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Organizational factors and specific risks on construction sites

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ABSTRACT

Introduction: This study develops an empirical test of two theoretical models using the approach of Structural Equation Model (SEM) to test the relationships between specific organizational factors of safety management system (SMS) and specific risk variables. *Method:* Two SEM models with two and four latent variables, respectively, and 10 observed risk variables were used to identify the strongest relationships that may lead to an accident on site. A random sample of 474 construction sites were visited and assessed in Spain from 2003 to 2010. Most of the samples were small and medium sized enterprises (SMEs), which is the predominant type of company in the Spanish construction industry. To assess the risk on sites and get the measurements of the variables included in the models, the validated method CONSRAT (Construction Sites Risk Assessment Tool) was used. After estimating the proposed models, an adequate fit was obtained for both of them. *Results:* Results provide empirical evidence that: (a) the factor "Resources on site" is more determinant in explaining influences on risk variables because of their influence on all risk variables (Model 1); (b) the factor "Site structure complexity" (which includes structure and organization, and safety resources available on site) has a stronger effect on risk variables than other factors related to intrinsic characteristics of the work, site, or companies (Model 2). *Conclusions:* These results mean that the complexity and resource factors that depend on companies are those that have the greatest impact on risks, which makes it possible for companies to undertake the appropriate risk control measures. *Practical Application:* These results can help construction firms obtain earlier information about which organizational elements can affect future safety conditions on site, improve those elements for preventing risks, and consequently, avoid accidents before they occur.

1. Introduction

Most studies in the Health and Safety (H&S) construction sector start by emphasizing their unsafe conditions, being one of the most risky industries of the world, with high incident rates over most other industries (Bavafa et al., 2018; Dillon et al., 2017; Jin et al., 2019; Zhou et al., 2015). Swuste, Frijters, and Guldenmund (2012) claimed that the "Construction sector is different" because its special characteristics and processes are mostly related with organizational issues. It seems that this industry has some inherent aspects that produce poor safety behavior.

Current research on occupational health and safety in construction is continually evolving and includes several factors to be analyzed. From the classical narrow focus on accident analyses, other events have become relevant, which broadens the scope of H&S research (Hollnagel, 2008; Khanzode et al., 2012) to include: safety climate and culture, information technologies, workers orientation, management, and risk assessment (Jin et al., 2019). There was a change in direction around 2009, as these authors showed, which was a limited number of works adopting a point of view of human factors related to construction safety (Carpio-de los Pinos et al., 2021; Hallowell et al., 2020).

Because lagging safety indicators (e.g., accidents rates), showed a low capacity to predict future accidents, it is important to analyze precursors to accidents identifying leading indicators (Hinze et al., 2013; Sparer & Dennerlein, 2013).

In this way, studies have adopted a more proactive approach focusing attention on predictive leading indicators capable of providing early warnings and to show how future safety behavior can be improved (Hinze, Thurman, et al., 2013; Lingard et al., 2017; Salas & Hallowell, 2016). As a consequence, a transition in the literature has occurred, moving from lagging indicators to new leading proactive ones (Alruqi & Hallowell, 2019; Forteza et al., 2020). The most important proactive methods are risk assessment, lead-

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ing indicators, and precursor risk analyses, which may predict future problems (Dillon et al., 2017). Among the main precursors, these authors included: the lack of connection between crew and work procedures; inexistence or poor safety plans and lack of flexibility to adapt changes; lack of work preparation and improvisation; poor safety records; lack of safety activity and supervision of crew mainly because of low qualified foremen and/or their lack of experience; and finally, lack of control barrier and visual warning, among others. The problem with the quality of safety plans and their influence on site was recently reviewed in studies (González García et al., 2021; Martinez-Rojas et al., 2020).

One specific characteristic about leading indicators is that they connect with the Safety Management System (SMS) and therefore they also affect future safety commitment. What most of the researchers have done is consider a group of organizational characteristics within the firm's SMS and show theoretical or empirical evidence on the relationship between SMS factors and accident precursors (Pereira et al., 2018; Zhang et al., 2018). In this way, Pereira et al. (2018) developed a method to connect a set of SMS factors with several accident precursors. Despite there being limited empirical evidence, other research has tried to directly connect specific organizational or SMS factors with several procedures of risk assessments (Cheng et al., 2012; Forteza et al., 2017; Manu et al., 2013; Wu et al., 2015).

Due to the non-contingent nature of accident causation, the probability that a risk becomes an accident is often empirically predicted to be low, and obviously is much more difficult to connect SMS factors with an immediate accident event. However, because those SMS factors are related to accident precursors, they are considered leading indicators of accidents (Bentley, 2009).

This paper provides empirical evidence to identify how organizational factors are directly connected with each specific risk variable in order to identify a set of organizational leading indicators of accidents in construction sites. In terms of accident prevention, a direct implication of the results is the possibility of intervening early, even before the risks can be identified on-site.

1.1. Literature review

A construction site is a work setting under continuous change, with constant interactions between workers, machinery, and all kinds of resources on site (Pereira et al., 2018). In addition to this day-to-day evolution of sites, other factors related to safety management (specifically with the organizational ones) affect the final results of safety performance, which are referred to in the literature as precursors (Alruqi & Hallowell, 2019; Bellamy, 2009; Jørgensen, 2016; Wang et al., 2016).

Related to the analyses of precursors, Alruqi and Hallowell (2019, p. 1) assert that there is a relationship between SMS and injury rates and state that "leading indicators are the measures of the safety management system." According to these authors, the most important indicators related to safety management issues are safety inspections and observations, safety resources, staffing for safety, and owner involvement. Of special interest is the distinction that this research proposed about the two kinds of leading indicators, active and passive ones. The active are related to everything being done preparing for work on site (e.g., hazard reporting and accident analysis, safety inspections and observations, and pre-task meetings); and the passive are related to previous decisions or plans before site works starts, which normally do not change (e.g., safety training, safety resources, staffing for safety, owner involvement, safety incentives programs, formal safety inspections, and worker behavior observation).

Similar conclusions were made by another study that found an important relationship between management performance and safety conditions (Abudayyeh et al., 2006). Other studies have focused on analyzing the key managerial factors to explore the relationships among them. The principal factors mentioned are, for example, agents' responsibility, general supervision, and more specifically on safety, the health and safety plan, crew responsibility, meetings, training, and so forth (Bavafa et al., 2018; Cheng et al., 2012; Forteza et al., 2017; Jin et al., 2019; Mohamed, 1999). These studies concluded the same as Abas et al. (2020) about the importance of safety procedures on construction sites and their direct connection to safety performance. They are also in line with Pereira et al.'s (2018) study, which connects specific SMS factors with accident precursors, distinguishing between internal and external SMS; and also are closely related with Alruqi and Hallowell's (2019) classification of active and passive leading indicators. Summing up, these previous studies can be classified as pertaining to the predictive research line on safety, which try to connect elements of the SMS with accident precursors, and also with likely future problems in order to improve future safety performance or to avoid accidents (Hallowell et al., 2013; Salas & Hallowell, 2016).

