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# Enhancing Construction Health & Safety Through Early Integration of Construction Health and Safety Agents

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## Abstract

Many construction accidents are attributed to design stage decision-making. Design for Safety (DfS) is a proactive approach to improving health and safety (H&S) performance; however, its effectiveness is often limited by late inclusion of Construction Health and Safety Agents (CHSAs) in the project. This study examines factors affecting CHSA integration in the design stage and proposes an integrative framework to improve H&S performance. A quantitative, positivist approach was adopted. Data was collected from construction professionals in South Africa, including CHSAs, project managers, engineers, and architects wherein 85 respondents participated. Descriptive and inferential statistical analysis were conducted using the Kruskal-Wallis H-test and Spearman's rank correlation to test hypotheses related to CHSA integration, collaboration, and technological enablers. The findings revealed strong agreement on the significance of early CHSA integration, interdisciplinary collaboration, and the adoption of the Common Data Environment (CDE). The results confirmed significant positive relationships between CHSA integration, collaboration and H&S performance, and CDE adoption and collaboration. Key barriers identified included designers' concerns regarding professional liability and limited H&S expertise within design teams. The study concludes that early CHSA involvement, supported by collaborative practices and enabling technologies, can significantly enhance DfS implementation and improve H&S outcomes on construction projects.

## Keywords
Construction Health and Safety Agents; Design for Safety; Collaboration; Health and Safety Performance; Common Data Environment.

## 1. Introduction
A substantial body of research confirms that many construction-related incidents originate not during execution, but at the design stage, where risk-laden decisions inadvertently embed hazards into construction processes long before site activities commence (Smallwood, 1996; Erickson, 2016; Tözer, et al., 2024). When H&S considerations are insufficiently integrated during design, risks become inherent to projects, resulting in inadequate construction planning, elevated accident rates, and avoidable cost and schedule overruns (Deacon & Smallwood, 2017; Nai'em, et al., 2020).

In response to these persistent challenges, Design for Safety (DfS) has gained international recognition as a preventative strategy that seeks to address construction hazards at their source. DfS emphasises the systematic integration of H&S considerations into early project planning and design decision-making. Extensive empirical research demonstrates that early hazard identification and elimination significantly improve construction H&S performance while simultaneously enhancing project efficiency and constructability (Bong, et al., 2015; Manu et al., 2019; Akinlolu, et al., 2022). Further evidence indicates that effective DfS implementation contributes to reductions in injuries and fatalities, improved productivity, and better cost and time performance on construction projects (Karakhan & Gambatese, 2017; Karakhan et al., 2018). Nonetheless, despite these proven benefits, the uptake and consistent application of DfS principles remain limited, particularly within developing construction contexts.

A recurring concern within DfS discourse relates to accountability and capacity for design-stage safety implementation. Although designers are increasingly recognised as key contributors to construction risk profiles, studies repeatedly report resistance or hesitance among designers to assume substantive H&S responsibilities. This reluctance is commonly attributed to inadequate H&S training, ambiguity regarding practical safety implementation, and concerns relating to professional liability exposure (Liang et al., 2020; Karakhan & Gambatese, 2017; Che et al., 2021). In South Africa, despite the Construction Regulations (2014) clearly mandating designers to consider H&S during design, empirical research indicates that design-stage safety integration remains limited and largely inconsistent over time (Smallwood, 2024; Famakin et al., 2023).

Within this regulatory and operational landscape, Construction Health and Safety Agents (CHSAs) are positioned as specialists equipped with the technical knowledge necessary to identify, assess, and mitigate construction-related H&S risks. The South African Construction Regulations formally recognise the CHSA as a competent professional responsible for representing the client's H&S obligations throughout the project lifecycle (SACPCMP, 2013; Deacon, 2016). However, multiple studies highlight that CHSAs are typically appointed late in the project lifecycle, often after critical design decisions have already been finalised (Smallwood, 2024; Rantsatsi, Musonda & Agumba, 2023a). This delayed appointment significantly limits the CHSA's ability to influence risk elimination at source, effectively relegating their role to reactive safety monitoring rather than proactive design-stage prevention.

