up a safety and health plan), Retrieved from https://curia.europa.eu/. Accessed January 2023.

Oh, T.K., Kwon, Y.J., Oh, B.H., Gwon, Y.I., Yoon, H.K., 2021. Suggestions for safety coordinator's roles at each construction stage (client, designer, supervisor, and contractor) to improve safety and health activities in South Korea. Safety Science 133, 104994. https://doi.org/10.1016/j.ssci.2020.104994.

Oliveira, V.S., Santos, C.J.D.O., Vasconcelos, B.M., 2023. Digital tools for prevention through design application: A systematic review. Work 76 (4), 1345–1356. https://doi.org/10.3233/WOR-220603.

OSHA (2024) Occupational Safety and Health Administration. Retrieved from https://www.osha.gov/. Accessed January 2024.

Patrucco, M., Pira, E., Pentimalli, S., Nebbia, R., Sorlini, A., 2021. Anti-collision systems in tunneling to improve effectiveness and safety in a system-quality approach: A review of the state of the art. Infrastructures 6 (3). https://doi.org/10.3390/infrastructures6030042.

Peterson, J.E., 1973. Principles for controlling the occupational environment. In Department of Health, Education, and Welfare, Public Health Service, Centers fo Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 74-117 (Ed.), *The industrial environment - its evaluation and control, 3rd edition* (pp. 511-517). U.S.: Cincinnati, OH.

Rangasamy, V., Yang, J., 2024. The convergence of BIM, AI and IoT: Reshaping the future of prefabricated construction. J. Build. Eng. 84 https://doi.org/10.1016/j.jobe.2024.108606.

Raynal, A.L., Hermanns, R.G., 2018. Implementation of the directive 89/391/EEC in Europe. Occup. Med. 68 (2), 147. https://doi.org/10.1093/occmed/kqx177.

Rebelo, M., Silveira, F., Czarnocka, E., Czarnocki, K., 2019. Construction safety on scaffolding: Building information modeling (BIM) and safety management-A systematic review. U. Porto J. Eng. 5 (2), 46–60. https://doi.org/10.24840/2183-6493_005.002_0006.

Romero, Á., González, M.N., Segarra, M., Villena, B.M., Rodríguez, Á., 2019. Mind the gap: Professionalization is the key to strengthening safety and leadership in the construction sector. Int. J. Environ. Res. Public Health 16 (11). https://doi.org/10.3390/ijerph16112045.

Ros Serrano, A., Ortiz-Marcos, I., Palomo Sánche, J.G., Uruburu Colsa, A., 2013. A proposal for improving safety in construction projects by strengthening coordinators' competencies in health and safety issues. Saf. Sci. 54, 92–103. https://doi.org/10.1016/j.ssci.2012.12.004.

Royal Decree, 1., 1997. *Royal decree of 24 October 1627/97 laying down minimum safety and health at construction sites.* (BOE n° 256 ed.). Spain. Retrieved from https://www.boe.es/eli/es/rd/1997/10/24/1627/con Assessed March 2023.

Rubio-Romero, J., López-Arquillos, A., Martinez-Aires, M., Carrillo-Castrillo, J., 2014. Prevention through design (PTD) concept at university. engineering & architecture