Despite all these new tendencies introducing some changes in the safety management approach, many sites are still managed under old reactive systems using (in the best of situations) lagging indicators such as checklists, risk assessments, and accident or incident checking (Liu & Liao, 2019). This behavior can be explained in part because the construction sector is characterized as being composed mainly of Small and Medium sized Enterprises (SMEs). All around the word, SMEs represent 90% of all firms in the sector. In developed countries the percentage is even higher, with around 95% of companies hiring 65% of workers (Hillary, 2017; Jin et al., 2019). These firms have the highest accident rates and, generally because of their intrinsic structure, also lower resources in specific areas of safety management (Cagno et al., 2013; Gunduz & Laitinen, 2017). This fact made it very difficult, if not impossible, to study the relationship between SMS factors and accident precursors because most of the SMEs do not have formalized systems. Forteza et al. (2017) proposed developing this kind of research, trying to directly connect organizational factors related with site complexity and resource endowment (aspects that are common to all firms and sites, whether or not they have SMS systems) with the specific risk levels assessed on site. These organizational complexity and resource factors converge with Alruqi and Hallowell's (2019) factors and, as with others also mentioned above, assessing the risk on site can be considered a leading indicator (Salas & Hallowell, 2016).

As Fan et al. (2020) concluded in their "map out the future of occupational health and safety research," there is a research gap on H&S issues in SMEs. Also, it should be noted that these firms usually face problems to access all kind of resources (e.g., human, economics, and technological resources on site; Walker & Tait, 2004). For this reason, Fan et al. (2020) encouraged the development of research to achieve new knowledge about the main weaknesses and peculiarities of construction SMEs. The few studies on H&S management in SMEs emphasize the limited resources and isolation problems of these firms, which are manifested in low knowledge and poor comprehension of key H&S documentation (e.g., safety plans or risk assessments; Cagno et al., 2011; Cheng et al., 2010; Fan et al., 2020).

Many of the organizational factors reviewed up to this point have been studied by several authors because of their important impact on the poor safety performance of this sector (Fang, Xie, Huang, & Li, 2004; Swuste et al., 2016; Wu et al., 2015). In fact, there is research aimed at studying the relationship between sets of organizational factors and risk conditions, with some studies focused specifically on site (Fang et al., 2004; Forteza et al., 2017; Liu & Liao, 2019; Teo & Ling, 2006; Wu et al., 2015). Forteza et al. (2017) considered different organizational variables grouped into two factors (organizational complexity and resources) and showed empirical evidence about their connection with the level of risk on construction site measured by an index composed of different risk variables that were measured onsite. Despite these advances in research, those management factors affecting risk onsite seem to be ignored by the majority of agents in the construction industry (Fang, Huang, et al., 2004; Wu et al., 2017).

Considering the specificities of the companies in the construction sector that have been mentioned above, this paper proposes to extend and actualize Forteza et al.'s (2017) study. Table 1 shows the results of the actualization and extension of these authors' revision following their structure of organizational factors and variables. As can be seen, the organizational variables are grouped into two global factors referring to complexity and resources, respectively. These two global factors are decomposed into four others sub-factors related to the firm and the site, which finally are formed upon different organizational variables, most of them having been previously studied in the literature (e.g., some managerial factors). The research references reported in Table 1 indicate the studies that analyze the relationship between these managerial and organizational factors (independently if they pertain or do not pertain to the SMSs), with different results on the firm's H&S commitment (such as level of risks, incidents, and accidents rates).

As Bavafa et al. (2018) mentioned, there are a huge number of studies trying to assess the effectiveness of critical factors belonging to safety programs, but there is still a lack of research to connect all those factors and analyze their interactions. Even when it is possible to identify a set of studies that analyze how different management factors impact H&S performance, to the best of our knowledge there is not any previous study that identifies how a set of specific managerial and organizational factors are connected with specific risks on site, estimating explicitly some connection paths between them. This is the main contribution of this paper. This is relevant because identifying the organizational resources and site structure elements that have a significant impact on specific risks, the level of risk on site can be reduced or organizations can pay more attention to some specific risks by modifying the level of resources and/or correcting deficiencies in site structure. In other words, this work proposes a broader approach to risk management compared to traditional risk assessments, which are only focused on immediate causes, and consequently, on partial scenarios.

The goal of this study is to provide an empirical test of a model on the relationship between organizational factors and specific risk variables, which is aimed at identifying possible interventions on site and organizational factors needed to improve risk levels on site to eventually avoid accidents.

2. Theoretical model and hypotheses

2.1. Model

The goal of this study is to propose and test a model of the relationship between organizational factors and a set of specific risk variables. The starting point is Forteza et al.'s (2017) model, which simplified form is reproduced in Fig. 1. This model states that F1 (Site complexity) and F3 (Site structure complexity) increases site risk (positive relationship), and that F2 (Firm's structure resources) and F4 (Safety management resources) decreases site risk (negative relationship).

This study looked into the effects that different factors related to organizational complexity and resources have on an aggregate risk on site index constructed upon 10 different risks on site variables. More specifically, it is proposed to decompose this aggregate site risk index to analyze how organizational aspects can affect each different risk on site variable. The question is which specific risk is affected by complexity or resources on site. Table 2 shows the individual risk variables and the aggregated site risk index.

It is proposed to first group the four organizational factors of constructions sites into two global factors, one for measuring complexity and one for resources (see Table 1), and then explore the relationships between those two factors and each variable of risk on site (Model 1 in Fig. 2). To obtain deeper knowledge about the different paths of effects, a second model is proposed where the two global organizational factors are extended into their initial four independent factors (Model 2 in Fig. 2).

2.2. Hypotheses

In line with the literature and previous empirical evidence, Fig. 2 included the general hypotheses proposed to test in this article. In Model 1, it is proposed that site complexity (Global factor 1, GF1) has a positive relationship with each of the 10 risk variables considered in this study (this is the general hypothesis 1); while resources on site (Global factor 2, GF2) have a negative impact

Table 1
Composition of Factors, Organizational variables and corresponding references.

Global factors	Factors	Organizational Variables	Research references on H&S impacts
GF1. Complexity	F1. Site complexity	OV1. Project OV2. Site size	(Fan et al., 2020*; Fang, Xie, et al., 2004*; Forman, 2013; Han et al., 2014; Hatipkarasulu, 2010; Hon et al., 2010; Manu et al., 2010; Oppenauer & Voorde, 2018*)
	F3. Site structure complexity	OV6. Internal organization structure OV7. Job planning and design	(Abas et al., 2020*; Alruqi & Hallowell, 2019*; Bavafa et al., 2018*; Dillon et al., 2017*; Fang, Huang, et al., 2004; Grill & Nielsen, 2019*; Gunduz & Laitinen, 2017*; Hinze, Thurman, et al., 2013; López-Alonso et al., 2013; Manu et al., 2013; Swuste et al., 2012; Xia et al., 2020*; Yung, 2009, 2009; Zhang et al., 2018*)
GF2. Resources	F2. Firm's structure resources	OV4. Promoter OV5. Contractor	(Abudayyeh et al., 2006; Bavafa et al., 2018*; Baxendale & Jones, 2000; Behm, 2005; Camino López et al., 2008, 2011; Cheng et al., 2010; Dillon et al., 2017*; Fang, Huang, et al., 2004; Gunduz & Laitinen, 2017*; Hinze, Hallowell, et al., 2013; Hinze, Thurman, et al., 2013; Holte et al., 2015; Liao & Perng, 2008; Pérez-Alonso et al., 2011; Ros et al., 2013; Salas & Hallowell, 2016*; Wu et al., 2015; Xia et al., 2020*; Huang & Hinze, 2006)
	F4. Safety Management resources	OV8. Coordination OV9. Preventive functions OV10. H&S plan	(Adam et al., 2009; Alruqi & Hallowell, 2019*; Bavafa et al., 2018*; Baxendale & Jones, 2000; Borys, 2012; Conchie et al., 2013; Dillon et al., 2017*; Fang, Huang, et al., 2004; Grill & Nielsen, 2019; Gunduz & Laitinen, 2017; Hallowell & Gambatese, 2009; Hinze, Thurman, et al., 2013; Jarvis & Tint, 2009; Jiang et al., 2015*; Mahmoudi et al., 2014; Manu et al., 2013; Ros et al., 2013; Yung, 2009*)