In addition to late CHSA involvement, the literature consistently identifies weak collaboration among design-stage stakeholders as a major barrier to effective H&S integration. Fragmented professional roles, limited interdisciplinary engagement, and poorly defined communication channels between designers and CHSAs undermine the systematic application of DfS principles (Bavafa et al., 2018; Manu et al., 2018a; Son et al., 2024). Recent studies emphasise that enhanced collaboration during early project stages is critical to improving construction H&S performance and achieving meaningful risk reduction outcomes (Rantsatsi, Musonda & Agumba, 2023b).

Emerging digital collaboration tools—such as Building Information Modelling (BIM) and Common Data Environments (CDEs) have been identified as potential enablers of early H&S integration. These platforms facilitate shared access to design information, improve information transparency, and support early hazard identification across disciplines, thereby creating opportunities for CHSAs to meaningfully contribute during design (Muhuri et al., 2019; Jaafar et al., 2024). Despite this potential, empirical research examining how such collaborative mechanisms can be systematically leveraged to support the early and effective integration of CHSAs during the design phase remains limited.

Although the literature extensively addresses DfS principles and designer responsibilities, a clear empirical gap exists regarding structured frameworks for the early integration of CHSAs into construction project design, particularly within the South African construction industry. There remains limited guidance on when, how, and to what extent CHSAs should be involved during design to maximise H&S outcomes. This study addresses this gap by empirically examining CHSA inclusivity, stakeholder collaboration, and DfS application, to develop a framework to enhance construction safety through the early and effective integration of CHSAs in project design.

## 1.1 Objectives

The primary objective of this study is to enhance construction health and safety performance by promoting the early and effective integration of CHSAs into the design phase of construction projects.

To achieve this primary objective, the study pursues the following specific objectives:

1. To examine current practices relating to the appointment and involvement of CHSAs during the design phase of construction projects within the South African construction industry.
2. To assess the extent and effectiveness of collaboration between CHSAs and other design-stage stakeholders in supporting the application of DfS principles.
3. To evaluate the potential role of digital collaboration tools, such as BIM and CDEs, in facilitating CHSA inclusivity and early hazard identification during project design.

## 2. Literature Review

### 2.1 Design for Safety as a Proactive Strategy for Construction Health and Safety

DfS in the construction industry refers to a systematic approach that seeks to enhance occupational health and safety (H&S) performance by integrating safety considerations into design decisions from the designer's perspective (Poghosyan, et al., 2018). Zhou, et al. (2022) describe DfS as a critical link that connects the broader project safety lifecycle with engineering design models and subsequent construction activities. Their study emphasises that safety deficiencies introduced at the design stage can result in significant negative consequences in later project phases, including property damage, financial losses, project delays, and increased exposure of construction workers to safety risks.

The origins of the DfS concept can be traced to the early 1950s, following the publication of an accident prevention manual by the United States National Safety Council (Liu, et al., 2023). This manual introduced the notion of "design for safety" by highlighting the need to incorporate safety principles during the design of new construction projects. Since then, DfS has evolved through the contributions of various research institutions and professional bodies. A major step towards formalising the concept occurred in 1992, when the International Organisation for Standardisation (ISO) released an international standard aimed at guiding the inclusion of safety considerations within the design process (Zhu, et al., 2023).

Ibrahim, et al. (2022) observe that the conceptual development of DfS is underpinned by two key theoretical foundations. The first is Lorent's theory, which asserts that design attributes directly influence the nature and frequency of workplace accidents. The second is the Time Influence Curve (TIC) theory, which suggests that the potential to improve safety outcomes is greatest during the early stages of project development and decreases significantly once construction activities have commenced. Together, these theories reinforce the importance of early design interventions in preventing occupational accidents.

According to Gambatese, et al. (2017), the emergence of DfS has been driven by the adoption of best practices drawn from the "design for construction safety toolbox", which provides practical guidance to assist designers in making safer design choices during project planning and design phases. The toolbox aims to establish alignment between design and construction stages to enhance construction worker safety outcomes. While design teams are typically composed of engineers and architects, studies indicate that these professionals may fail to recognise certain construction-related hazards that could otherwise be identified by CHSAs, who approach design decisions from a safety-specialist perspective (Zhou, et al., 2022). Consequently, DfS has been advanced as a structured approach to improving design quality and regulatory compliance while addressing occupational hazards and accident prevention at source (Poghosyan, et al., 2018).