students' perspective. Paper presented at the 53-56. Retrieved from https://www.taylorfrancis.com/chapters/edit/10.1201/b16490-12.
Samsudin, N.S., Mohammad, M.Z., Khalil, N., Nadzri, N.D., Izam Che Ibrahim, C.K., 2022. A thematic review on prevention through design (PtD) concept application in the construction industry of developing countries. Saf. Sci. 148, 105640 https://doi.org/10.1016/j.ssci.2021.105640.
Samsudin, N.S., Khalil, N., Mohammad, M.Z., Md Ajis, A., Hamzah, H., Che Ibrahim, C.K. I., Manu, P., 2023. An ontology to represent the prevention through design (PtD) concept in integrated project delivery (IPD) in the construction industry from an architectural perspective. Buildings 13 (5). https://doi.org/10.3390/buildings13051128.
Seeling, R., 2001. Possibilities of implementing the resolution no 92/57 es of the council of the EU ministries in germany. Statyba 7 (4), 286–293. https://doi.org/10.1080/13921525.2001.10531738.
Smallwood, J., Allen, C., 2023. Practitioners' perceptions of the potential impact of industry 4.0 on construction health and safety. J. Eng., Design and Technol. 21 (2), 486–501. https://doi.org/10.1108/JEDT-11-2021-0635.
Song, L., Li, R.Y.M., Yao, Q., 2022. An informal institution comparative study of occupational safety knowledge sharing via French and English tweets: Languaculture, weak-strong ties and AI sentiment perspectives. Saf. Sci. 147, 105602 https://doi.org/10.1016/j.ssci.2021.105602.
Taat, N.H.M., Abas, N.H., Hasmori, M.F., 2022. (2022). The barriers of building information modelling (BIM) for construction safety. Paper Presented at the 214, 121–130. https://doi.org/10.1007/978-981-16-7920-9_15.
Thirugnana Sambandan, V., Felix Kala, T., Nallusamy, S., 2021. Influence of cultural values on strategic and operational aspects of construction safety management in sustainable business organisations. J. Green Eng. 11 (1), 39–53.
Toh, Y.Z., Goh, Y.M., Guo, B.H.W., 2017. Knowledge, attitude, and practice of design for safety: Multiple stakeholders in the Singapore construction industry. J. Constr. Eng. Manag. 143 (5) https://doi.org/10.1061/(ASCE)CO.1943-7862.0001279.
Toole, T.M., 2005. Increasing engineers' role in construction safety: Opportunities and barriers. J. Prof. Issues Eng. Educ. Pract. 131 (3), 199–207. https://doi.org/10.1061/(ASCE)1052-3928(2005)131:3(199).
Toole, T.M., Gambatese, J., 2008. The trajectories of prevention through design in construction. J. Saf. Res. 39 (2), 225–230. https://doi.org/10.1016/j.jsr.2008.02.026.
Torrecilla-García, J.A., Pardo-Ferreira, M., Rubio-Romero, J., 2021. Overall introduction to the framework of BIM-based digital twinning in decision-making in safety management in building construction industry. Direccion y Organizacion 74, 31–38. https://doi.org/10.37610/DYO.V0I74.600.
Tymvios, N., Gambatese, J.A., 2016. Perceptions about design for construction worker safety: Viewpoints from contractors, designers, and university facility owners. J. Constr. Eng. Manag. 142 (2) https://doi.org/10.1061/(ASCE)CO.1943-7862.0001067.
Weinstein, M., Gambatese, J., Hecker, S., 2005. Can design improve construction safety?: Assessing the impact of a collaborative safety-in-design process. J. Constr. Eng. Manag. 131 (10), 1125–1134. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:10(1125).
Winge, S., Albrechtsen, E., Arnesen, J., 2019. A comparative analysis of safety management and safety performance in twelve construction projects. J. Saf. Res. 71, 139–152. https://doi.org/10.1016/j.jsr.2019.09.015.
Žarković, M., Ćetković, J., Redzepagic, S., Đurović, G., Vujadinović, R., Živković, A., 2022. Economic growth determinants in new and old EU countries with focus on construction. Technol. Econ. Dev. Econ. 28 (6), 1622–1648. https://doi.org/10.3846/tede.2022.17598.
Zeng, L., Li, R.Y.M., 2022. Construction safety and health hazard awareness in Web of Science and Weibo between 1991 and 2021. Saf. Sci. 152, 105790 https://doi.org/10.1016/j.ssci.2022.105790.
Zhu, J., Liu, W., 2020. A tale of two databases: The use of Web of Science and Scopus in academic papers. Scientometrics 123 (1), 321–335. https://doi.org/10.1007/s11192-020-03387-8.
Zou, P.X.W., Redman, S., Windon, S., 2008. Case studies on risk and opportunity at design stage of building projects in Australia: Focus on safety. Architectural Eng. Des. Manage. 4 (3–4), 221–238. https://doi.org/10.3763/aedm.2008.0082.