Source: Forteza et al., (2017) actualized and extended.
*Reference added to Forteza et al.'s (2017) review.

on each risk variable (which is the general hypothesis 2). In the case of Model 2, since it decomposed both global factors (GF1 and GF2) into their two factors considered in Forteza et al.'s (2017) model, the hypotheses of their effects on each risk on site variables are stated accordingly, that is, the two factors related to complexity increase all variables of risk on site, while the two factors reflecting level of resources reduce all variables of risk on site. Next, the hypotheses about the effect of organizational factors on risk variables are justified.

2.2.1. Hypothesis factor 1. Global factor of complexity

Onsite complexity is, in most projects, an important factor affecting risk conditions (Forteza et al., 2017). This factor includes endogenous elements coming from the own nature of the project as well as more exogenous ones that the site complexity generates. Among the first endogenous ones, type of project, building configuration and site environment conditions, number of floors, specific characteristics of stage, and so forth, can be included. The second exogenous factors are related to several issues and aspects that are decided before work starts, and will condition the development of the site. Those can encompass the type of contracting, number of companies on site, subcontracting, type of work on site, or number of works. The complexity factor considered is in line with precursors of accidents or "early step in an injury event" referred by Bentley (2009). The complexity elements are not directly related to an accident but they have the ability to enhance precursors of accidents. Table 1 shows a complete list of references that provide some empirical or theoretical background for this global factor of complexity, named *GF 1. Complexity*. Accordingly, it is proposed that site complexity (e.g., having more complex work and site, bigger sites, more difficult site environments, and a higher number of firms on site or multilevel structures for subcontracting) is related to an increment in specific variables of risks on sites. Therefore, the first hypothesis can be generally stated as follows: "*The more complex the site and its organizational structure, the higher the level in each risk on site variable.*" To test this hypothesis, it will split into 10 independent hypotheses corresponding to each risk on site variables of the study.

2.2.2. Hypothesis factor 2. Global factor of resources on site

The global factor of resources on site incorporates two main elements: (a) company general resources and (b) specific resources for safety. The former includes company resources depending on

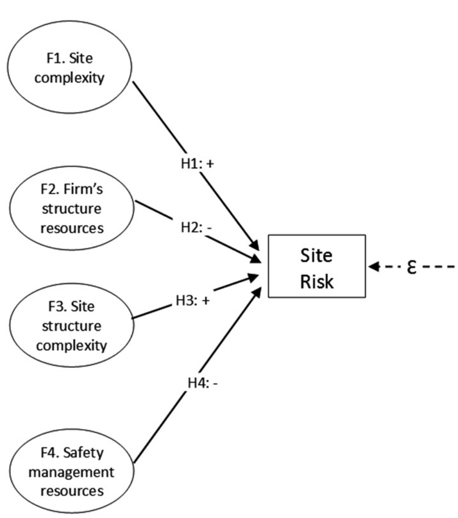

Fig. 1. Forteza et al.'s (2017) simplified model and set of hypotheses.

Table 2
Risk on Site Index and its decomposed variables. Source: Own elaboration from Forteza et al.'s (2017).

Risk on Site Index (SRI)	Disaggregated risk on site variables
SRI. Average of 10 risk variables	RV1. H&S plan compliance
	RV2. General conditions
	RV3. Collective protections
	RV4. Work access
	RV5. Fall of height
	RV6. Other risks
	RV7. Process
	RV8. Collectives protections
	RV9. Personal protections
	RV10. Auxiliary resources and machinery

their typology and internal structure, as well as all the resources assigned to be available on site, which usually depends on the agreements and demands of the agents involved (promoter and contractor). Within the latter elements (specific resources for safety) are the safety coordinator designated by the promotor, their continuous follow ups and documented work, the H&S functions assigned to the contractor's staff, and the existence and adequacy of the safety plan specific for the site. As has been reviewed in literature, resources are an important element of safety performance and they are considered a principal safety leading indicators (Alruqi & Hallowell, 2019). That study classified two kinds of leading indicators (active and passive) that are related, respectively, with near and long term safety performance. The second global factor (see GF2 in Table 1) includes some of these leading indicators analyzed by Alruqi and Hallowell (2019). A complete list of references giving theoretical and empirical background to this factor is reported in Table 1 (GF2). Therefore, the second hypothesis can be generally stated as follows: "*The more resources on site, the lower the level in each risk on site variable.*".

Similarly to hypothesis 1, it will test one independent hypothesis for each of the proposed path relationships from the global factor of resources to each specific variable of risk on site. Fig. 2 illustrates the graphical representation of the reduced model with both general hypotheses, where the arrows represent the corresponding set of split hypotheses.

3. Methods

3.1. Sample and data collection

The sample is composed of 474 construction sites that were assessed in Majorca (Spain) between 2003 and 2010. Those sites were randomly extracted using on site Communication Form (compulsory form for contractor and promoter at that time) in Majorca (Balearic Islands), which is a region historically characterized by having the highest accident rate of the whole construction sector in the country of Spain. The sample is representative of different types of sites, compositions and type of companies, levels of subcontracting, and structure of contracting. Sites in the sample also have a variety in their personnel structure and worker's resources.

Mainly multi-family buildings (44.6%) compose this sample, then single-family buildings (43.9%). Sites in the sample have about 2–3 floors (60.7%), with a total height of about 9 to12 meters. Regarding the different agents of sites, the promoters are professional firms in most of cases (56.8), going on with self-promoter (34.9%) and, finally, the promoter by public administration (8.6). Regarding Constructors, most of them are firms (86.4%), followed by self-workers (13.6%). Most of construction sites of the sample have just one firm contracted directly by promotor (contractor,