Within the literature, the concept of DfS is often referred to using alternative but closely related terms, including Designing for Construction Safety (DfCS), Construction Hazard Prevention through Design (CHPtD), Prevention through Design (PtD), and Safe Design (SD) (Ibrahim, et al., 2022; Zhou, et al., 2022). Although terminology may differ, these concepts share a common objective: the prioritisation of H&S during the design process. For consistency, this study adopts the term DfS. At its core, DfS promotes the elimination, mitigation, or reduction of construction hazards through informed design choices, thereby reducing risks associated with construction activities (Teo, et al., 2016). As such, DfS is widely regarded as one of the most proactive and effective strategies for preventing both fatal and non-fatal workplace accidents in construction.

In recent years, increasing scholarly attention has been directed towards the application of DfS as a means of ensuring that design interventions are inherently safer for construction workers (Manu, et al., 2019). Although not exhaustive, Table 1 presents a synthesis of key studies published over the past decade that have contributed to the advancement of knowledge on DfS within the construction industry.

Table 1. Summary of DfS related studies conducted between 2013 to 2023

| **Focus area** | **Outline** | **Research gap** | **Author** |
|---|---|---|---|
| Safe Construction through design | The influence of construction designs on safety priorities at construction sites | Quantifying the impact of design on safety, developing design tools and processes to enhance safety, and improving communication between designers and construction workers. | (Larsen and Whyte, 2013) |
| Testing the time-safety influence curve | Explores the timing of when H&S considerations are made regarding how to control work-related hazards. | The paper does not consider the impact of different safety management practices on the relationship between pre-construction decision-making and risk control effectiveness. | (Lingard, et al., 2014) |
| Designers' role in construction projects | The awareness of designers of their role in construction safety and how procurement systems promote safety in design – as cost considerations may limit designers' ability to apply DfS in projects. | The role of designers in recognising and managing risks, and the training and education of designers in health and safety. | (Bong, et al., 2015) |
| Prevention through design | Design safety knowledge and attitudes among structural and civil engineers in construction. | The development of a broader understanding of the role H&S in design and the adoption of DfS to enhance the sustainability of construction projects. | (Goh and Chua, 2015) |
| BIM system in DfS | Development of a framework for worker H&S using a proposed BIM system to assess the H&S index of projects. | Integrating BIM with other H&S management systems and developing training programs for designers on how to use BIM systems to enhance safety. | (Teo, et al., 2016) |
| Sustainable design and construction | The level of integration of DfS practices into sustainable design and construction. Identifying enablers and barriers to DfS adoption in the architecture, engineering, and construction industry. | There is limited research on the barriers to implementing DfS practices in the construction industry. This makes it hard to develop effective strategies for overcoming these challenges. | (Karakhan and Gambatese, 2017) |
| Knowledge, attitude and practice of DfS amongst construction industry stakeholders | Examines the knowledge, attitude, and practise of various stakeholders and suggests interventions to enhance DfS implementation in the construction industry. | Assessment of the impact of DfS on construction accidents. The paper does not explore why some stakeholders have better knowledge, attitudes, and practices related to DfS than others. | (Toh, et al., 2017) |

| | | | |
|---|---|---|---|
| Validation of the Time-Safety Influence Curve as a basis of DfS | The capacity to reduce construction risks during the initial phases of construction | The lack of practical methods and processes to effectively integrate specialised H&S knowledge into early design stages, despite recognising its theoretical importance. | (Karakhan, et al., 2018) |
| Automation in Design | Enhancing designer knowledge with automation for comprehensive safety risk reviews | Integrating BIM systems with existing DfS methods. | (Hossain, et al., 2018) |
| Design for occupational safety | Assessing organisational capacity to implement DfS | Future research should concentrate on designing and applying interventions that effectively build a robust safety culture within organisations. | (Manu, et al., 2019) |
| Reviewing how research through design is interpreted | Explores the evolution and adoption of the two theories for DfS in industry. | Need to evaluate how effective DfS is at reducing injuries and fatalities in the construction industry. | (Tymvios,et al., 2020) |

## 3. Methodology

This study adopted a positivist, quantitative research methodology to examine the influence of early integration of an CHSA on H&S performance during the design stage of construction projects. The methodological approach was selected to enable objective measurement, hypothesis testing, and statistical analysis of relationships between DfS implementation, stakeholder collaboration, and perceived H&S outcomes.