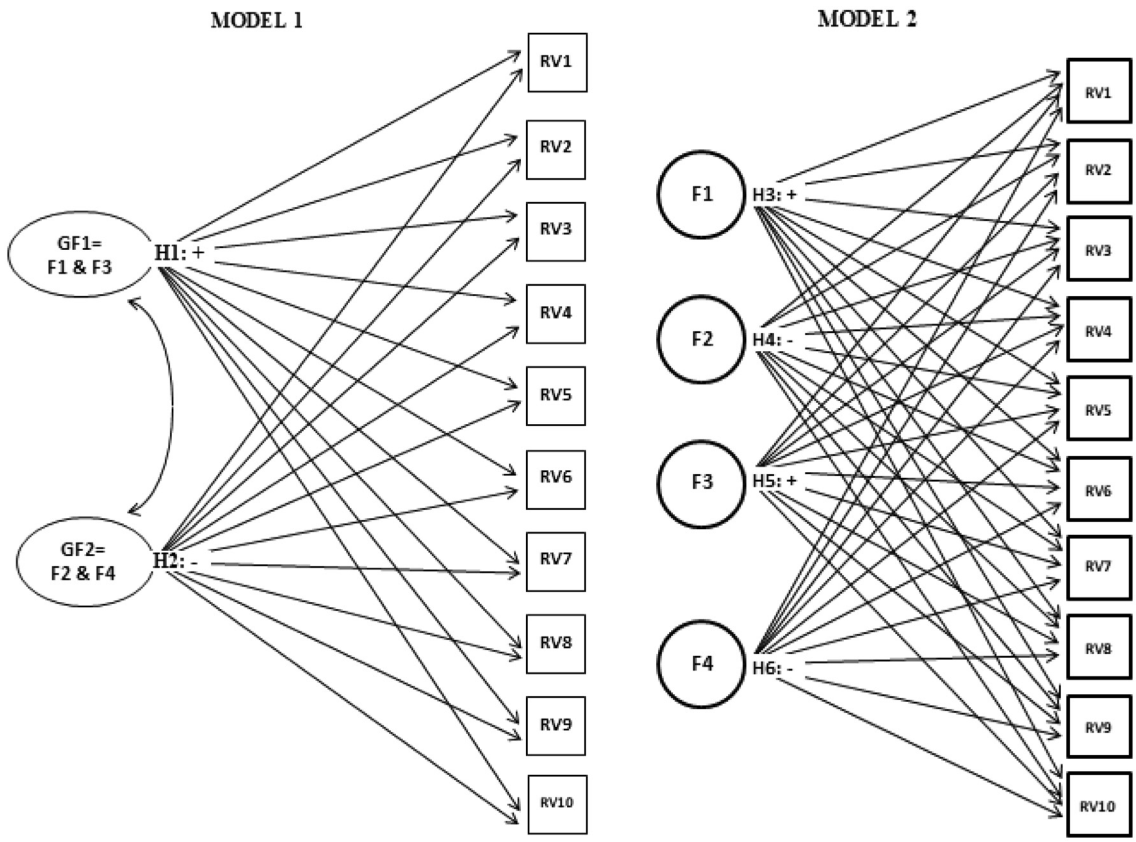

Fig. 2. Models 1 and 2 of effects of organizational factors on specific risk on sites variables.

83.1%) and those working on site at the same time as more than one company (58.9). Most of the sites have outsourcing (54.8%).

The sites in the sample were assessed using the Construction Sites Risk Assessment Tool (CONSRAT) validated by Forteza et al. (2016), which develops an assessment process in several steps. The process begins on site with a site inspection and an interview with a site responsible. After that a documented revision follows in order to check the adequacy of the documentation and the real live conditions on site. The procedure continues with an assessment of the risk conditions, including general conditions and specific stage risk conditions. Finally, all data and information related to organizational variables are collected (Table 1).

3.1.1. Organizational variables

Table 1 shows the composition of the factors related to the organizational variables considered in CONSRAT, along with an updated list of literature references that expands their conceptual background. Forteza et al. (2017) grouped the organizational factors into four different ones using an expert panel consultation and the corresponding confirmatory factor analysis (see Fig. 1). As can be seen in Table 1, those four factors were related with either site complexity or site resource issues, respectively. In order to facilitate the goal of this paper (i.e. fitting a relational model that allows estimating the effect of organizational factors into each specific risk on site variable), and also for parsimony purposes, this paper proposes first to aggregate those organizational factors into only two general ones, one for complexity of the site and another for available resources on site (Fig. 2, Model 1). According to most of the studies reviewed, these two global factors can be viewed as general precursors of safety behavior at work and this is the reason to consider them in Model 1.

Notwithstanding, as has already been mentioned, the alternative model (Fig. 2, Model 2) will be fit, considering the four organizational factors initially considered in Forteza et al. (2017).

3.1.2. Risk variables

In reference to risk variables of the model, the values on site of about 10 variables are obtained: RV1 (H&S plan compliance); RV2 (General conditions); RV3 (Collective protections); RV4 (Work access); RV5 (Fall of height); RV6 (Other risks); RV7 (Process); RV8 (Collective protections); RV9 (Personal protections); and RV10 (Auxiliary resources and machinery); all going on with validated model of CONSRAT (Forteza et al., 2016).

Data matrix with all variables was processed and checked for potential data mistakes and missing values. No data imputation methods were implemented in the absence of missing values. Multivariate normality tests to assess the underlying statistical assumptions of SEM estimation methods were implemented. Although the results did not strictly fulfill assumption of multivariate normality, detecting small deviations (skewness and kurtosis z values below |1.00|, the robust maximum likelihood method (MLR) was used with LISREL 10 software (Jöreskog and Sörbom, 2018). Covariance errors between indicators were not implemented for the estimated models. To assess overall fit of the model, *chi-square*, the relative/normed *chi-square* to degrees of freedom (*df*) ratio, the Root Mean Square Error of Approximation (*RMSEA*) and its 90% Confidence Interval (with a *p*-value related to *RMSEA* < 0.05), the Standardized Root Mean Squared Residual (*SRMR*), and the Comparative Fit Index (*CFI*) were the used indices. A model can be considered to fit the data if the *chi-square test* is non-significant, *chi-square/df* < 3, *RMSEA* < 0.05, *SRMR* < 0.08, and *CFI* $\geq$ 0.95 (Hu and Bentler, 1999; Schreiber et al., 2006). Regarding analytic fit for single parameters, the 5% significance criterion was adopted (i.e., *t*-value of parameters of |2.00|). Finally, a chi-square test was used for model fit comparison (Models 1 and 2).

4. Results

The appendix includes a summary statistics and the correlation matrix for all variables in the models: Organizational Variables (OV) and Risk Variables (RV).

Fig. 3 shows the fit results of Model 1. The arrows from factors to indicators represent the factor loadings of latent variables, and the arrows from factors to risk indicators represent the standardize path coefficients as linear regression weights predicted by the model. Dashed arrows represent statistically non-significant relationships. Following this approach, each path coefficient can be used as a proxy of causal relationships between these represented variables (Loehlin, 2004). Model 1 presents an overall good fit with *chi-square/df* under 3 (2.05), a *RMSEA* of 0.05, with a non-significant *p*(*RMSEA* < 0.05 = 0.52), a *CFI* value clearly above of 0.95 (0.97), and a SRMR clearly below of 0.08 (0.043).

As for the results on the latent variables measurement model (reflective), all factor loadings of GF1 and GF2 are statistically significant at p <.01. Complexity obtained factor loadings ranging from 0.21 to 0.80, all adequate excepting OV1 (Complexity of project) with a loading below 0.40. With respect to Resources onsite, all factor loadings are clearly above 0.40, ranging from 0.48 to 0.74. Going on to analytical fit of Model 1 parameters, the different effects from the two factors over every risk variable can be seen. While factor GF1 has significant effect on 7 of the 10 variables (not for RV2, RV3 and RV6), factor GF2 has significant effects on all risk variables. All these path coefficients are significant at p <.01, positive for GF1, and negative for GF2, as expected in previous hypothesis.