A deductive research strategy was employed, drawing on established theories and prior empirical studies to test predefined relationships between variables. The study focused on three core variables: (1) the application of DfS principles during design, (2) the extent of CHSA involvement in the design phase, and (3) perceived impacts on construction H&S performance. This approach aligns with a positivist epistemology and objectivist ontology, which regard H&S performance indicators as measurable and independent of subjective interpretation.

Primary data was collected using a structured, questionnaire-based survey administered to construction professionals involved in the design and pre-construction stages of projects in South Africa. The questionnaire comprised closed-ended Likert-scale items to ensure standardised data collection, minimise researcher bias, and support quantitative analysis. An online survey platform was used due to its cost efficiency and ability to reach a geographically dispersed professional sample.

A descriptive research design was applied to summarise patterns in stakeholder perceptions regarding DfS awareness, CHSA involvement, and design-stage H&S practices. Descriptive statistics were used to analyse central tendencies and distributions, while the internal consistency of the questionnaire was assessed using Cronbach's alpha to ensure reliability. Given the ordinal nature of the data, non-parametric statistical tests were utilised. Spearman's rank correlation was employed to examine relationships between early CHSA involvement, DfS implementation, and H&S performance, while the Kruskal–Wallis H-test was used to identify differences in perceptions among stakeholder groups.

The findings from the quantitative analysis informed the development of an evidence-based framework aimed at enhancing the early and structured integration of CHSAs during the design phase, with the overarching goal of improving construction health and H&S outcomes.

## 4. Data Collection

The target population for this study comprised of built-environment professionals registered with SACPCMP, SACAP, CIDB, SACQSP, and/or ECSA, who are directly involved in the construction design phase. These included architects, engineers (civil, structural, and electrical), construction project managers, quantity surveyors, environmental consultants, and CHSAs. A targeted (purposive) sampling technique was employed to ensure that participants possessed relevant professional expertise and experience related to design-stage decision-making and DfS practices.

Sample size determination was guided by Cochran's (1977) formula for survey-based quantitative research, using a 95% confidence level and a 10% margin of error, which is appropriate for exploratory industry studies. This calculation yielded an ideal sample size of approximately 96 respondents. The final dataset comprised 85 valid responses, which falls within the acceptable statistical range and is sufficient for quantitative analysis, including descriptive statistics, Spearman rank correlation, and Kruskal–Wallis non-parametric testing (Hair et al., 2019). This sample size is consistent with established practices in construction management research, where expert, purposive samples are commonly prioritised for analytical validity.

Data was collected using a structured questionnaire designed to capture quantitative data aligned with the study's objectives, research questions, and hypotheses. The questionnaire was informed by an extensive review of literature on DfS, CHSA roles, and design-stage H&S practices, with key constructs operationalised into measurable variables. The instrument consisted primarily of closed-ended questions, measured using a five-point Likert scale, to enable standardised responses and facilitate statistical analysis. The questionnaire was structured into four sections: (1) demographic information; (2) CHSA integration during the design phase; (3) application of DfS principles; and (4) perceived design-stage H&S outcomes. Clear and concise wording was used to minimise ambiguity and ensure consistent interpretation across respondents.

The questionnaire was administered online using Google Forms to allow efficient access to a geographically dispersed professional population within the South African construction industry. Distribution was conducted through professional associations and industry bodies, direct engagement with construction companies and design firms during site audits, and online professional platforms, including WhatsApp groups and virtual industry meetings. This approach ensured consistent data collection and broad participation from relevant design-stage stakeholders.