The greatest magnitude for relationships between factors and risk indicators is obtained from Resources onsite (GF2) and site general conditions (RV2), with a standardized path coefficient of −0.91. That is, according to the Model 1, the general site conditions can be 83% affected by resources on site. There are also relevant relationships between GF2 and other risk variables as −0.83 (r^2 = 0.69) with both Compliance with safety plan (RV1), and Falls from height (RV5), −0.72 (r^2 = 0.52) with the Process (RV7), and −0.66 (r^2 = 0.44) with both Collective protections (RV3) and Access (RV4). This way, lower resources on site, as firm contractor resources and preventive functions of site responsible, imply increasing of risk indicators, as general conditions on site, fences, circulations, tidiness, safety signage and site electrical installation. Analogously, Model 1 brings evidence where lack of resources in companies and assignment of preventive functions can contribute to a higher level of falls from height risk.

In general, the magnitude of effects (all positive) exerted by complexity factors is slightly lower than resources on site, ranging from the lowest 0.40 (r^2 = 0.16) with RV4 to the highest 0.58 (r^2 = 0.34) with RV10. These results indicate that a higher complexity on contracting, number of companies, level of subcontracting, number of works, and location of different workers on the workplace, can increase some risk indicators, especially Fall of height and Auxiliary resources and machinery. Finally, it's important to note that the correlation between the two latent variables (GF1 and GF2) is 0.86 (p <.01), that is, Model 1 brings evidence of a positive and high correlation between complexity and resources on site.

To obtain a more specific pattern of relationships, it was decided to fit a second model (Model 2 in Fig. 2) where factors GF1 and GF2 were discomposed into 4 factors: (a) site complexity (F1), (b) firm's structure resources (F2), (c) complexity of the site structure (F3), and (d) site management resources (F4). Model 2 (Fig. 4) presents an overall good fit with *chi-square/df* under 3 (1.82), a *RMSEA* clearly below 0.05 (0.044), with a non-significant *p*(*RMSEA* < 0.05 = 0.79), a *CFI* value above of 0.95 (0.98), and a SRMR below 0.08 (0.035). Again, dashed lines have not reached statistical significance.

Following a model comparison approach, a chi-square test for fit comparison between the two fitted models was statistically significant ($\Delta\chi^2$ = 67.65, Δdf = 25, p <.001) and indicated a better fit of Model 2.

Although the overall fit of Model 2 is good, both the specific factor F1 (Site complexity), belonging to the general factor of complexity (GF1), and the specific factor F2 (Firm's structure resources), belonging to the general factor of resources onsite (GF2), do not reach statistically significant effects on risk indicators. Consequently, the specific factors F3 (Complexity of the site structure; from GF1) and F4 (Safety management resources; from GF2) are those that present a consistent effect on the risk indicators.

Results about the specific factors' measurement model show that all factor loadings are statistically significant at p <.01, including risk-unrelated factors F1 and F2, ranging from 0.45 to 0.94. The latent variable F3 explains the 59.29% of the variance of internal firm's organization (OV6), and the 62.41% of the variance of site planning (OV7). Meanwhile, F4 explains the 33.64% of the variance of safety coordination resources (OV8), the 57.76% of the variance of preventive assignments (OV9), and finally, the 22.09% of the variance of the health and safety plan adequacy (OV10).

Going on to analytical fit of Model 2 parameters, while factor F3 has significant effect on 8 of the total of 10 variables (not for RV2 and RV4), factor F4 has significant effects only on two risk variables, the two variables not related to F3 (RV2 and RV4). All these path coefficients are significant at p <.01, positive for F3, and negative for F4, as expected in the hypothesis. More concretely, F3 obtains positive path coefficients, in order, on RV5 (0.86), RV7 (0.73), RV3 (0.58), RV1 (0.53), RV10 (0.52), RV6 (0.50), RV8 (0.44), and RV9 (0.40); that is, the greater the complexity of the site structure, the worse the fall of height (r^2 = 0.74), the process (r^2 = 0.53), general collective protections (r^2 = 0.34), H&S plan compliance (r^2 = 0.28), auxiliary resources and machinery (r^2 = 0.27), other risks (r^2 = 0.25), collectives protection (r^2 = 0.19), and personal protections (r^2 = 0.16). Regarding F4, obtains negative path coefficients, in order, on RV2 (−0.72) and RV4 (−0.49); that is, the greater the safety management resources, the better the safety general conditions (r^2 = 0.52) and site access (r^2 = 0.24). Finally, the correlation between F3 and F4 is 0.80 (p <.01), in the same way that the model showed a positive and high correlation between complexity and resources on site as general factors.

Based on these results, it can be concluded that factor F3 (Site structure complexity), is more determinant for predicting risk variables, given its influence over more risk variables and their path coefficients. In this sense, Model 2, with empirical best fit, has allowed us to determine which part of Complexity of site (GF1) and Resources onsite (GF2) has more influence on risk variables. Results show that the factors related with structure and organization and, secondly, with safety resources made available on site, and introduced by participating companies, have stronger effect than intrinsic characteristics of the work, site, or companies.

5. Discussion

Regarding Model 1 results (Fig. 3), with good overall and analytic fit, the general factor Complexity (GF1) maintains a direct and positive relationship on the risk variables H&S plan compliance (RV1), Work access (RV4), Fall of height (RV5), Process

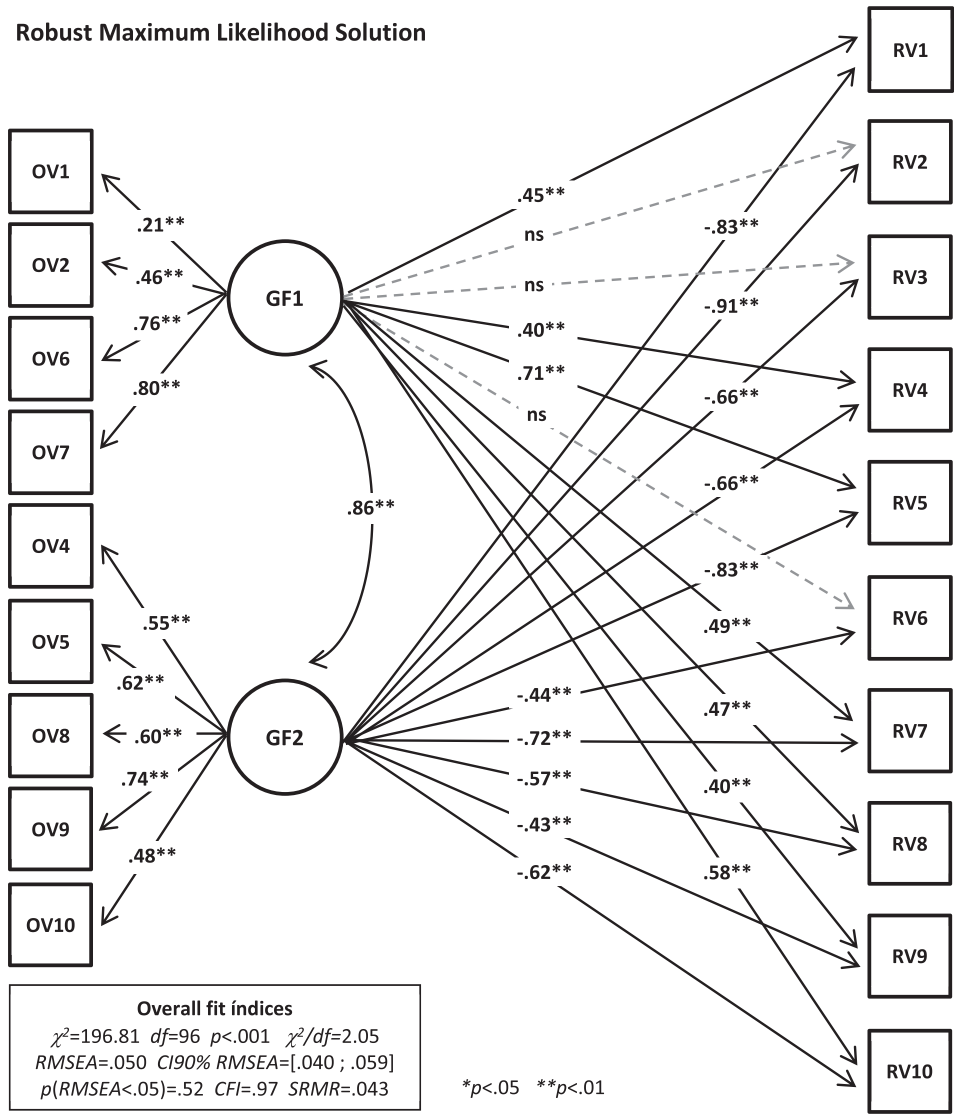

Fig. 3. Structural equation model of the influence of Complexity (GF1) and Resources on site (GF2) over each specific risk (RV1 to RV10) on site (Model 1).

(RV7), Collectives protections (RV8), Personal protections (RV9), and Auxiliary resources and machinery (RV10). These results converge with similar evidences obtained in previous studies, where several construction site complexity elements are related to results in H&S, or directly to risk levels (Abas et al., 2020; Fan et al., 2020; Forteza et al., 2017; Grill & Nielsen, 2019; Oppenauer & Voorde, 2018). This relationship establishes that the more complex the construction site is, the higher the risk levels are identified in it, and more resources are needed to control the risks. This relationship is especially strong with the risk of fall of height (RV5, $r^2 = 0.50$), one of the most important risks in the construction sector, widely identified in the literature.

Regarding the weight of the organizational variables on GF1, the Internal organization structure (OV6) and Job planning and design (OV7) are the ones that reach the greatest involvement in the generation of risks, and with a lower incidence follow the complexity of Project (OV1) and the size (OV2). OV6 and OV7 are precisely the two organizational factors on which to intervene and modify, since the project (OV1) or the size (OV2) are non-modifiable elements. It can be concluded that deficiencies in both the organizational structure and the planning and design of the construction site can lead to an increase in several risks, more specifically the risk of falling from a height. The evidence indicates that an early intervention on these variables can contribute to reducing the probability of such risks.

Model 1 also concludes that the global factor 2 Resources (GF2) presents a statistically significant and negative relationship with all risk variables. These results are in line with previous evidence in the literature in which different levels of resources are connected to H&S performance (Bavafa et al., 2018; Dillon et al., 2017; Fang et al., 2015; Forteza et al., 2017). Thus, the more resources on the construction site, the less risk detected. In this case, the relationship shows a higher magnitude with the variables H&S plan compliance (RV1) and Fall of height (RV5), both with r^2 equals 0.69. It's important to note that H&S plan compliance can be considered a fundamental element for safety onsite monitoring (Dillon et al., 2017). Regarding the organizational variables related to GF2, the Preventive Functions (OV9), the Contractor structure resources (OV5), and the Coordination resources (OV8) have a greater factor loading. These are key elements of preventive specialization of site resources that have a relevant influence on the incidence and severity of risks since they reveal the importance of the preventive functions of site personnel, the functions and means of coordination, and the level of resources of the contractor.

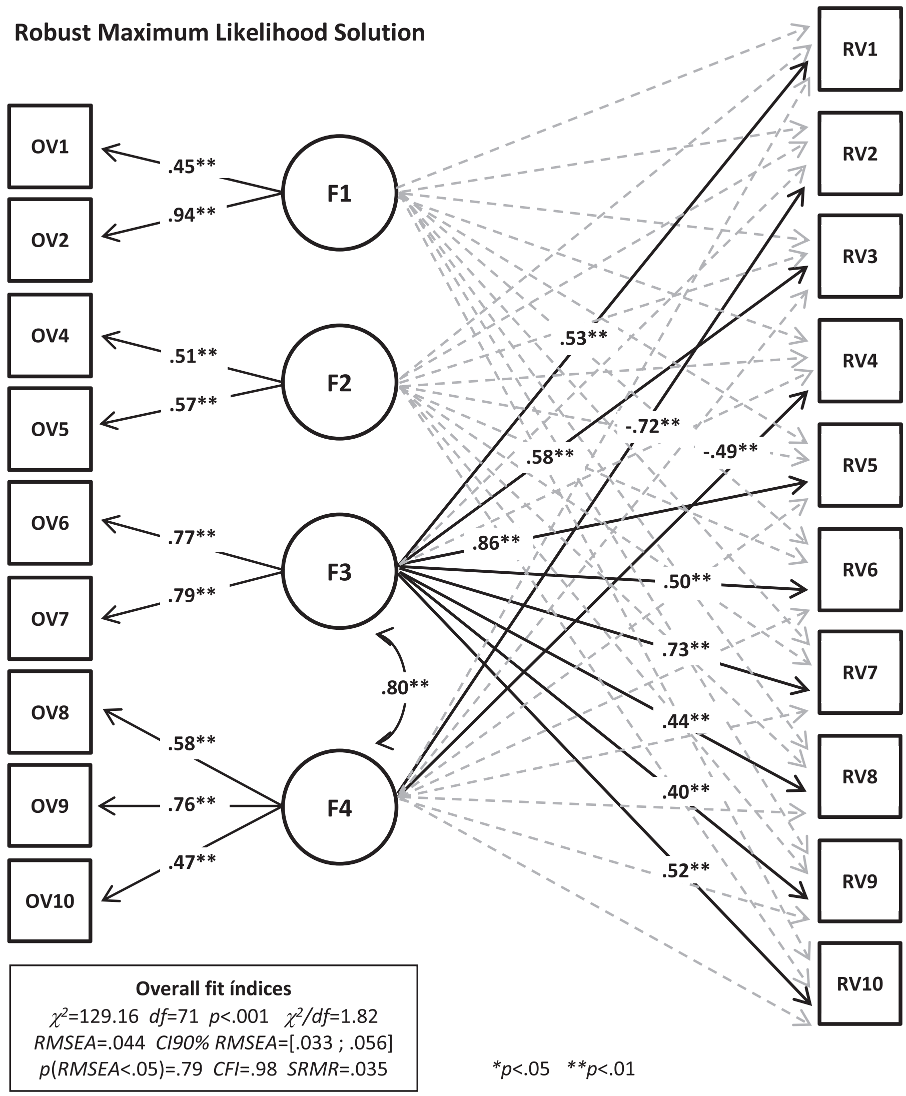

Fig. 4. Structural equation model of the influence of organizational specific factors: Site complexity (F1), Firm's structure resources (F2), Site structure complexity (F3), and Safety management resources (F4) on each specific risk on site (Model 2).