## 5. Results and Discussion

### 5.1 Numerical Results

The mean scores ranged from 4.29 to 4.58. This suggests that respondents strongly agreed with the statements, which is further supported by the negative skewness across all items. "C1. CHSA is one of the important members of the project team in the project design phase." had the highest mean = 4.58, which endorses that one of the essential members in the project team is CHSA.  The standard deviation ranges from 0.743 to 0.853. This indicates moderate variability in responses. A low standard deviation suggests that respondents' views are consistent with a few outliers. Items like "C1 - CHSA is one of the important members of the project team in the project design phase" showed higher consistency with a standard deviation of 0.743. In contrast, the item "C4 - A CHSA plays a significant function in the design phase of a construction project" showed greater variation (SD = 0.853), indicating that respondents had differing perceptions of this issue in this study, as shown in Table 2. High mean scores indicate clear consensus on the essential role of CHSA integration and collaboration in addressing their perceived isolation and late inclusion throughout the project lifecycle. This supports previous research (Rantsatsi et al., 2023b; Emuze & Smallwood, 2014), which found that poor collaboration hinders project H&S. Strong agreement that CHSAs are key team members and that teamwork improves H&S indicates the industry recognises the limits of fragmented models. The CHSA's role is increasingly seen as central to the design process and to effective DfS practice (Gambatese et al., 2017).

Table 2. Agreement levels on CHSA Integration

| **Item** | **Mean** | **SD** | **Skewness** | **Agreement Level** |
|---|---|---|---|---|
| C1. CHSA is one of the important members of the project team in the project design phase | 4.58 | .743 | -2.312 | Strongly Agree |
| C2. The timing of CHSA's contracting is key to effective DfS implementation in the project lifecycle | 4.49 | .793 | -2.277 | Strongly Agree |
| C3. The early involvement of CHSAs minimizes the occurrence of incidents and accidents associated with design choices. | 4.30 | .753 | -1.245 | Strongly Agree |
| C4. A CHSA plays a significant function in the design phase of a construction project. | 4.34 | .853 | -1.433 | Strongly Agree |
| C5. CHSAs are equipped with the essential competence to participate in the design phase of the construction project. | 4.29 | .824 | -1.236 | Strongly Agree |
| C6. CHSAs are effective in identifying and mitigating design-related hazards during the project lifecycle | 4.29 | .765 | -1.359 | Strongly Agree |

## 5.2 Inferential Statistics

The Shapiro-Wilk test was used to test the data distribution hypothesis since the sample size was less than 200 (Table 3):
H0: The data is normally distributed
H1: The data is not normally distributed

Table 3: Tests for normality

| Tests of Normality | | | |
|---|---|---|---|
| | Shapiro-Wilk | | |
| | Statistic | df | Sig. |
| CHSA Integration | .793 | 85 | <.001 |
| Barriers | .823 | 85 | <.001 |
| Facilitators | .796 | 85 | <.001 |
| Collaboration Scale | .817 | 85 | <.001 |
| CDE | .892 | 85 | <.001 |
| PerceivedBenefits | .917 | 85 | <.001 |
| HS_Performance | .927 | 85 | <.001 |

## 5.3 Proposed Improvements

Based on the empirical findings from respondents, the following improvements are proposed to enhance early CHSA integration and DfS implementation. All numerical values are drawn from the research's descriptive and inferential analyses

### 5.3.1 At Process level improvements

***Mandate early CHSA appointment*** – The strong agreement with item C2 ("The timing of CHSA's contracting is key to effective DfS implementation", *mean* = 4.49, *SD* = 0.793) confirms that late involvement remains a critical barrier. Clients should therefore appoint CHSAs at project inception (Stage 1) rather than after design freeze.

***Establish design-gate safety reviews*** – The collaboration scale achieved a mean of 4.48 (*SD* = 0.533) and showed a significant positive correlation with H&S performance ($\rho$ = 0.471, *p* < 0.01). This supports the introduction of formal review gates where designers and the CHSA jointly assess hazard registers and risk mitigation measures.
***Define clear DfS roles and responsibilities*** – The high mean for facilitators (4.51, *SD* = 0.582) and agreement that "collaborative efforts between designers and CHSAs can enhance safety outcomes" (*mean* = 4.64) indicate readiness for structured role definitions. A RACI matrix should specify the CHSA's consultative authority during each design stage.