In this way, empirical evidence shows that a higher level of both specific resources in terms of site safety coordination and the involvement of personnel in preventive functions have an impact on risk reduction. These results coincide with the precursors globally or specifically identified by Dillon et al. (2017).

Once the relationship between the complexity and resource general factors and the risk indicators had been proved, a more specific model was fitted in which each of the general factors was divided into two specific factors (Model 2). The general Complexity factor was divided into Site complexity (F1: OV1 and OV2) and Site structure complexity (F3: OV6 and OV7); the general factor Resources (GF2) was divided into Firm's structure resources (F2: OV4 and OV5) and Safety Management Resources (F4: OV8, OV9, and OV10). The fit of Model 2 was even better than Model 1, although they can be considered perfectly complementary. Results show that specific factors F1 (belonging to GF1) and F2 (belonging to GF2) were not significantly related to any risk variable. This way, both the complexity of the construction site and the site size remain independent of risk indicators, in the sense that these two organizational variables are not easily modifiable. However, the specific factors Complexity of site structure (F3, belonging to GF1) and Safety Management Resources (F4, belonging to GF2) have a significant impact on risk variables, according to the expected hypotheses.

The contribution of F3, embracing internal organization structure and job planning, is very important because it reaches significant effects on 8 of 10 risk indicators (except on RV2 and RV4). These results are consistent with the relationships analyzed by other studies that related aspects of the organizational structure and internal planning of the work with impacts on the performance of the H&S (Abas et al., 2020; Bavafa et al., 2018; Dillon et al., 2017; Forteza et al., 2017; Grill & Nielsen, 2019; Gunduz & Laitinen, 2017; Zhang et al., 2018). The highest relationship between F3 and risk indicators corresponds to fall of height (RV5, $r^2 = 0.74$), followed by Process (RV7, $r^2 = 0.53$). Regarding the organizational variables related to F3, OV6 and OV7, obtained very similar factor loadings, 0.77 and 0.79, respectively; that is, the internal organization structure and the job planning and design have the same weight in terms of the effect on risk. So, the evidence shows that the lack of resources in the internal structure of the construction site and job planning negatively alter the adequate sequence of the planned processes, possibly due to a lack of control or organization thereof. Alterations or loss of control in the process sequences are one of the causes of risk generation (Swuste et al., 2016).

The role of F4, composed by coordination resources (OV8), preventive functions (OV9), and H&S plan adequacy (OV10), is also significant but with more reduced impact on only two risk variables: General conditions (RV2, $r^2 = 0.52$) and Work access (RV4, $r^2 = 0.24$). These results are consistent with the relationships analyzed by other authors who related aspects of specific resources in terms of H&S, preventive functions of those responsible for the site, and the adequacy of the H&S plan with H&S performance (Adam et al., 2009; Dillon et al., 2017; Alruqi & Hallowell, 2019; Bavafa et al., 2018; Baxendale & Jones, 2000; Forteza et al., 2017; Grill & Nielsen, 2019; Gunduz & Laitinen, 2017). Regarding the organizational variables related to F4, OV8, OV9, and OV10, obtained different factor loadings, 0.58, 0.76, and 0.47, respectively; that is, the most important factor with effect on risks is Preventive functions, followed by Safety resources coordination, and H&S plan. This obtained evidence implies, on one hand, that deficiencies both in the specific personal resources at H&S, in the preventive functions assumed by those responsible, as well as in the adequacy of the H&S plan, have an important effect on the general safety conditions onsite (which include permanent monitoring aspects such as cleanliness, order, safety means, and general protections, signage, etc.); and on the other hand, on the adaptation of the specific access to the workplace, as a specific aspect of good monitoring and preventive organization of the construction site. In other words, a higher level of specific resources in terms of the construction site safety coordination and the involvement of the site personnel in preventive functions has an impact on risk reduction. This reduction has a significant impact on the general safety conditions of work. These results also coincide with the precursors identified by Dillon et al. (2017).

Regarding the implications of this study, first, it has confirmed the relevance of the involvement of organizational and resource aspects on the risks generated onsite, in accordance with the recommendation by Ali Bavafa et al. (2018) on creating research lines on that relationship. Second, evidence shows that the Internal organization structure and the Job planning and design exert an important effect on the generation of the risk of falling from a height and on the deviation in the planned processes, among six other specific risk variables. Regarding the Coordination resources and the Preventive functions, together with the fulfillment of the H&S plan, have a fundamental effect on the general level of safety of the work (General conditions) and on the adaptation to the construction process (Process).

Third, the operationalization of this broad set of specific organizational factors, both related to the construction site complexity and the available resources, allows the identification of those aspects capable to reduce the incidence and severity of its associated specific risks. These organizational factors can be considered leading indicators of the onsite risk levels, mainly of the risks with greater path coefficients estimated using SEM models.

By way of example, if a significant risk level of falling from height is detected, the complexity factors that are their potential generators should be analyzed and improved. In this way, action could be taken to reduce the level of subcontracting, the extension in the hiring of companies, the number of works or workers, and the location of workers onsite. If, for example, risk problems in general H&S conditions are detected onsite, those organizational aspects with greater effect on this risk variable should be reviewed (such as the work of the coordinator, the preventive functions and involvement of the personnel and work managers, and the adequacy of the H&S plan). Obviously, it is necessary to act directly on the focus that produces the risk conditions, but also on the organizational factors that may favor such conditions to prevent them from happening over and over again without control.

Fourth, it is worth commenting on the complementarity of the results obtained from the two SEM fitted models (Figs. 3 and 4). Although the Global Complexity (GF1) and the Global Resources (GF2) (Fig. 3) show significant path coefficients on the set of onsite specific risks, a second model splitting both factors into four specific factors (Fig. 4) shows that two of the four factors are not risk-related: the Site complexity (F1) and the Firm's structure resources (F2). This specific model (with the best overall fit) identifies the Complexity of site structure (F3) and Safety management resources (F4) as significantly risk-related organizational factors.

All this evidence can make a relevant contribution to the use of proactive elements that influence the generation of risk predictors with early warnings before the risk materializes (Hinze, Thurman, et al., 2013; Lingard et al., 2017; Salas & Hallowell, 2016). Both the use *per se* of leading indicators and the inclusion of organizational factors in the risk analysis represent the unique contribution of this rigorous empirical study. In addition, these findings are especially applicable to SMEs belonging to the construction sector, all characterized by their lack of resources (Cagno et al., 2011; Cheng et al., 2010; Fan et al., 2020). Thus, SMEs must increase the onsite specific resources of safety management and limit the complexity derived from the internal organization and job planning. In other words, it is a matter of having personnel involved in the construction site to control and monitor safety measures, and on the other hand, of limiting the hiring of companies and subcontractors, with excessive outside personnel, as well as controlling the locations in the works with more risk. All these actions coincide with the lines proposed by Alruqi and Hallowell (2019, p. 1) in which they identified leading indicators related to safety management issues like safety resources and staffing for safety.