### 5.3.2 Technological enablers

***Integrated CDE/BIM platform*** – The CDE construct had a mean of 4.30 (*SD* = 0.622) and a moderate positive correlation with collaboration ($\rho$ = 0.428, *p* < 0.01). This validates that a CDE acts as a "single source of truth" and should be mandated from the feasibility stage.
***Automated hazard checking*** – Given that CDE adoption is perceived to "increase collaboration amongst project team members for effective DfS implementation" (*mean* = 4.39), BIM-based rule-checking systems should be implemented to flag safety issues (e.g., fall protection, access) in real time

### 5.3.3 Capacity and Contractual mechanisms

***DfS competency requirements*** – Designers' lack of H&S expertise was identified as a barrier (item D3: *mean* = 4.08, *SD* = 1.140). Mandatory DfS modules should be integrated into engineering and architectural curricula, and continuing professional development (CPD) on DfS should be required for all design professionals.
***Liability protection frameworks*** – Designers' liability concerns were evident (item D6: *mean* = 4.09, *SD* = 1.070). Standard contractual clauses that fairly share design-related H&S liability among clients, designers, and CHSAs are urgently needed.

### 5.3.4 Numerical summary supporting improvements

Table 4 summarises the mean scores for the main constructs, confirming strong agreement across all areas and highlighting the highest readiness for facilitators and collaboration.

Table 4. Means, standard deviations and agreement levels of constructs

| **Construct** | **Mean** | **SD** | **Agreement Level** |
|---|---|---|---|
| Facilitators | 4.51 | 0.582 | Strongly Agree |
| Collaboration Scale | 4.48 | 0.533 | Strongly Agree |
| CHSA Integration | 4.38 | 0.635 | Strongly Agree |
| CDE | 4.30 | 0.622 | Strongly Agree |
| Perceived Benefits | 4.30 | 0.510 | Strongly Agree |

| **Construct** | **Mean** | **SD** | **Agreement Level** |
|---|---|---|---|
| H&S Performance | 4.21 | 0.635 | Strongly Agree |
| Barriers | 4.11 | 0.989 | Agree |

*Source: Research Survey Data*

The Kruskal-Wallis H-test from the data revealed that profession and number of projects significantly influence perceptions. Project managers and respondents involved in 1–3 projects consistently gave higher mean ranks for collaboration and facilitators, indicating that less complex workloads and project management roles are more receptive to collaborative DfS practices

### 5.4 Validation

The proposed improvements are supported by the reliability and inferential statistics from the survey data ($N = 85$). The overall instrument showed excellent internal consistency (Cronbach's $\alpha = 0.948$). Spearman's rank-order correlations confirmed all three hypotheses: CHSA integration with H&S performance ($\rho = 0.310$, $p < 0.01$), collaboration with H&S performance ($\rho = 0.471$, $p < 0.01$), and CDE with collaboration ($\rho = 0.428$, $p < 0.01$). The Shapiro-Wilk test indicated non-normal data ($p < 0.001$), justifying the use of non-parametric tests. These results empirically ground the proposed improvements in measurable, statistically significant relationships.

## 6. Conclusion

This study successfully met all three objectives. The first objective was achieved by confirming that early integration of CHSAs during the design phase positively influences H&S performance ($\rho = 0.310$, $p < 0.01$). The second objective was achieved by demonstrating that collaboration between CHSAs and designers has an even stronger positive association with H&S outcomes ($\rho = 0.471$, $p < 0.01$). The third objective was achieved by validating that adoption of a CDE significantly enhances collaboration among project stakeholders ($\rho = 0.428$, $p < 0.01$).

The unique research contribution is an empirically validated framework that positions the CHSA as a co-equal design-stage partner. Unlike prior models that focus primarily on designer obligations, this framework rests on three actionable pillars: early CHSA appointment at project inception, structured collaborative workflows (e.g., design-gate safety reviews), and a technology backbone comprising CDE and Building Information Modelling (BIM). This configuration enables proactive hazard elimination by ensuring specialised H&S expertise informs design decisions from the earliest stages.

We conclude that the marginalisation of CHSAs in the design phase is avoidable. Early, collaborative, and technology-enabled CHSA integration directly improves construction H&S performance, facilitating a shift from reactive H&S management to a genuinely preventive paradigm.

**Limitations** – The cross-sectional design precludes causal inference, and the sample, while adequate, is limited to the South African construction context. Perceptual data may not fully reflect objective H&S outcomes such as accident rates.

**Future research** – Longitudinal case studies are required to establish causality and measure the framework's impact on actual incident reduction. Comparative studies across developing and developed countries would also clarify how regulatory and cultural contexts influence DfS implementation.

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