One of the limitations of the study is related to the absence of psychosocial variables such as climate and safety culture, or the attitudes toward the safety of workers, colleagues, or supervisors; the models only include the measure of the level of involvement in safety matters of the person in charge of the construction site. The inclusion of these variables in future works will complete and even improve the explanation of the variability of the risk indicators, and therefore, the improvement of the understanding of accidents in the construction sector. Another limitation of the study is that no criteria were established to control for the technical judgment in measuring onsite risk, although all measurements were carried out in a standardized way by the same technical staff. Despite these limitations, the obtained evidence makes it possible to increase rigorous empirical knowledge on organizational factors identified as precursors of risk in construction sites.

6. Conclusions

The aim of this study was to obtain rigorous empirical evidence on the potential connection among organizational factors as complexity and resources with construction onsite specific risks. The evidence found contributes to the previous research that connect safety leading indicators in order to undertake early interventions. The objective of these interventions is to prevent the development of possible future risks caused by deficiencies in the organizational and resource systems of the construction site (Hinze, Thurman, et al., 2013; Lingard et al., 2017; Salas & Hallowell, 2016). Specifically, this study takes as a reference a research line that develops studies onsite and relates different organizational aspects with poor safety performance (Fang et al., 2004; Forteza et al., 2017; Liu & Liao, 2019; Teo & Ling, 2006; Wu et al., 2015). Using CONSRAT (Forteza et al., 2016), 474 construction sites were assessed and both organizational (OV) and specific risk variables (RV) were obtained. Two complementary SEM models were fitted connecting these variables with a different number of latent factors. The first model is more general considering two factors and the second one is more specific proposing four latent factors. According to the results obtained after the estimation of the alternative specification of the models and their corresponding set of hypotheses, the conclusions of this study can be summarized as follows:

1. There is a contribution to provide new empirical evidence on the relationship between aspects of work organization and specific risks onsite with a novel and relevant contribution.
2. This study can be considered the first to analyze in detail the relationship between organizational factors and specific risks through rigorous empirical methods for testing using a large sample of construction sites.
3. The evidence found makes it possible to identify the traceability from the onsite risks towards the organizational factors with which they are most strongly related.
4. The complexity of the construction site "created" by those in the organization who are responsible for organizing and contracting systems has a greater impact on the generation and maintenance of risks than the complexity of the construction site due to its characteristics (size, design, and location). Similarly, the specific resources assigned to the site have much greater influence than the general resources that companies may have.

In summary, on the one hand, the results represent a new empirical contribution to previous studies that related organizational aspects with different H&S performance results. It is a contribution to the existing lack of empirical studies carried out in real construction sites (Bellamy, 2009; Jørgensen, 2016; Niskanen et al., 2016; Swuste et al., 2016; Wang et al., 2016). On the other hand, it tried to fill the important gap in the literature on health and safety in SMEs (Fan et al., 2020), which are the predominant type of company, both in number and in safety problems, in the construction sector.

7. Declarations of interest

None.

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Appendix

Correlation matrix of Organizational Variables (OV) and Risk Variables (RV).

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. OV1	–																			
2. OV2	.42**	–																		
3. OV3	.11*	.15**	–																	
4. OV4	.38**	.47**	.21**	–																
5. OV5	.14**	.24**	.11*	.28**	–															
6. OV6	.17**	.37**	.03	.44**	.29**	–														
7. OV7	.16**	.34**	.08	.38**	.46**	.61**	–													
8. OV8	.23**	.34**	.12**	.41**	.37**	.41**	.39**	–												
9. OV9	.19**	.27**	−.01	.37**	.52**	.42**	.47**	.44**	–											
10. OV10	.13**	.19**	.05	.27**	.28**	.27**	.32**	.47**	.34**	–										
11. RV1	−.10*	−.05	.29**	−.19**	−.18**	−.25**	−.20**	−.21**	−.40**	−.27**	–									
12. RV2	−.16**	−.26**	.10*	−.34**	−.27**	−.32**	−.25**	−.31**	−.43**	−.32**	.40**	–								
13. RV3	−.15**	−.19**	.31**	−.17**	−.19**	−.29**	−.21**	−.21**	−.44**	−.25**	.66**	.48**	–							
14. RV4	−.11*	−.14**	.16**	−.19**	−.14**	−.16**	−.10*	−.16**	−.27**	−.19**	.38**	.54**	.51**	–						
15. RV5	−.15**	.02	.38**	−.04	−.06	−.08	.04	−.08	−.29**	−.11*	.57**	.34**	.63**	.44**	–					
16. RV6	−.02	.05	.40**	−.03	.04	−.07	.04	−.01	−.17**	−.04	.30**	.25**	.35**	.33**	.50**	–				
17. RV7	−.12*	−.06	.32**	−.10*	−.10*	−.13**	−.09	−.10*	−.36**	−.15**	.58**	.39**	.64**	.45**	.76**	.43**	–			
18. RV8	−.14**	−.01	.08	−.09	−.06	−.01	−.02	−.09*	−.14**	−.10*	.17**	.09	.34**	.21**	.40**	.21**	.30**	–		
19. RV9	−.09*	.02	.30**	−.04	.01	−.05	.09	−.02	−.10*	−.06	.34**	.19**	.39**	.32**	.50**	.38**	.42**	.26**	–	
20. RV10	−.01	.06	−.08	−.02	−.03	.01	.06	−.03	−.14**	−.04	.17**	.05	.14**	.16**	.24**	.14**	.20**	.05	.18**	–

Summary of descriptive statistics of OVs and RVs.

OVs and RVs	Minimum	Maximum	Mean	SD	Mean SE
OV1. Complexity of project	0	100	19.23	17.64	0.81
OV2. Size of site	0	92.21	54.82	14.15	0.65
OV3. Stage characteristics	0	100	16.24	19.32	0.89
OV4. Promoter resources	0	100	61.42	25.6	1.18
OV5. Constructor resources	4.67	84.72	41.22	16.01	0.74
OV6. Internal organization structure	0	100	19.11	18.94	0.87
OV7. Job planning and design	0	92.21	54.92	14.06	0.65

(*continued on next page*)

Appendix (*continued*)

OVs and RVs	Minimum	Maximum	Mean	SD	Mean SE
OV8. Coordination resources	0	100	16.24	21.03	0.97
OV9. Preventive functions	0	100	61.42	25.8	1.19
OV10. H&SP adequacy	4.67	84.72	41.22	16.03	0.74
RV1. H&S plan complement	0.33	0.96	0.77	0.2	0.01
RV2. General conditions	0.13	1	0.65	0.14	0.01
RV3. Collective protections	0.33	1	0.79	0.19	0.01
RV4. Access	0.33	1	0.66	0.18	0.01
RV5. Falls from height	0.11	1	0.8	0.18	0.01
RV6. Other risks	0.17	0.96	0.67	0.15	0.01
RV7. Process	0.33	1	0.79	0.21	0.01
RV8. Collective protections	0	1	0.92	0.17	0.01
RV9. Personal protection equipment	0	1	0.74	0.41	0.02
RV10. Auxiliary resources and machinery	0.33	1	0.8	0.19	0.01

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